INSTRUCTION MANUAL

MODEL 9110E
NITROGEN OXIDES ANALYZER

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SAFETY MESSAGES

Your safety and the safety of others is very important. We have provided many important safety messages in this manual. Please read these messages carefully.

A safety message alerts you to potential hazards that could hurt you or others. Each safety message is associated with a safety alert symbol. These symbols are found in the manual and inside the instrument. The definition of these symbols is described below:

	GENERAL SAFETY HAZARD: Refer to the instructions for details on the specific hazard.
	CAUTION: Hot Surface Warning.
	CAUTION: Electrical Shock Hazard.
	TECHNICIAN SYMBOL: All operations marked with this symbol are to be performed by qualified maintenance personnel only.

CAUTION
The analyzer should only be used for the purpose and in the manner described in this manual. If you use the analyzer in a manner other than that for which it was intended, unpredictable behavior could ensue with possible hazardous consequences.

This analyzer is for indoor use only and for altitudes up to 2000 m (6500 ft).

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USER NOTES:

1. M9110E DOCUMENTATION

1.1. Available Documentation

Thank you for purchasing the Model 9110E Nitrogen Oxides Analyzer! The documentation for this instrument is available in different formats:

- Printed format, part number 044100100

Additional documentation for the Model 9110E Nitrogen Oxides Analyzer is available from TAI's website at http://www.teledyne-ai.com/manuals/

- APICOM software manual, part number 03945
- Multi-drop manual, part number 02179
- DAS manual, part number 02837.
- Ethernet configuration document, part number 04324.

Other documentation may be added to the website in the future.

1.2. Manual Structure

1.0 Table of Contents:

Outlines the contents of the manual in the order the information is presented. This is a good overview of the topics covered in the manual. There is also a list of appendices, figures and tables. In the electronic version of the manual, clicking on a any of these table entries automatically views that section.

2.0 Specifications and Warranty

A list of the analyzer's performance specifications, a description of the conditions and configuration under which EPA equivalency was approved and TAI's warranty statement.

3.0 Getting Started

Concise instructions for setting up, installing and running your analyzer for the first time.

4.0 FAQ & Glossary:

Answers to the most frequently asked questions about operating the analyzer and a glossary of acronyms and technical terms.

5.0 Optional Hardware & Software

A description of optional equipment to add functionality to your analyzer.

6.0 Operation Instructions

Step by step instructions for operating the analyzer.

7.0 Calibration Procedures

General information and step by step instructions for calibrating your analyzer.

8.0 EPA Protocol Calibration

Specific information regarding calibration requirements for analyzers used in EPA-regulated monitoring applications.

9.0 Instrument Maintenance

Description of preventative maintenance procedures that should be regularly performed on you instrument to assure good operating condition. This includes information on using the iDAS to predict possible component failures before they happen.

10.0 Theory of Operation

An in-depth look at the various principals by which your analyzer operates as well as a description of how the various electronic, mechanical and pneumatic components of the instrument work and interact with each other. A close reading of this section is invaluable for understanding the instrument's operation.

11.0 Troubleshooting & Repair

This section includes pointers and instructions for diagnosing problems with the instrument, such as excessive noise or drift, as well as instructions on performing repairs of the instrument's major subsystems.

Appendices

For easier access and better updating, some information has been separated out of the manual and placed in a series of appendices at the end of this manual. These include

version-specific software menu trees, warning messages, definitions of iDAS & serial I/O variables as well as spare part listings, repair questionnaire, interconnect drawing, detailed pneumatic and electronic schematics.

1.3. How to use this Instruction Manual

Throughout this manual, words printed in capital, bold letters, such as **SETUP** or **ENTR** represent messages as they appear on the analyzer's front panel display.

The flowcharts in this manual contain typical representations of the analyzer's display during the described operations. These representations are not necessarily exact and may differ slightly from the actual display of your instrument.

NOTE:
Warnings and special notes are called out in bold, centered frames such as this one.

Cautionary notes with special symbols such as this one may appear throughout the manual indicating hazardous operations requiring either trained, technical personnel or particular attention.

USER NOTES:

2. SPECIFICATIONS, APPROVALS AND WARRANTY

2.1. M9110E Operating Specifications

Table 2-1: Model 9110E Basic Unit Specifications

Min/Max Range (Physical Analog Output)	Min: 0-50 ppb Max: 0-20 ppm
Measurement Units	ppb, ppm, µg/m^3, mg/m^3 (user selectable)
Zero Noise[1]	0.2 ppb (RMS)
Span Noise[1]	<0.5% of reading above 50 ppb or 0.2 ppm, whichever is greater
Lower Detectable Limit[2]	0.4 ppb
Zero Drift (24 hours)	<0.5 ppb (at constant temperature and voltage.)
Zero Drift (7 days)	1 ppb (at constant temperature and voltage.)
Span Drift (7 Days)	<0.5% of full Scale (at constant temperature and voltage.)
Linearity	1% of full scale
Precision	0.5% of reading
Temperature Coefficient	< 0.1% per °C
Voltage Coefficient	< 0.1% per V
Lag Time[1]	20 s
Rise/Fall Time[1]	95% in <60 s
Sample Flow Rate	500 cm^3/min. ± 10%
Temperature Range	5 - 40 °C operating and EPA equivalency
Humidity Range	0-95% RH non-condensing
Dimensions H x W x D	18 cm x 43 cm x 61 cm (7" x 17" x 23.6")
Weight, Analyzer	18 kg (40 lbs)
Weight, Ext Pump Pack	7 kg (16 lbs)
AC Power Rating	100 V, 50/60 Hz (3.25A); 115 V, 60 Hz (3.0 A); 220 - 240 V, 50/60 Hz (2.5 A)
Power, Ext Pump	100 V, 50/60 Hz (3.25A); 115 V, 60 Hz (3.0 A); 220 - 240 V, 50/60 Hz (2.5 A)
Environmental	Installation category (over-voltage category) II; Pollution degree 2
Analog Outputs	4 outputs
Analog Output Ranges	All Outputs: 0.1 V, 1 V, 5 V or 10 V (user selectable) Three outputs convertible to 4-20 mA isolated current loop. All Ranges with 5% under/over range
Analog Output Resolution	1 part in 4096 of selected full-scale voltage (12 bit)
Status Outputs	8 Status outputs from opto-isolators, 7 defined, 1 spare
Control Inputs	6 Control inputs, 4 defined, 2 spare
Serial I/O	1 RS-232; 1 RS-485 or RS-232 (configurable) Communication speed: 300 - 115200 baud (user selectable)
Certifications	USEPA: Reference Method Number RFNA 1194-099 CE: EN61326 (1997 w/A1: 98) Class A, FCC Part 15 Subpart B Section 15.107 Class A, ICES-003 Class A (ANSI C63.4 1992) & AS/NZS 3548 (w/A1 & A2; 97) Class A.

[1] As defined by the USEPA.
[2] Defined as twice the zero noise level by the USEPA.

2.2. EPA Equivalency Designation

The Model 9110E Analyzer is designated as Reference Method Number RFNA-1194-099 (same designation as model M200A) as per 40 CFR Part 53 when operated under the following conditions:

- Range: Any full-scale range between 0-0.05 and 0-1.0 ppm (parts per million).
- Ambient temperature range of 5 to 40 ^{o}C.
- Line voltage range of 105-125 VAC or 220-240 VAC, at 50 or 60 Hz.
- Equipped with PTFE filter element in the internal filter assembly.
- Equipped with ozone supply air filter

External vacuum pump capable of 10 in-Hg-A at 2 standard liters per minute (slpm) or better.

Software settings:

Dynamic span	OFF
Dynamic zero	OFF
Cal-on-NO_2	OFF
Dilution factor	OFF
Temp/Pressure compensation	ON
AutoCal	ON or OFF
Independent range	ON or OFF
Auto-range	ON or OFF
Converter efficiency	Acceptable values of 0.96 to 1.02

Under the designation, the analyzer may be operated with or without the following optional equipment:

- Rack mount with or without slides.
- Rack mount for external pump.
- Zero/span valve options.
- Nafion-type permeation sample gas conditioner
- Internal zero/span (IZS) option with:
  - NO_2 permeation tube - 0.4ppm at 0.7 liter per minute; certified/uncertified.
  - NO_2 permeation tube - 0.8 ppm at 0.7 liter per minute; certified/uncertified.

  Under the designation, the IZS option cannot be used as the source of calibration.
- 4-20mA isolated analog outputs.
- Status outputs.
- Control inputs.
- RS-232 output.
- Ethernet communications option

2.3. CE Mark Compliance

The Teledyne Instruments Nitrogen Oxides Analyzers M9110E, M9110EH and M9110EM were tested and found to be fully compliant with:

EN61326 (1997 w/A1: 98) Class A, FCC Part 15 Subpart B Section 15.107 Class A, ICES-003 Class A (ANSI C63.4 1992) & AS/NZS 3548 (w/A1 & A2; 97) Class A.

Tested on January 02-06, 2003 at CKC Laboratories, Inc., Report Number CE03-005.

The Teledyne Instruments Nitrogen Oxides Analyzers M9110E, M9110EH and M9110EM were tested and found to be fully compliant with:

EN61010-1 (2001)

Tested on January 27-20, 2003.

2.4. Warranty

Warranty Policy (02024C)

Prior to shipment, TAI equipment is thoroughly inspected and tested. Should equipment failure occur, TAI assures its customers that prompt service and support will be available.

Coverage

After the warranty period and throughout the equipment lifetime, TAI stands ready to provide on-site or in-plant service at reasonable rates similar to those of other manufacturers in the industry. All maintenance and the first level of field troubleshooting is to be performed by the customer.

Non-API Manufactured Equipment

Equipment provided but not manufactured by TAI is warranted and will be repaired to the extent and according to the current terms and conditions of the respective equipment manufacturers warranty.

General

TAI warrants each product manufactured by TAI to be free from defects in material and workmanship under normal use and service for a period of one year from the date of delivery. All replacement parts and repairs are warranted for 90 days after the purchase.

If a product fails to conform to its specifications within the warranty period, TAI shall correct such defect by, in TAI's discretion, repairing or replacing such defective product or refunding the purchase price of such product.

The warranties set forth in this section shall be of no force or effect with respect to any product: (i) that has been altered or subjected to misuse, negligence or accident, or (ii) that has been used in any manner other than in accordance with the instruction provided by TAI or (iii) not properly maintained.

THE WARRANTIES SET FORTH IN THIS SECTION AND THE REMEDIES THEREFORE ARE EXCLUSIVE AND IN LIEU OF ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR PARTICULAR PURPOSE OR OTHER WARRANTY OF QUALITY, WHETHER EXPRESSED OR IMPLIED. THE REMEDIES SET FORTH IN THIS SECTION ARE THE EXCLUSIVE REMEDIES FOR BREACH OF ANY WARRANTY CONTAINED HEREIN. TAI SHALL NOT BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES ARISING OUT OF OR RELATED TO THIS AGREEMENT OF TAI'S PERFORMANCE HEREUNDER, WHETHER FOR BREACH OF WARRANTY OR OTHERWISE.

Terms and Conditions

All units or components returned to TAI should be properly packed for handling and returned freight prepaid to the nearest designated Service Center. After the repair, the equipment will be returned, freight prepaid.

3. GETTING STARTED

3.1. Unpacking and Initial Setup

CAUTION
The M9110E weighs about 17 kg (40 pounds) without options installed. To avoid personal injury, we recommend to use two persons to lift and carry the analyzer.

Inspect the received packages for external shipping damage. If damaged, please advise the shipper first, then TAI.

Included with your analyzer is a printed record (Form number 04490) of the final performance characterization performed on your instrument at the factory. This record is an important quality assurance and calibration record for this instrument. It should be placed in the quality records file for this instrument.

- Carefully remove the top cover of the analyzer and check for internal shipping damage.
- Remove the set screw located in the top, center of the rear panel.
- Remove the screws fastening the top cover to the unit (four per side).
- Lift the cover straight up.

CAUTION
Printed Circuit Assemblies (PCA) are static sensitive. Electrostatic discharges, too small to be felt by humans, are large enough to destroy sensitive circuits.

Before touching a PCA, fasten a properly installed grounding strap to your wrist or touch a bare metal part of the chassis to discharge any electrostatic potentials.

Never disconnect electronic circuit boards, wiring harnesses or electronic subassemblies while the unit is under power.

Do not position the equipment so that it is difficult to operate the disconnecting device.

- Inspect the interior of the instrument to make sure all circuit boards and other components are in good shape and properly seated.
- Check the connectors of the various internal wiring harnesses and pneumatic hoses to make sure they are firmly and properly seated.
- Verify that all of the optional hardware ordered with the unit has been installed. These are checked on the paperwork (Form 04490) accompanying the analyzer.
- Once you have determined that no shipping damage exists and the unit includes all expected hardware options, remove three, red colored shipping screws from the bottom of the chassis, shown in Figure 3-1.

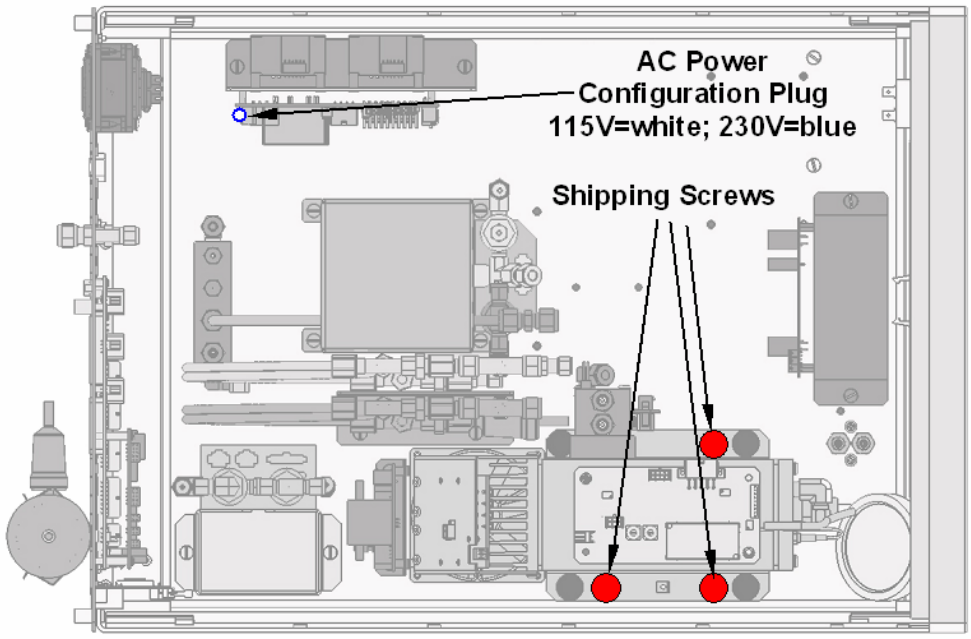


Figure 3-1: Location of Shipping Screws and Power Configuration Plug

NOTE
Save these shipping screws and re-install them whenever the unit is shipped.

A certain ventilation clearance is required for the operation of the analyzer:

Area	Minimum required clearance
Back of the instrument	10 cm / 4 inches
Sides of the instrument	2.5 cm / 1 inch
Above and below the instrument	2.5 cm / 1 inch

Various rack mount kits are available for this analyzer. See Chapter 5 of this manual for more information.

3.2. M9110E Layout

Figure 3-2 shows a top-down view of the analyzer. The shown configuration includes the Ethernet board, IZS option, zero-air scrubber and an additional sample dryer. See Chapter 5 for optional equipment. Figure 3-3 shows the rear panel configuration with optional zero-air scrubber mounted to it and two optional fittings for the IZS option. Figure 3-4, finally shows the front panel layout of the analyzer.

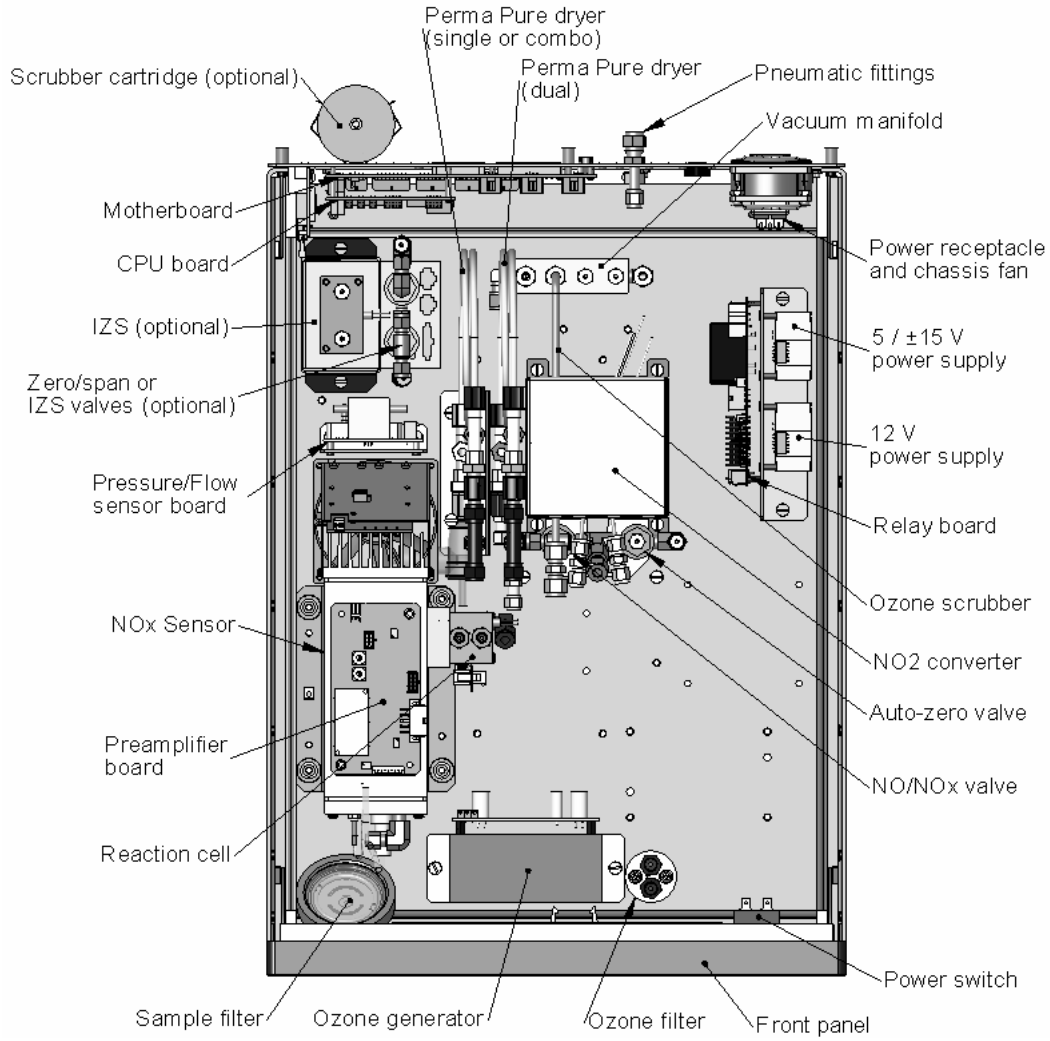


Figure 3-2: M9110E Layout

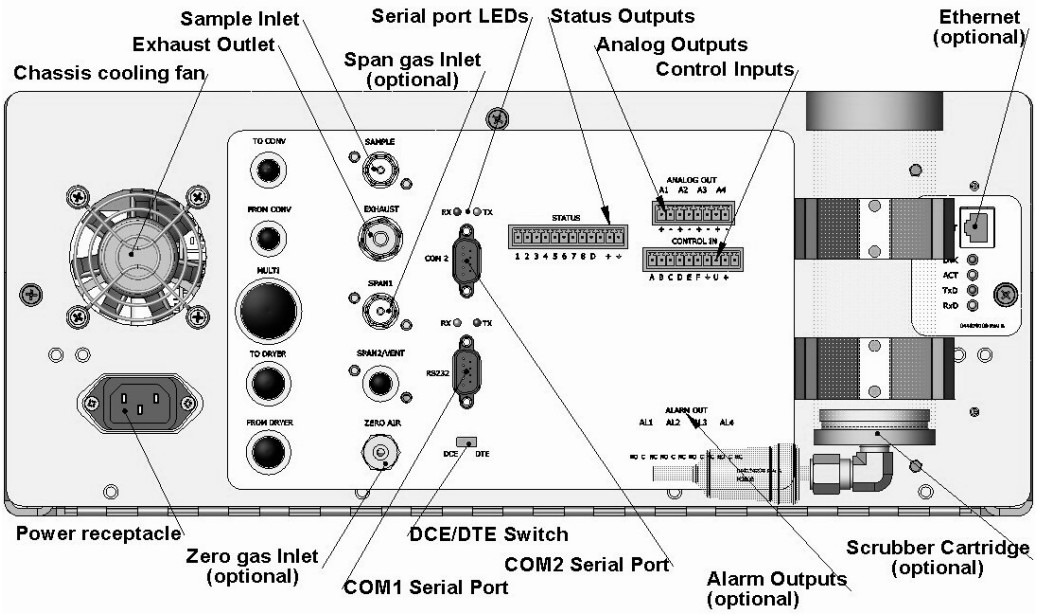


Figure 3-3: M9110E Rear Panel Layout

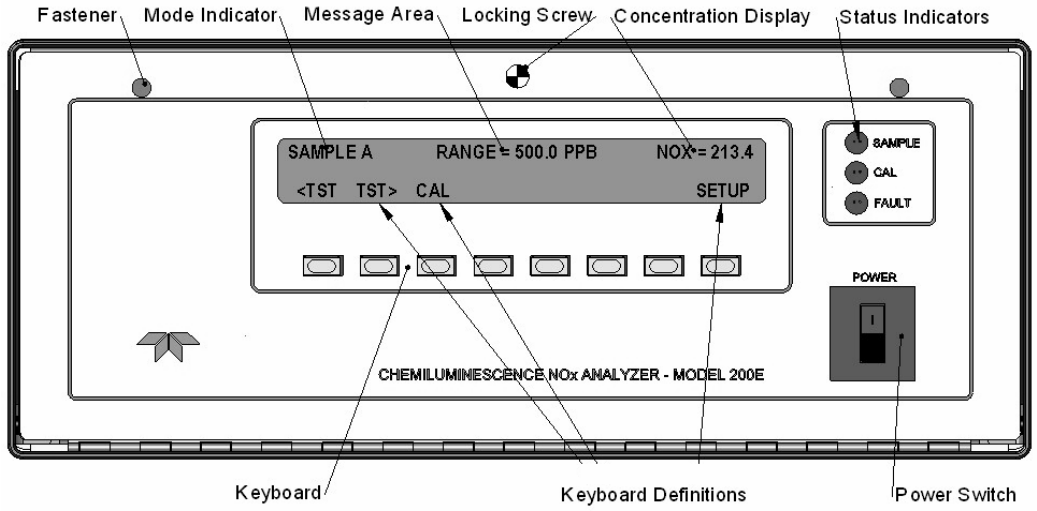


Figure 3-4: M9110E Front Panel Layout

3.3. Pneumatic Connections

Sample and calibration gases should only come into contact with PTFE (Teflon), FEP, glass or stainless steel materials. Figure 3-5 and Figure 3-6 illustrate the most common configurations for gas supply and exhaust lines to the Model 9110E Analyzer. Appendix D contains more detailed pneumatic flow diagrams for the analyzer and its various (pneumatically related) options.

CAUTION
To prevent dust from getting into the analyzer, it was shipped with small plugs inserted into each of the pneumatic fittings on the rear panel. Make sure that all dust plugs are removed before attaching exhaust and supply gas lines.

Please refer to Figure 3-3 for pneumatic connections at the rear panel and Table 3-1 for nomenclature.

Table 3-1: Inlet / Outlet Connector Nomenclature

Rear Panel Label	Function
Sample	Connects the sample gas to the analyzer. When operating the analyzer without zero span option, this is also the inlet for any calibration gases.
Exhaust	Connects the exhaust of the analyzer with the external vacuum pump.
Span	On Units with zero/span valve or IZS option installed, this port connects the external calibration gas to the analyzer.
Zero Air	On Units with zero/span valve or IZS option installed, this port connects the zero air gas or the zero air cartridge to the analyzer.

- Attach a sample inlet line to the sample inlet port. Ideally, the pressure of the sample gas should be equal to ambient atmospheric pressure.
- In applications where the sample gas is received from a pressurized manifold, a vent must be provided to equalize the sample gas with ambient atmospheric pressure before it enters the analyzer. The vented gas needs to be routed outside the immediate area or shelter surrounding the instrument.

CAUTION
Maximum pressure of any gas at the sample inlet should not exceed 1.5 in-Hg above ambient pressure and ideally should equal ambient atmospheric pressure.

CAUTION
The exhaust from the external pump needs to be vented outside the immediate area or shelter surrounding the instrument using a maximum of 10 meters of 1/4” PTFE tubing.

- Attach the 1/4" exhaust line to the exhaust port of the analyzer and to the inlet port of the pump.
- Attach zero air and span gas supply lines as appropriate (Figure 3-5 and Figure 3-6) to the rear panel (Figure 3-3). For this type of analyzer, zero air and span gas are defined as follows.

3.3.1. Span Gas Defined

Span gas is defined as a gas specifically mixed to match the chemical composition of the type of gas being measured at near full scale of the desired measurement range. To measure NO_X with the M9110E NO_X Analyzer, it is recommended that you use a span gas with an NO concentration equal to 80% of the measurement range for your application.

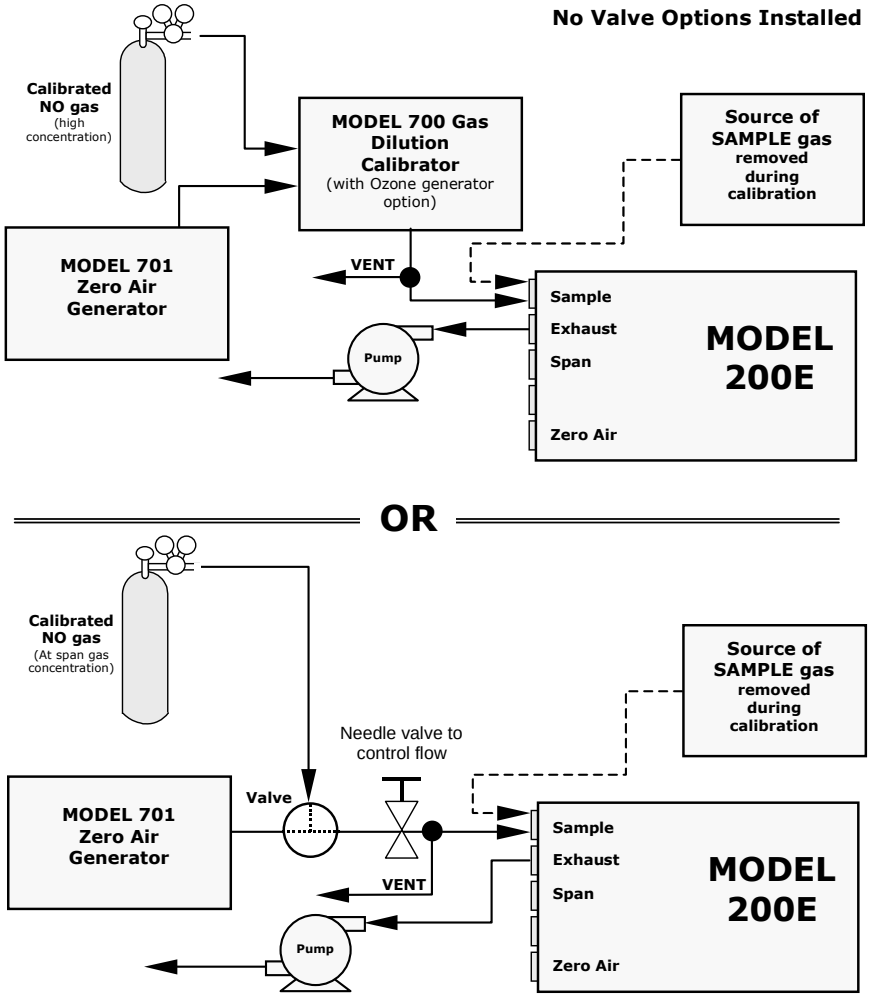


Figure 3-5: Basic Pneumatic Connections for Units Without Valve Options

For example, if the measurement is NO_X in ambient air between 0 and 500 ppb, an appropriate span gas would be NO in air at 400 ppb NO concentration (80% of maximum range). Even though NO gas in nitrogen could be used as a span gas, the matrix of the balance gas is different and may cause interference problems or yield incorrect calibrations. The same applies to gases that contain high concentrations of other compounds (for example, CO_2 or H_2O). The span gas should match all concentrations of all gases of the measured medium as closely as possible.

Cylinders of calibrated NO gas traceable to NIST-standard reference materials specifications (also referred to as EPA protocol calibration gases) are commercially available.

Some applications, such as EPA monitoring, require a multipoint calibration where span gases of different concentrations are needed. We recommend using an NO gas of higher concentration combined with a gas dilution calibrator such as a TAI Model 700. This type of calibrator mixes a high concentration gas with zero air (both supplied externally) to accurately produce span gas of the desired concentration. Linearity profiles can be automated with this model and run unattended overnight. The dynamic range of the M700 is about 0.1 to 0.001 times the original span concentration.

If a dynamic dilution system such as the TAI model 700 is used to dilute high concentration gas standards to low, ambient concentrations, ensure that the NO concentration of the reference gas matches the dilution range of the calibrator. Choose the NO gas concentration such that the dynamic dilution system operates in its mid-range and not at the extremes of its dilution capabilities. For example, a dilution calibrator with 10-10000 dilution ratio will not be able to accurately dilute a 5000 ppm NO gas to a final concentration of 500 ppb, as this would operate at the very extreme dilution setting. A 100 ppm NO gas in nitrogen is much more suitable to calibrate the M9110E analyzer (dilution ratio of 222, in the mid-range of the system's capabilities).

3.3.2. Zero Gas Defined

Zero air or zero calibration gas is defined as a gas that is similar in chemical composition to the measured medium but without the gas to be measured by the analyzer, in this case NO and NO_2. If your analyzer is equipped with an IZS or external zero air scrubber option, it is capable of creating zero air from ambient air. However, if your application is not a measurement in ambient air, the zero calibration gas should be matched to the matrix of the measured medium. Pure nitrogen could be used as a zero gas for applications where NO_X is measured in nitrogen.

For analyzers without zero air options, a zero air generator such as the TAI Model 701 can be used. Please visit the company website for more information.

If your analyzer is equiped with either the zero/span valve option (Option 50) or the internal zero/span option (Option 51), the pneumatic connections should be made as shown in Figure 3-6 (see also Appendix D for detailed diagram).

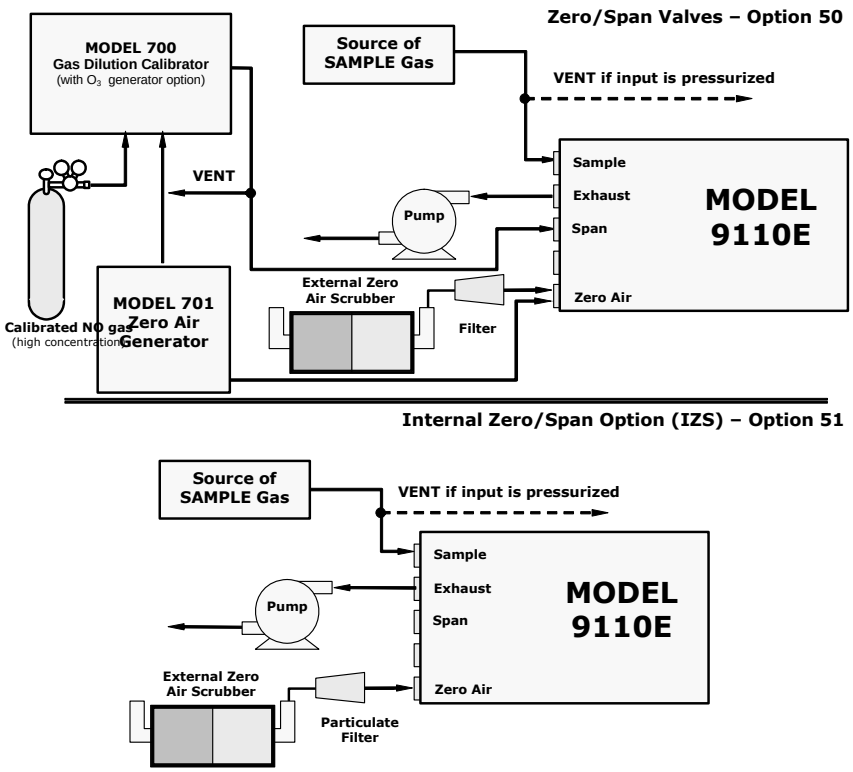


Figure 3-6: Basic Pneumatic Connections for Units With Valve Options

Once the appropriate pneumatic connections have been made, check all pneumatic fittings for leaks using the procedures defined in Section 11.5.

WARNING
Gas flow must be maintained at all times for units with IZS Options installed. The IZS option includes a permeation tube which emits NO_2. Insufficient gas flow can build up NO_2 to levels that will damage the instrument. Remove the permeation device when taking the analyzer out of operation.

3.4. Electrical Connections

Refer to Figure 3-3 for the location of the rear panel electrical and pneumatic connections.

3.4.1. Power Connection

Attach the power cord to the analyzer and plug it into a power outlet capable of carrying at least 10 A current at your AC voltage and that it is equipped with a functioning earth ground.

The M9110E analyzer can be configured for both 100-130 V and 210-240 V at either 50 or 60 Hz., To avoid damage to your analyzer, make sure that the AC power voltage matches the voltage indicated on the rear panel serial number label and that the frequency is between 47 and 63 Hz. Refer to Figure 3-1 to locate and identify the power configuration plug if necessary.

If you need to reconfigure your analyzer for one of the other voltage ranges, contact the factory for an optional power configuration jumper (shown in Figure 3-1)

CAUTION
The correct voltage and frequency needs to be supplied to the analyzer as listed on the label on the rear panel of the instrument .
Power connections must have a functioning ground connection.

3.4.2. Analog Output Connections

Attach a strip chart recorder and/or data-logger to the appropriate contacts of the analog output connecter on the rear panel of the analyzer.

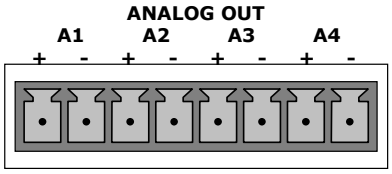


Figure 3-7: Analog Output Connector

Output channels **A1**, **A2** and **A3** are assigned to the NO_X, NO and NO_2 concentration signals of the analyzer. The output labeled A4 can be set by the user for output of any test parameter accessible through the <TST TST> keys on the front panel display. Section 6.7.4 describes how to change that setting.

Optional current loop outputs are available for analog output channels A1-A3. Pin-outs for the analog output connector at the rear panel of the instrument are listed in Table 3-2.

The default analog output voltage setting of the M9110E is 0 - 5 VDC with a range of 0-500 ppb. To change these settings, see Sections 6.5 and 6.7.3.

Table 3-2: Analog Output Pin-Outs

Pin	Analog Output	Data Type	Voltage Signal	Current Signal
1	A1	NO_X	V Out	I Out +
2			Ground	I Out -
3	A2	NO	V Out	I Out +
4			Ground	I Out -
5	A3	NO_2	V Out	I Out +
6			Ground	I Out -
7	A4	Test Channel	V Out	not available
8			Ground	not available

If you wish to utilize the analyzer's status outputs to interface with a device that accepts logic-level digital inputs, such as programmable logic controller (PLC) chips, you can access them through a 12 pin connector on the analyzer's rear panel labeled STATUS.

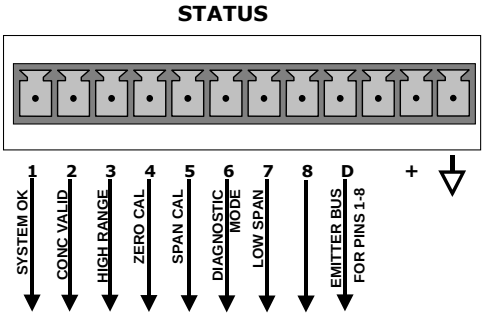


Figure 3-8: Status Output Connector

Table 3-3: Status Output Signals

Pin #	Status	Condition (ON = Conducting)
1	SYSTEM OK	ON if no faults are present.
2	CONC VALID	ON if concentration measurement (NO, NO2 or NOx) is valid. OFF any time the hold-off feature is active.
3	HIGH RANGE	ON if unit is in high range of the Auto Range Mode.
4	ZERO CAL	ON whenever the instrument is in ZERO point calibration mode.
5	SPAN CAL	ON whenever the instrument is in SPAN point calibration mode.
6	DIAG MODE	ON whenever the instrument is in diagnostic mode.
7	Unused	
8	Unused	
D	EMITTER BUS	The emitters of the transistors on pins 1-8 are tied together.
	Unused	
+	DC POWER	+ 5 VDC, 300 mA (combined rating with Control Output, if used).
⏚	Digital Ground	The ground level from the analyzer's internal DC power supplies

If you wish to use the analyzer to remotely activate the zero and span calibration modes, several digital control inputs are provided through a 10-pin connector labeled CONTROL IN on the analyzer's rear panel.

There are two methods for energizing the control inputs. The internal +5V available from the pin labeled "+" is the most convenient method. However, if full isolation is required, an external 5 VDC power supply should be used.

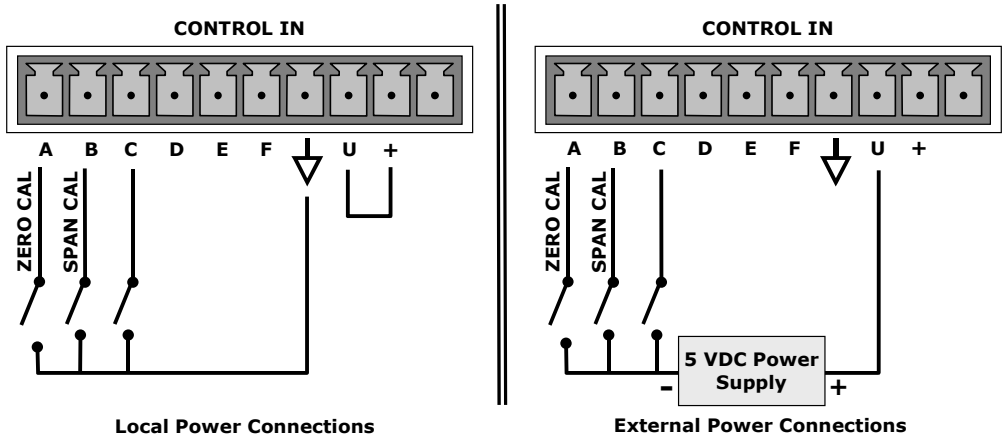


Figure 3-9: Control Input Connector

Table 3-4: Control Input Signals

Input #	Status Definition	ON Condition
A	REMOTE ZERO CAL	The analyzer is placed in Zero Calibration mode. The mode field of the display will read **ZERO CAL R**.
B	REMOTE SPAN CAL	The analyzer is placed in low span calibration mode as part of performing a low span (midpoint) calibration. The mode field of the display will read **LO CAL R**.
C	SPARE	
D	SPARE	
E	SPARE	
F	SPARE	
⏚	Digital Ground	The ground level from the analyzer's internal DC power supplies (same as chassis ground).
U	External Power input	Input pin for +5 VDC required to activate pins A - F.
+	5 VDC output	Internally generated 5V DC power. To activate inputs A - F, place a jumper between this pin and the "U" pin. The maximum amperage through this port is 300 mA (combined with the analog output supply, if used).

If you wish to utilize one of the analyzer's two serial ports, attach the serial cable that is included with the analyzer to the COM1 serial port on the rear panel. Connect the other end to a serial port on your computer and set the computer serial port to 115000 baud transfer

speed, 8 data bits, no parity, 1 stop bit and Xon/Xoff flow control. Use the APICOM remote control software that was included with the analyzer to connect to the instrument or use any terminal emulation program. Refer to Section 6.9 of this manual for instructions on configuration and usage of the serial port, Section 6.11 for remote operation of the analyzer.

3.4.3. Ethernet Connection and Configuration

If your M9110E is equipped with an Ethernet option (described in Section 5.8.3), the analyzer needs to be configured to match the network settings of your internal network. Please change the first three of the following parameters to configure the Ethernet functionality:

- (IP) A static IP address (default value is 000.000.000.000).
- (GTWY) A static network gateway IP address (default is 000.000.000.000).
- (SNET) A subnet mask (default is 255.255.255.0).
- (PORT) A TCP/IP port number (default is 3000, does not need to be changed).

Note that the M9110E currently does not support DHCP or dynamic IP addresses. All of the above settings can be changed by following the procedure described in Section 6.9.9 of this manual. To do this quickly, press the following keys on the analyzer's front panel: **SETUP** – **MORE** – **COMM** – **INET** and configure the individual items shown on the menu and listed above.

3.5. Initial Operation

If you are unfamiliar with the theory of operation of the M9110E analyzer, we recommend that you read Chapter 10 before proceeding. For information on navigating the analyzer's software menus, see the menu trees described in Appendix A.1.

3.5.1. Startup

After electrical and pneumatic connections are made, turn on the instrument and supply power to the external pump. The exhaust and PMT cooler fans should start. The display should immediately display a single, horizontal dash in the upper left corner of the display. This will last approximately 30 seconds while the CPU loads the operating system. Once the CPU has completed this activity, it will begin loading the analyzer firmware and configuration data. During this process, a string of messages will appear on the analyzer's front panel display as shown in Figure 3-10. The analyzer should automatically switch to **SAMPLE** mode after completing the boot-up sequence and start monitoring NO_X, NO, NO_2 gases.

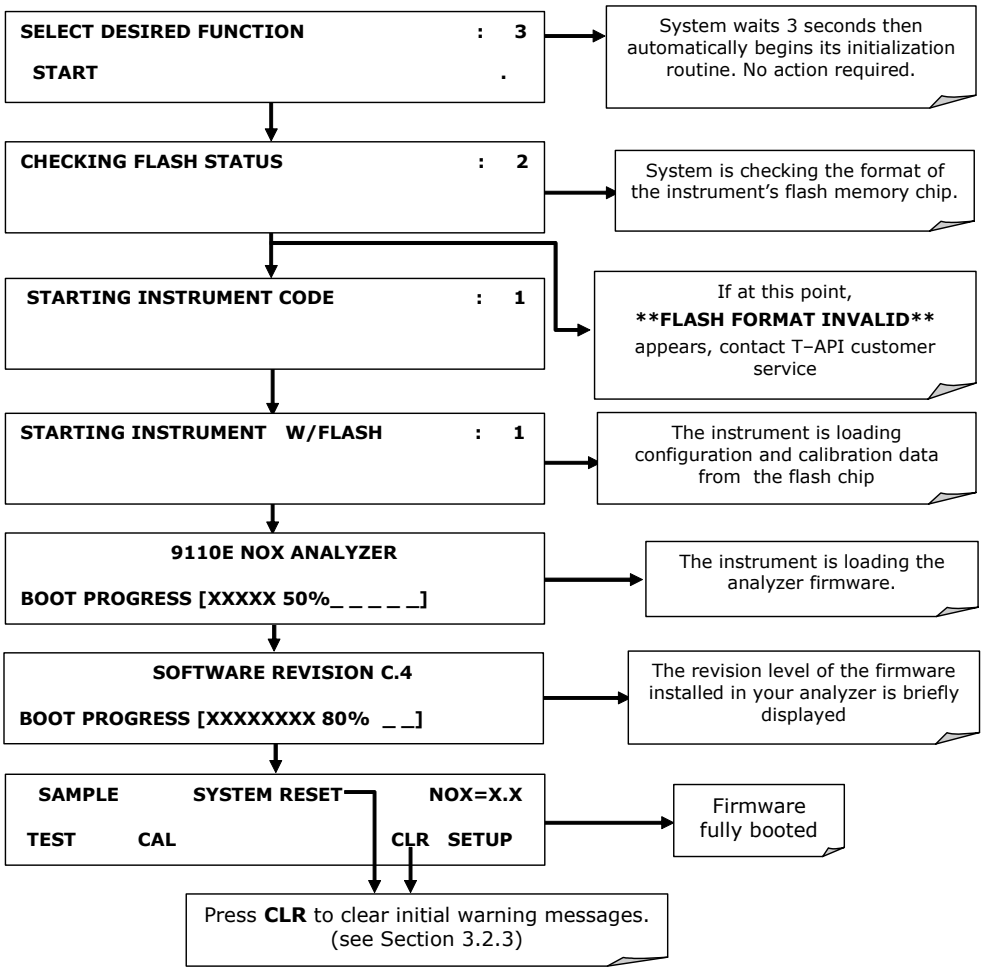


Figure 3-10: Front Panel Display During Startup Sequence

3.5.2. Warm-Up

The M9110E requires about 30 minutes warm-up time before reliable NO_X, NO and NO_2 measurements can be taken. During that time, various portions of the instrument's front panel will behave as follows. See Figure 3-4 for locations.

Table 3-5: Front Panel Display During System Warm-Up

Name	Color	Behavior	Significance
Concentra-tion Field	N/A	Switches between NO_X, NO and NO_2	This is normal operation.
Mode Field	N/A	Displays blinking "SAMPLE"	Instrument is in sample mode but is still in the process of warming up (hold-off period is active).

Name	Color	Behavior	Significance
STATUS LEDs			
Sample	Green	On	Unit is operating in sample mode, front panel display is continuously updated.
Cal	Yellow	Off	The instrument's calibration is not enabled.
Fault	Red	Blinking	The analyzer is warming up and out of specification for a fault-free reading.

3.5.3. Warning Messages

During warm-up, internal temperatures and other parameters may be outside of specified limits. The software will suppress most warning conditions for 30 minutes after power up. The following table includes a brief description of the various warning messages that may appear after the warm-up time. If warning messages persist after 30 minutes, investigate their cause using the troubleshooting guidelines in Chapter 11. To view and clear warning messages, use the following key strokes:

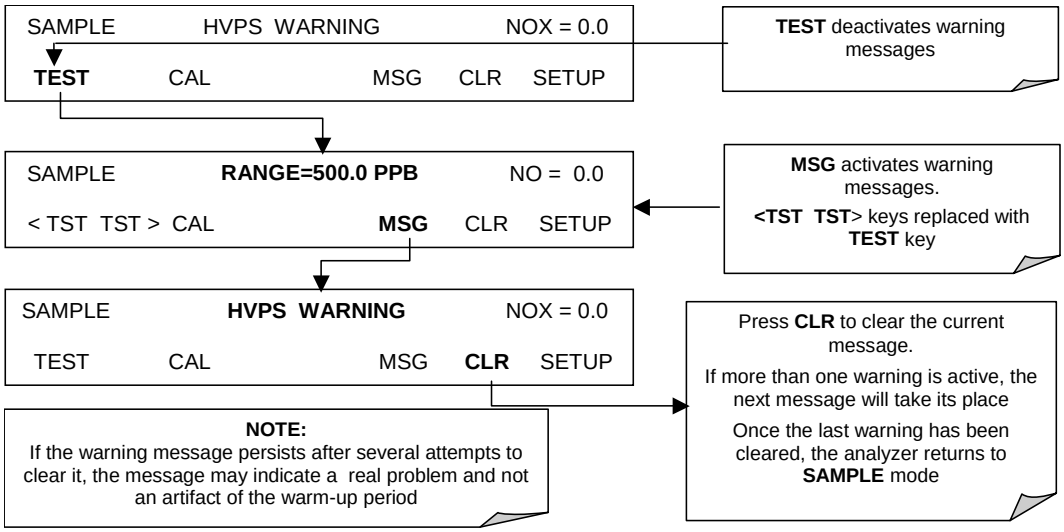


Table 3-6: Possible Warning Messages at Start-Up

Message	Definition
ANALOG CAL WARNING	The instrument's A/D circuitry or one of its analog outputs is not calibrated.
AZERO WRN XXX.X MV	The reading taken during the auto-zero cycle is outside of specified limits. The value XXX.X indicates the auto-zero reading at the time of the warning.
BOX TEMP WARNING	The temperature inside the M9110E chassis is outside the specified limits.
CANNOT DYN SPAN	Remote span calibration failed while the dynamic span feature was ON
CANNOT DYN ZERO	Remote zero calibration failed while the dynamic zero feature was ON.
CONFIG INITIALIZED	Configuration was reset to factory defaults or was erased.
CONV TEMP WARNING	NO_2 converter temperature is outside of specified limits.
DATA INITIALIZED	iDAS data and settings were erased.
HVPS WARNING	High voltage power supply for the PMT is outside of specified limits.
IZS TEMP WARNING	On units with IZS options installed: The permeation tube temperature is outside of specified limits.
OZONE FLOW WARNING	Ozone flow is outside of specified limits.
OZONE GEN OFF	Ozone generator is off, which is intentional for the warm-up period. This is the only warning message that automatically clears itself after warmup.
PMT TEMP WARNING	PMT temperature is outside of specified limits.
RCELL PRESS WARN	Reaction cell pressure is outside of specified limits.
RCELL TEMP WARNING	Reaction cell temperature is outside of specified limits.
MANIFOLD TEMP WARN	Dilution or bypass manifold temperature is outside of warning limits (if installed).
REAR BOARD NOT DET	The CPU is unable to communicate with the motherboard.
RELAY BOARD WARN	The firmware is unable to communicate with the relay board.
SAMPLE FLOW WARN	The flow rate of the sample gas is outside the specified limits.
SYSTEM RESET	This message appears every time the analyzer was powered up.

3.5.4. Functional Check

After the analyzer's components have warmed up for at least 30 minutes, verify that the software properly supports any hardware options that were installed.

Check to make sure that the analyzer is functioning within allowable operating parameters. Appendix A and C include a list of test functions viewable from the analyzer's front panel as well as their expected values. These functions are also useful tools for diagnosing performance problems with your analyzer (Chapter 11). The enclosed *Final Test and Validation Data Sheet* (part number 04490) lists these values before the instrument left the factory. To view the current values of these test functions press the <TST TST> keys:

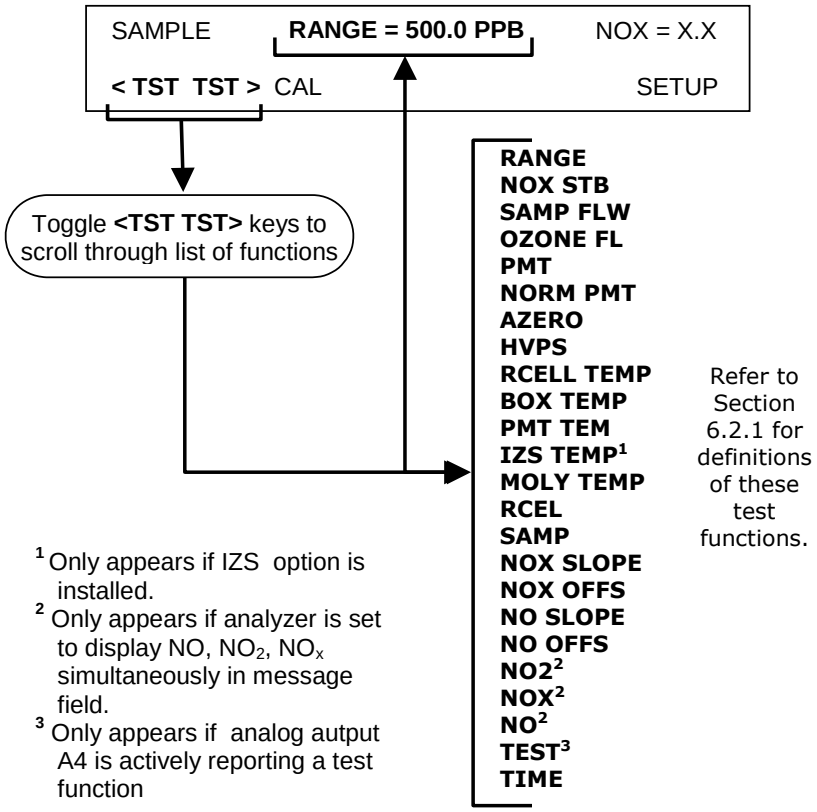


Figure 3-11 and Figure 3-12 show the analyzer flow diagrams without and with options installed. Refer to these diagrams whenever troubleshooting or a thorough understanding of the analyzer operation is required. Note that valve options for zero/span valves or IZS are principally the same, except that the span gas stream is connected differently in the zero/span option.

More detailed pneumatic diagrams for all configurations (base, zero/span valves, IZS, sample dryer) can be found in Appendix D, diagram number 04574.

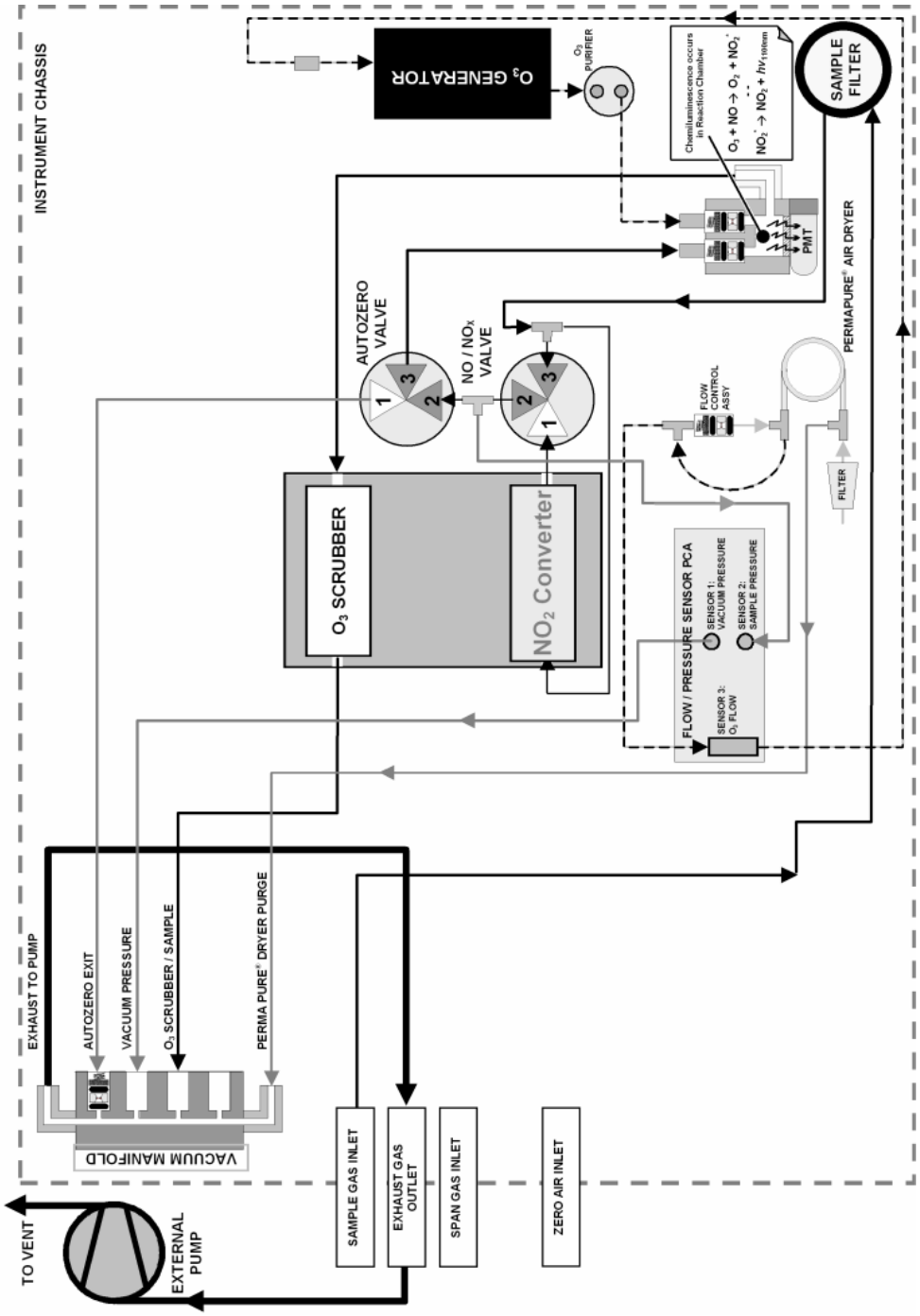


Figure 3-11: M9110E Pneumatic Diagram In Standard Configuration

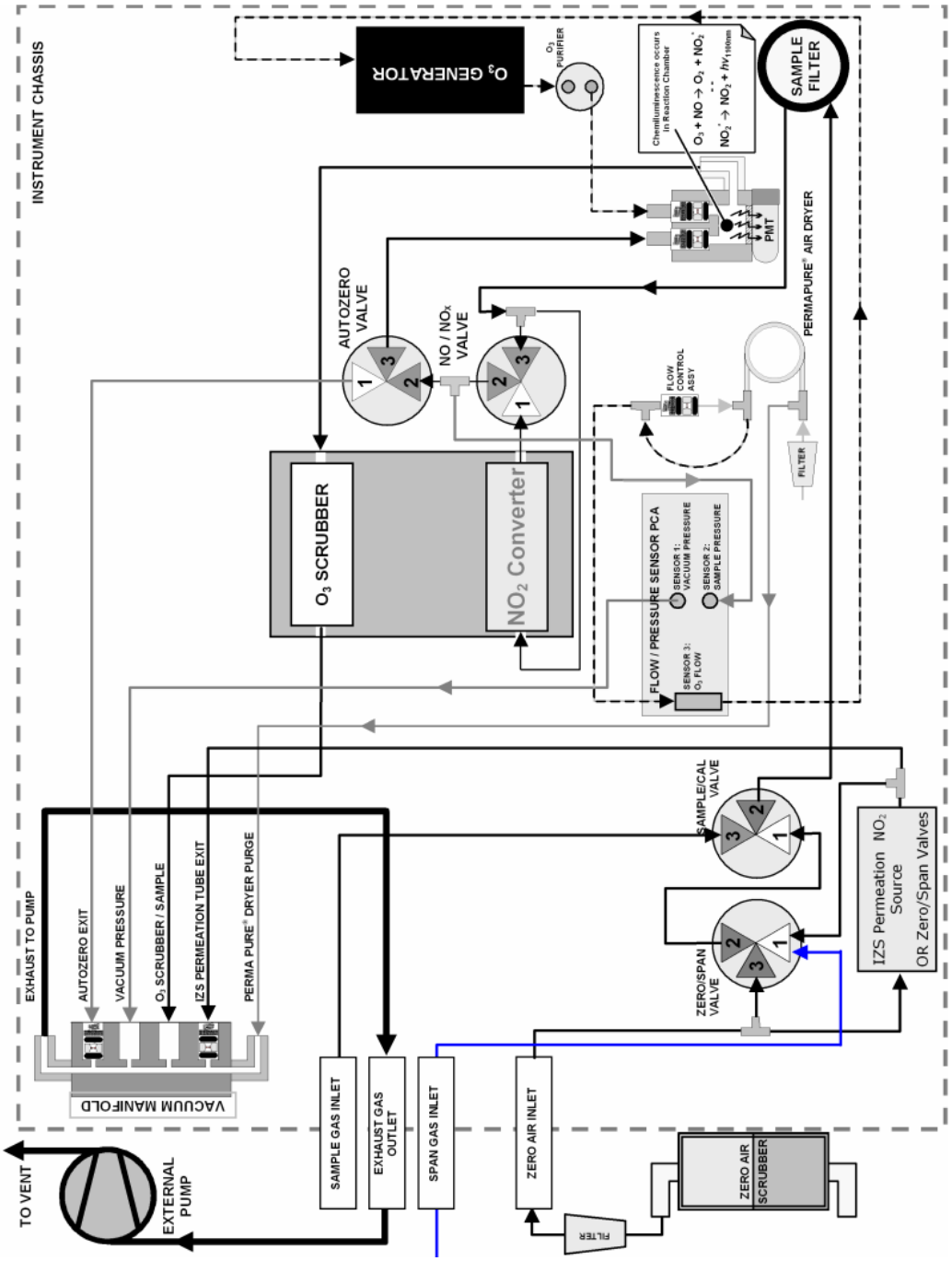


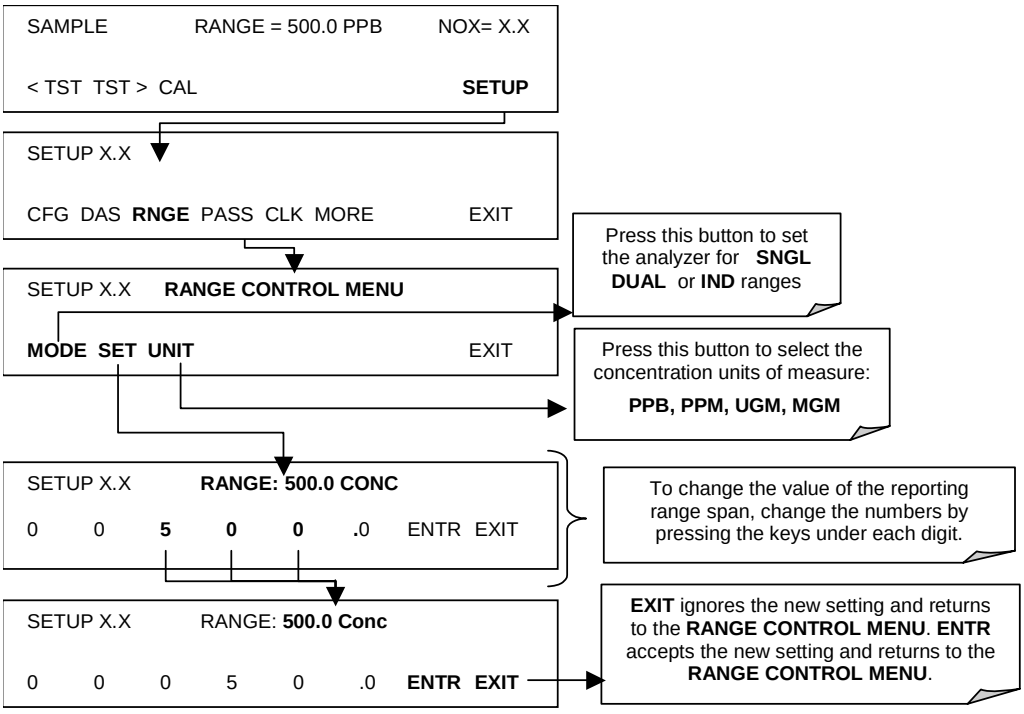
Figure 3-12: M9110E Pneumatic Diagram With Options Installed

3.6. First Calibration

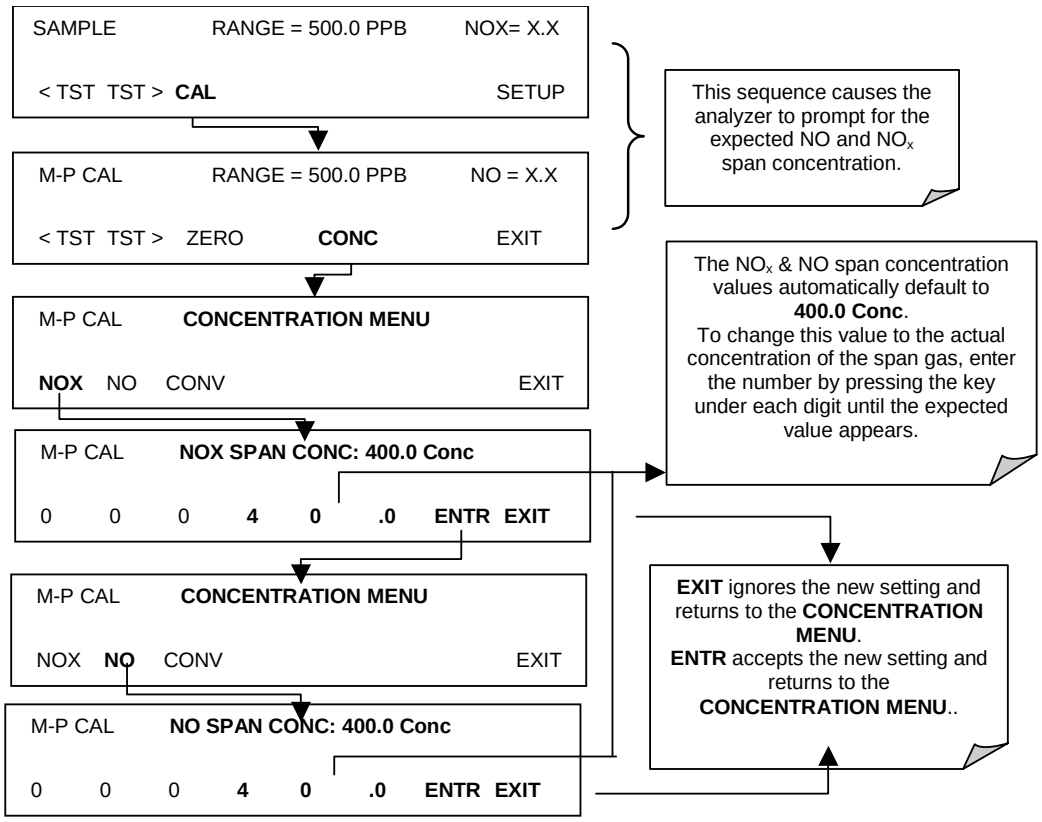
3.6.1. Basic Calibration Procedure

The initial calibration should be carried out using the 500 ppb range, a span gas with about 400 ppb NO and with the unit set for **SINGLE** range, which will enable you to compare your calibration results to the factory calibration as listed on the *Final Test and Validation Data Sheet*. The following three-step procedure assumes that the instrument does not have any of the available zero/span (Z/S) valve options installed. Chapter 7 contains instructions for calibrating instruments with Z/S valve options, Chapter 8 for EPA protocol calibration.

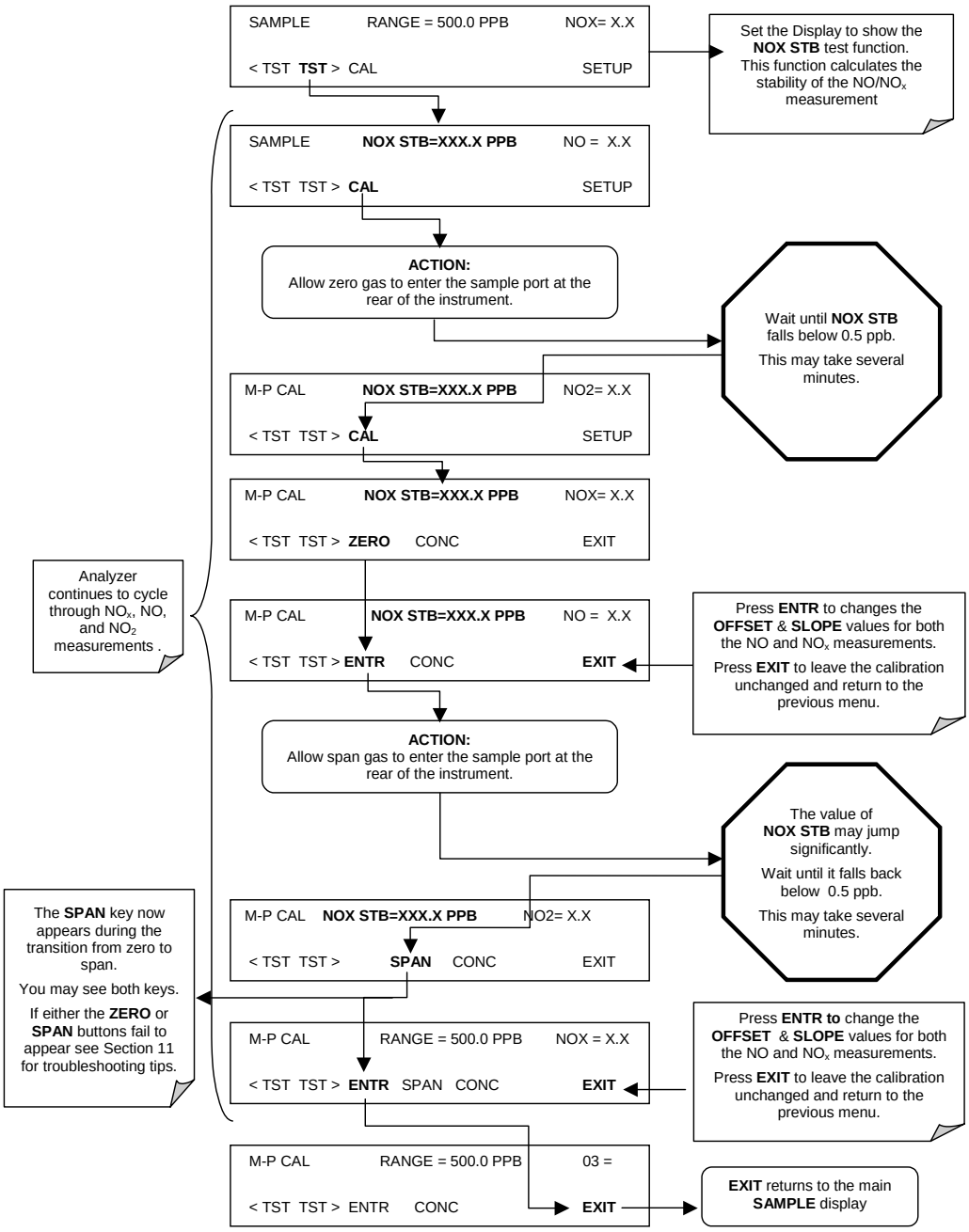
Set the analog output range of the M9110E:



Set the expected NO and NOx span gas concentration. If you supply NO gas to the analyzer, the values for expected NO and NO_x need to be identical.



Perform the zero/span calibration procedure:



The Model 9110E analyzer is now ready for operation.

3.6.2. Interferences for NO_X Measurements

The chemiluminescence method for detecting NO_X is subject to interference from a number of sources including water vapor (H_2O), ammonia (NH_3), sulfur dioxide (SO_2) and carbon dioxide (CO_2) but the Model 9110E has been designed to reject most of these interferences. Section 10.1.5 contains more detailed information on interferences.

Ammonia is the most common interferent, which is converted to NO in the analyzer's NO_2 converter and creates a NO_X signal artifact. If the Model 9110E is installed in an environment with high ammonia, steps should be taken to remove the interferent from the sample gas before it enters the reaction cell. TAI offers a sample gas conditioning option to remove ammonia and water vapor (Section 5.8).

Carbon dioxide diminishes the NO_X signal when present in high concentrations. If the analyzer is used in an application with excess CO_2, contact TAI customer service for possible solutions. Excess water vapor can be removed with one of the dryer options described in Section 5.8. In ambient air applications, SO_2 interference is usually negligible.

NOTE
Once you have completed the above set-up procedures, please fill out the quality questionnaire that was shipped with your unit and return it to TAI.
This information is vital to our efforts in continuously improving our service and our products. Thank you.

4. FREQUENTLY ASKED QUESTIONS & GLOSSARY

4.1. Frequently Asked Questions

The following list contains some of the most commonly asked questions relating to the Model 9110E NO_x Analyzer.

Q: Why is the **ZERO** or **SPAN** key not displayed during calibration?
A: The M9110E disables certain keys whenever the chosen value is out of range for that particular parameter. In this case, the expected span or zero value is too different from the actually measured value and the instrument does not allow to span or zero to that point. If, for example, the span set point is 400 ppb and the measurement response is only 50 ppb, the SPAN button will not appear to prevent the user from spanning to an out-of-range response curve. Chapter 11 describes this in detail.

Q: Why does the **ENTR** key sometimes disappear on the front panel display?
A: Sometimes the **ENTR** key will disappear if you select a setting that is invalid or out of the allowable range for that parameter, such as trying to set the 24-hour clock to 25:00:00 or a range to less than 10 or more than 20000 ppb. Once you adjust the setting to an allowable value, the **ENTR** key will re-appear.

Q: Why does the analyzer not respond to span gas?
A: There are several reasons why this can happen. Section 11.3.2 has some possible answers to this question.

Q: Can I automate the calibration of my analyzer?
A: Any analyzer with zero/span valve or IZS option can be automatically calibrated using the instrument's AutoCal feature.

Q: Can I use the IZS option to calibrate the analyzer?
A: Yes. However, the accuracy of the IZS option's permeation tube is only ±5%. Whereas this may be acceptable for basic calibration checks, the IZS option is not permitted as a calibration source in applications following US EPA protocols. To achieve highest accuracy, it is recommended to use cylinders of calibrated span gases in combination with a zero air source. TAI offers a zero air generator Model 701 and a gas dilution calibrator Model 700 for this purpose.

Q: What do I do if the concentration on the instrument's front panel display does not match the value recorded or displayed on my data logger even if both instruments are properly calibrated?
A: This most commonly occurs for one of the following reasons: (1) a difference in circuit ground between the analyzer and the data logger or a wiring problem; (2) a scale problem with the input to the data logger. The analog outputs of the analyzer can be manually calibrated to compensate for either or both of these effects, see Section 6.7; analog outputs are not calibrated, which can happen after a firmware upgrade (Section 6.7.3.2).

Q: How do I measure the sample flow?
A: Sample flow is measured by attaching a calibrated flow meter to the sample inlet port when the instrument is operating. The sample flow should be 500 cm^3/min ±10%.
Chapter 11 includes detailed instructions on performing a check of the sample gas flow.

Q: How often do I need to change the particulate filter?
A: Once per week. Table 9-1 contains a maintenance schedule listing the most important, regular maintenance tasks. Highly polluted sample air may require more frequent changes.

Q: How long does the sample pump last?
A: The sample pump should last one to two years and the pump head should be replaced when necessary. Use the **RCEL** pressure indicator on the front panel to see if the pump needs replacement. If this value goes above 10 in-Hg-A, on average, the pump head needs to be rebuild.

Q: Do I need a strip chart recorder or external data logger?
A: No, the M9110E is equipped with a very powerful internal data acquisition system (iDAS). Section 6.9.10 describes the setup and operation in detail.

Q: Why does my RS-232 serial connection not work?
A: There are many possible reasons: 1) the wrong cable, please use the provided or a generic "straight-through" cable (do not use a "null-modem" type cable), 2) The DCE/DTE switch on the back of the analyzer is not set properly; make sure that both green and red lights are on, 3) the baud rate of the analyzer's COM port does not match that of the serial port of your computer/data logger. See Section 11.5.11 more trouble-shooting information.

4.2. Glossary

Acronym – A short form or abbreviation for a longer term. Often artificially made up of the first letters of the phrase's words.

APICOM – Name of a remote control program offered by Teledyne-API to its customers

ASSY - Acronym for *Assembly.*

Chemical formulas used in this document:

- NO_X – nitrogen oxides, here defined as the sum of NO and NO_2
- NO – nitric oxide
- NO_2 – nitrogen dioxide
- NO_Y – nitrogen oxides, often called *odd nitrogen*, the sum of NO, NO_2 (NO_X) plus other compounds such as HNO_3. Definitions vary widely and may include nitrate (NO_3^-), PAN, N_2O and other compounds.
- NH_3 – ammonia
- H_2O – water vapor
- CO_2 – carbon dioxide
- SO_2 – sulfur dioxide
- HNO_3 – nitric acid

DAS - Acronym for *Data Acquisition System*, the old acronym of iDAS

DIAG - Acronym for *diagnostics*, the diagnostic menu or settings of the analyzer

DOC – Acronym for *Disk On Chip*, the analyzer's central storage area for analyzer operating system, firmware, and data. This is a solid state device (→ IC) without mechanical, moving

parts that acts as a computer hard disk drive under → DOS with disk drive label "C". DOC chips come with 8 mb space in the E-series analyzer standard configuration but are available in larger sizes

DOS - *Disk Operating System*, the operating system underlying the M9110E firmware. The E-series analyzers use DR DOS.

EEPROM - Also referred to as a FLASH chip. Used to store the analyzer configuration and internally labeled and handled as "disk drive B:"

FEP - Acronym for Fluorinated Ethylene Propylene polymer, one of the polymers that *du Pont* markets as *Teflon*® (along with →PFA and →PTFE).

FLASH - Flash PFA is used as tubing material in the M9110E.memory is non-volatile, solid-state memory

I^2C bus – read: I-square-C bus. A serial, clocked serial bus for communication between individual analyzer components

IC – Acronym for *Integrated Circuit*, a modern, semi-conductor circuit that can contain many basic components such as resistors, transistors, capacitors etc in a miniaturized package used in electronic assemblies.

iDAS - Acronym for *Internal Data Acquisition System*, previously referred to as DAS.

LED - Acronym for *Light Emitting Diode.*

PCA - Acronym for *Printed Circuit Assembly*, this is the → PCB with electronic components installed and ready to use

PCB - Acronym for *printed circuit board*, the bare circuit board without components

PLC – Acronym for *programmable logic controller*, a device that is used to control instruments based on a logic level signal coming from the analyzer

PFA – Acronym for Per-Fluoro-Alkoxy, an inert polymer. One of the polymers that *du Pont* markets as *Teflon*® (along with →FEP and →PTFE).

PTFE – Acronym for Poly-Tetra-Fluoro-Ethylene, a very inert polymer material used to handle gases that may react on other surfaces. One of the polymers that *du Pont* markets as *Teflon*® (along with →PFA and →FEP). PTFE is used as the material for the ozone air filter as well as the sample gas filter.

PVC – Acronym for *Poly Vinyl Chloride*, a polymer used for downstream tubing in the M9110E.

RS-232 - An electronic communication protocol of a serial communications port

RS-485 - An electronic communication protocol of a serial communications port

TCP/IP - Acronym for *Transfer Control Protocol / Internet Protocol*, the standard communi-cations protocol for Ethernet devices and the Internet

VARS - Acronym for *variables*, the variables menu or settings of the analyzer

USER NOTES:

5. OPTIONAL HARDWARE AND SOFTWARE

This section includes a descriptions of the hardware and software options available for the Model 9110E Nitrogen Oxides Analyzer. For assistance with ordering these options please contact the sales department of Teledyne Analytical Instruments at:

TEL: 626-961-9221
FAX: 626-961-2538

WEB SITE: http://www.teledyne-ai.com/

5.1. External Pumps (Option 10)

The M9110E comes equipped with an external pump specified upon ordering. Whereas the analyzer can be re-configured for other voltages, operation at other than the original voltage/frequency may require a different external pump. A variety of external pumps are available for the M9110E series analyzers. The range of available pump options meets all typical AC power supply standards while exhibiting the same pneumatic performance.

TAI Part No.	Description
009810300	External pump for 115 VAC / 60 Hz power supply
009810400	External pump for 230 VAC / 50 Hz power supply
009810500	External pump for 110 VAC / 50 Hz power supply
009810600	External pump for 100 VAC / 50 Hz power supply
009810700	External pump for 220-240 VAC / 50-60 Hz power supply

5.2. Rack Mount Kits (Options 20-23)

There are several options for mounting the analyzer in standard 19” racks. The slides are three-part extensions, one mounts to the rack, one mounts to the analyzer chassis and the middle part remains on the rack slide when the analyzer is taken out. The analyzer locks into place when fully extended and cannot be pulled out without pushing two buttons, one on each side.

The rack mount brackets for the analyzer requires that you have a support structure in your rack to support the weight of the analyzer. The brackets cannot carry the full weight of an analyzer and are meant only to fix the analyzer to the front of a rack and to prevent it from sliding out of the rack through user intervention or vibration.

Option Number	Description
OPT 20A	Rack mount brackets with 26 in. chassis slides.
OPT 20B	Rack mount brackets with 24 in. chassis slides.
OPT 21	Rack mount brackets only
OPT 23	Rack mount for external pump (no slides).

5.3. Carrying Strap Handle (Option 29)

The chassis of the M9110EH/EM analyzer allows to attach a strap handle for carrying the instrument (Figure 5-1). The handle is located on the right side and pulls out to

accommodate a hand for transport. When pushed in, the handle is flush with the chassis and protrudes out about 9 mm / 3/8". Installing the strap handle prevents the use of the rack mount slides, although the rack mount brackets, Option 21, can still be used. We caution any user to prevent personal injury when using the strap handle, as the analyzer without options installed weighs about 17 kg (38 pounds). Make sure to disconnect all cables and tubing from the analyzer before carrying it.

Figure 5-1: M9110E with Carrying Strap Handle and Rack Mount Brackets

5.4. Current Loop Analog Outputs (Option 41)

This option adds isolated, voltage-to-current conversion circuitry to the analyzer's analog outputs. This option may be ordered separately for the first three of the analog outputs and can be installed at the factory or added later. Call TAI sales for pricing and availability.

The current loop option can be configured for any output range between 0 and 20 mA (for example 0-20, 2-20 or 4-20 mA). Information on calibrating or adjusting these outputs can be found in Section 6.7.6.

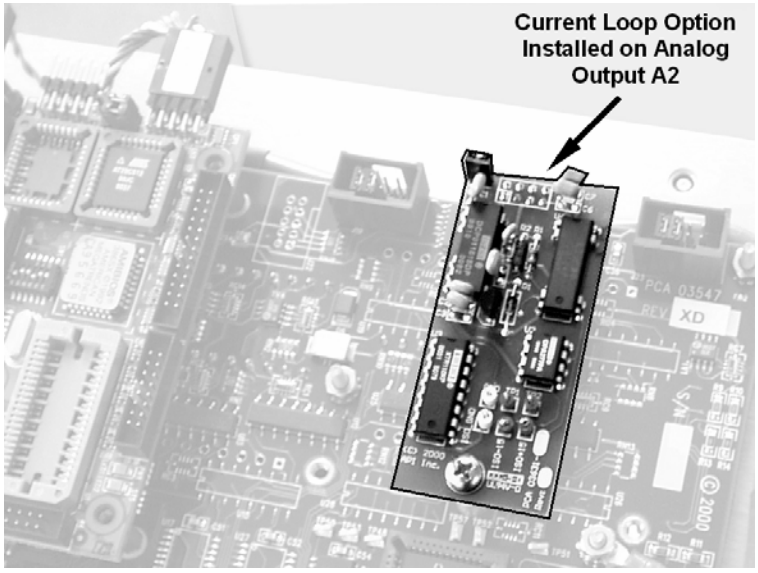


Figure 5-2: Current Loop Option Installed on the Motherboard

5.5. Particulate Filter Kit (Option 42A)

This option includes a one-year supply of 50 replacement, Teflon membrane, particulate filters, 47 mm in diameter, 1 micrometer pore size.

5.6. Calibration Valve Options

5.6.1. Zero/Span Valves (Option 50)

The Model 9110E NO_x analyzer can be equipped with a zero/span valve option for controlling the flow of calibration gases generated from external sources. This option contains two solenoid valves located inside the analyzer that allow the user to switch either zero, span or sample gas to the instrument's sensor. The user can control these valves from the front panel keyboard either manually or by activating the instrument's CAL or AutoCal features (Section 7.8). The valves may also be opened and closed remotely through the serial ports (Section 6.9) or through the external, digital control inputs (Section 6.8).

This option also includes a two-stage, external zero air scrubber assembly that removes all NO and NO_2 from the zero air source (ambient air). The scrubber is filled with 50% Purafil Chemisorbant® (for conversion of NO to NO_2) and 50% activated charcoal (for removal of NO_2). This assembly also includes a small particle filter to prevent scrubber particles to enter the analyzer as well as two more rear panel fittings so each gas can enter the analyzer separately.

Figure 3-12 shows the internal, pneumatic connections for a Model 9110E with the zero/span valve option installed. Table 5-1 describes the state of each valve during the analyzer's various operational modes.

Table 5-1: IZS or Z/S Valve States

Mode	Valve	Condition	Valve Port Connection NO = normally open port NC = normally closed port COM = common port
SAMPLE	Sample/Cal	Open to sample gas inlet	NO → COM
	Zero/Span	Open to zero air inlet	NO → COM
ZERO CAL	Sample/Cal	Open to zero/span inlet (activated)	NC → COM
	Zero/Span	Open to zero air inlet	NO → COM
SPAN CAL	Sample/Cal	Open to zero/span inlet (activated)	NC → COM
	Zero/Span	Open to span gas inlet / IZS gas (activated)	NC → COM

The state of the IZS valves can also be controlled:

- Manually from the analyzer's front panel by using the **SIGNAL I/O** controls located under the **DIAG** Menu (Section 6.8.1),
- By activating the instrument's AutoCal feature (Section 7.8),
- Remotely by using the external digital control inputs (Section 6.9), or
- Remotely through the RS-232/485 serial I/O ports (Section 6.9.10).

Sources of zero and span gas flow must be capable of supplying at least 600 cm^3/min as the analyzer draws about 500±50 cm^3/min into the instrument. Both supply lines should be vented outside of the analyzer's enclosure. In order to prevent back-diffusion and pressure drop effects, these vent lines should be between 2 and 10 meters in length.

5.6.2. Internal Zero/Span (IZS) (Option 51)

The M9110E can be equipped with an internal zero air and span gas generator system (IZS). This option includes a heated enclosure for a NO_2 permeation tube, an external scrubber for producing zero air and two valves for switching between the sample gas inlet and the output of the zero/span subsystem, functionally identical to the zero/span valve option.

The IZS option includes a two stage, external zero air scrubber assembly that removes all NO & NO_2 from the zero air source. The scrubber is filled with 50% Purafil Chemisorbant® (for conversion of NO to NO_2) and 50% activated charcoal (for removal of NO_2). This assembly also includes a small particle filter.

Span gas is created by passing zero air over a NO_2 permeation tube. This tube contains liquid NO_2, which slowly permeates through a permeable membrane into the surrounding air. The concentration of the NO_2 span gas is determined by three factors:

- Size of the membrane: The larger the area of the membrane, the more permeation occurs.
- Temperature of the NO_2: Increasing the temperature of the permeation tube increases the pressure inside the tube and therefore increases the rate of permeation.

- Flow rate of the zero air: If the previous two variables are constant, the permeation rate of the NO_2 into the zero air stream will be constant. Therefore, a lower flow rate of zero air produces higher concentrations of NO_2.

In order to keep the permeation rate constant, the IZS enclosure is heated by a PID (Proportional/Integral/Derivative) temperature control loop to a constant 50° C (10° above the maximum operating temperature of the instrument). A thermistor measures the actual temperature and reports it to the CPU for control feedback. The flow rate across the IZS oven is controlled with a critical flow orifice to 60±5 cm³/min.

Please note, that the IZS option does not contain the actual permeation tube, which needs to be ordered separately. See next option for description.

CAUTION
Gas flow must be maintained at all times for units with a permeation tube installed. Insufficient gas flow allows NO_2 gas to build up to levels that will severely contaminate the instrument.

Figure 3-12 shows the internal pneumatic connections for a Model 9110E with IZS option installed. Table 5-1 shows the operational state of the valves associated with the IZS option during the analyzer's various operational modes. SPAN gas on the zero/span valve option is equivalent with the permeation tube NO_2 gas stream on the IZS option.

The state of the IZS valves can also be controlled:

- Manually from the analyzer's front panel by using the **SIGNAL I/O** controls located under the **DIAG** Menu (Section 6.8.1),
- By activating the instrument's CAL or AutoCal features (Section 7.8),
- Remotely by using the external digital control inputs (Section 6.9), or
- Remotely through the RS-232/485 serial I/O ports (Section 6.9.10).

5.6.3. IZS Permeation Tubes (Options 53 & 55)

One IZS permeation tube is necessary to operate the IZS option (Option 51). Two different NO_2 permeation tubes are available, they are identical in size and shape but are designed to have different permeation rates.

Table 5-2: Available Permeation Source Options

Option	Permeation Rate (± 25%)	Approximate NO_2 Concentration
OPT 53	421 ng/min	300 - 500 ppb
OPT 55	842 ng/min	600 - 1000 ppb

Each tube is shipped with a calibration certificate, traceable to a NIST standard, specifying its actual NO_2 permeation rate to within ±5%. The calibration is performed at a tube temperature of 50°C and a flow rate of 0.56 liters per minute.

5.7. Scrubbers and Expendables

5.7.1. Charcoal Scrubber (Option 64A)

This kit includes a charcoal scrubber cartridge, which is used to remove NO_2 from an exhaust port. Applications include, but are not limited to, the removal of NO_2 from the pump exhaust if that exhaust cannot be vented outside the analyzer shelter or if the vent line is not far enough away from the analyzer inlet port (in which case the exhaust would be measured again by the analyzer). The kit does not include any mounting clips, filters or tubing. To order a refill for this cartridge, specify the refill kit listed below.

Older models of the nitrogen oxides analyzer used this type of charcoal scrubber to remove both NO_2 and excess ozone from the exhaust. However, we do not recommend this particular application because of the potentially explosive nature of the mixture.

5.7.2. Charcoal Refill Kit (Part# 00596)

This refill kit contains two plastic bottles with a total of 2.5 kg (5.5 pounds) charcoal, which lasts for about five refills of Option 64A.

5.7.3. Zero Air Scrubber (Option 64B)

This kit includes a zero air scrubber cartridge, which can be used to produce and supply zero air to the analyzer's ZERO inlet port. The cartridge mounts to the outside rear panel by means of two rubberized clips and contains two chemicals, 50% volume of Purafil Chemisorbant to convert NO to NO_2, followed 50% volume of charcoal to absorb NO_2.

The zero air scrubber exit contains a particle filter that retains any dust coming from the cartridge and connects with a 0.25" PVC tubing to the ZERO inlet port. The chemicals need to be exchanged periodically (use Option 43) to prevent saturation and break-through of NO_X into the zero air stream. This kit is recommended if no other zero air source is available and if the analyzer is equipped with the zero/span valve option (Section 5.6.1). The kit is included in the IZS option but not in the zero/span valve option.

5.7.4. Zero Air Scrubber Maintenance Kit (Option 43)

This kit includes the items needed to refurbish the external zero air scrubber.

Table 5-3: Contents of Zero Air Scrubber Maintenance Kit

TAI Part No.	Description
005960000	Activated charcoal refill
059700000	Purafil Chemisorbant® refill
FL0000001 [1]	Sintered filter for critical orifice port
FL0000003	Replacement particulate filter for zero air inlet fitting
OR0000001 [1]	O-Ring (qty:2) for critical orifice port
1 These items are required for units with IZS option only. They are used for rebuilding the IZS-exhaust critical flow orifice on the analyzer's exhaust manifold.	

5.7.5. M9110E Expendables Kit (Option 42)

This kit includes a recommended set of expendables for one year of operation of the M9110E. See Appendix B for a detailed listing of the contents.

5.7.6. M9110E Spare Parts Kit (Option 43)

This kit includes a recommended set of spare parts for 2-3 years of operation of the M9110E. It includes items such as the orifice holder, a spare PMT and other items that are recommended as backups to minimize down-time in case of component failures. See Appendix B for a detailed listing of the contents.

Formatted: Bullets and Numbering

5.8. Communication Options

5.8.1. RS232 Modem Cables (Options 60 and 60A)

The analyzer is shipped with a standard, shielded, straight-through DB-9F to DB-9F cable of about 1.8 m length, which should fit most computers of recent build. An additional cable of this type can be ordered as Option 60.

Option 60A consists of a shielded, straight-through serial cable of about 1.8 m length to connect the analyzer's COM1 port to a computer, a code activated switch or any other communications device that is equipped with a DB-25 female connector. The cable is terminated with one DB-9 female connector and one DB-25 male connector. The DB-9 connector fits the analyzer's COM1 port.

5.8.2. RS-232 Multidrop (Option 62)

The multidrop option is used with any of the RS-232 serial ports to enable communications of several analyzers with the host computer over a chain of RS-232 cables. The option consists of a small box, which can be attached to the analyzer, with a termination switch, a power connector and two serial ports, one incoming from the analyzer (cable supplied) and one outgoing port to the next analyzer's multi-drop box (requires additional cable Option 60). One Option 62 is required per analyzer. The first incoming port on the first box connects to the host computer and the outgoing port on the last multi-drop box needs to be terminated. Setup and user instructions are covered in the TAI Multidrop Manual, part number 021790000, available for download from the company website.

5.8.3. Ethernet (Option 63)

The Ethernet option allows the analyzer to be connected to any 10BaseT local area network. When installed, this option is electronically connected to the instrument's COM2 serial port making that port no longer available for RS-232/RS-485 communications through the COM2 connector on the rear panel. The option consists of a TAI designed Ethernet card (Figure 5-3), which is mechanically attached to the instrument's rear panel. A 2 m long, CAT-5 network cable terminated at both ends with standard RJ-45 connectors is included as well (part number WR0000067). Maximum communication speed is limited by the RS-232 port to 115.2 kbaud. See Section 6.9.9 for configuration.

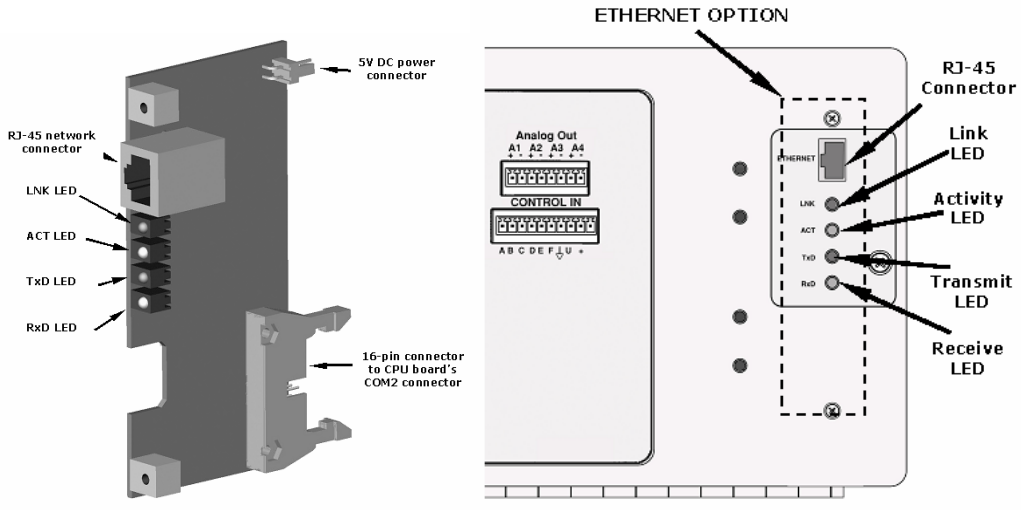


Figure 5-3: M9110E Ethernet Card and Rear Panel With Ethernet Installed

5.9. Sample Gas Conditioners (Options 86 & 88)

Several permeation devices using Nafion® permeation gas exchange tubes are available for applications with high moisture and/or moderate levels of NH_3 in the sample gas. This type of sample conditioner is part of the standard M9110E equipment to remove H_2O and NH_3 from the ozone generator supply gas stream but can be purchased for the sample gas stream as well. All gas conditioners remove water vapor to a dew point of about –20° C (~600 ppm H_2O) and effectively remove concentrations of ammonia up to about 1 ppm. More information about these dryers and their performance is available at http://www.permapure.com/.

The following options include the hardware required to install the dryers.

Table 5-4: Dryer and NH_3 Removal Options

Option Number	Description
Standard Equipment	Single gas conditioner (dryer / NH_3 removal) for ozone generator supply gas stream only. Includes mounting bracket for two dryers (Option 86 mounts on the back).
OPT 86	Single gas conditioner (dryer / NH_3 removal) for sample gas stream only. Mounts on the back of the existing dryer bracket. Converts analyzer to dual-conditioner instrument.
OPT 88	Single combination gas conditioner (dryer / NH_3 removal) for both the sample gas and ozone supply air. Replaces the standard dryer for O_3 air and comes with mounting bracket.

The combination conditioner is a low-cost option for drying both the sample gas and ozone supply air with one dryer. However, this dryer can only be used in applications where both sample and calibration gases (after dilution) are at or near ambient and constant concentrations of oxygen (about 20%), because the ozone generator needs a high and constant amount of oxygen to generate ozone properly. Stack applications or industrial applications in which the sample gas has a significantly reduced or highly variable concentration of

oxygen need to use the separate dryer option 86. The combination conditioner needs to be specified upon ordering the analyzer.

5.10. Additional Manual (Option 70)

Additional copies of the printed user's manual can be purchased from the factory. Please specify the serial number of your analyzer so that we can match the manual version.

5.11. Extended Warranty (Options 92 & 93)

Two options are available for extending the standard manufacturer's warranty (Section 2.3). Both options have to be specified upon ordering the analyzer.

Option Number	Description
OPT 92	Extends warranty to cover a two (2) year period from the date of purchase.
OPT 93	Extends warranty to cover a five (5) year period from the date of purchase.

USER NOTES:

6. OPERATING INSTRUCTIONS

To assist in navigating the analyzer's software, a series of menu trees can be found in Appendix A of this manual along with an index of software commands and references to the respective manual sections.

NOTE
The flow charts appearing in this section contain typical representations of the analyzer's display during the various operations being described. These representations may differ slightly from the actual display of your instrument.

6.1. Overview of Operating Modes

The M9110E software has a variety of operating modes. Most commonly, the analyzer will be operating in **SAMPLE** mode, in which sample gases are measured and a continuous read-out of the gas concentration is displayed. Test and warning functions can be examined and data can be viewed or downloaded.

Table 0-1: Analyzer Operating modes

Mode	Explanation
SAMPLE	Sampling normally, flashing text indicates adaptive filter is on.
M-P CAL	This is the basic calibration mode of the instrument and is activated by pressing the CAL key.
SETUP X.#[2]	SETUP mode is being used to configure the analyzer. The gas measurement will continue during this process.
SAMPLE A	Indicates that unit is in SAMPLE mode and AUTOCAL feature is activated.
ZERO CAL M[1]	Unit is performing ZERO calibration procedure initiated manually by the user.
ZERO CAL A[1]	Unit is performing ZERO calibration procedure initiated automatically by the AUTOCAL feature.
ZERO CAL R[1]	Unit is performing ZERO calibration procedure initiated remotely through the COM ports or digital control inputs.
LO CAL A	Unit is performing LOW SPAN (midpoint) calibration initiated automatically by the analyzer's AUTOCAL feature.
LO CAL R	Unit is performing LOW SPAN (midpoint) calibration initiated remotely through the COM ports or digital control inputs.
SPAN CAL M[1]	Unit is performing SPAN calibration initiated manually by the user.
SPAN CAL A[1]	Unit is performing SPAN calibration initiated automatically by the analyzer's AUTOCAL feature.
SPAN CAL R[1]	Unit is performing SPAN calibration initiated remotely through the COM ports or digital control inputs.
DIAG	One of the analyzer's diagnostic modes is active (Section 6.8).

[1] Only Appears on units with Z/S valve or IZS options.
[2] The revision of the analyzer firmware is displayed following the word **SETUP**, e.g., **SETUP C.4**.

The second operating mode is the **SETUP** mode. This mode is used for configuring various features and functions of the analyzer, such as the iDAS system, the analog output ranges,

or the COM port settings. The **SETUP** mode is also used for performing various diagnostic tests during troubleshooting.

The third operating mode is the **CAL** mode, which allows calibration of the analyzer in various ways. Because of its importance, this mode is described separately in Chapter 7.

The mode field (upper left corner) of the front panel display indicates the current operating mode (refer to Figure 3-4 for front panel features). In addition to the three main modes, there are mode variations, which are summarized in Table 0-1.

6.2. Sample Mode

This is the analyzer's standard operating mode. In this mode, the instrument is analyzing NO and NO_X and calculating NO_2 concentrations.

6.2.1. Test Functions

A series of test functions is available at the front panel while the analyzer is in **SAMPLE** mode. These parameters provide information about the present operating status of the instrument and are useful during troubleshooting (Section 11.1). They can also be recorded in one of the iDAS channels (Section 6.10.1.1) for data analysis. To view the test functions, press one of the **<TST TST>** keys repeatedly in either direction.

NOTE
A value of "XXXX" displayed for any of the TEST functions indicates an out-of-range reading or the analyzer's inability to calculate it.

NOTE
All pressure measurements are represented in terms of absolute pressure. Absolute, atmospheric pressure is 29.92 in-Hg-A at sea level. It decreases about 1 in-Hg per 300 m gain in altitude. A variety of factors such as air conditioning and passing storms can cause changes in the absolute atmospheric pressure.

Table 0-2: Test Functions Defined

Display	Parameter	Units	Description
RANGE	RANGE	PPB, PPM, UGM, MGM	The full scale limit to which the analyzer's analog outputs are currently set. This is not the physical range of the instrument. If the **Auto** range mode has been selected, two **RANGE** functions will appear. If the **IND** (independent) range mode has been selected, three **RANGE** functions will appear:
NOX STB	STABILITY	PPB, PPM, UGM, MGM	The stability is a standard deviation of the NO_X concentration over 25 samples, each recorded every 10 seconds. A low **nox stb** value indicates low variability in NO_X.
SAMP FLW	SAMPLE FLOW	cm^3/min (cc/m)	The flow rate of the sample gas through the reaction cell. This value is not measured but calculated from the sample pressure.
OZONE FL	OZONE FLOW	cm^3/min (cc/m)	Flow rate of the O_3 gas stream as measured with a flow meter
PMT	PMT Signal	MV	The raw output voltage of the PMT.
NORM PMT	NORMALIZED PMT Signal	MV	The output voltage of the PMT after normalization for auto-zero offset and temperature/pressure compensation (if activated).
AZERO	AUTO-ZERO	MV	The PMT signal with zero NO_X, which is usually slightly different from 0 V. This offset is subtracted from the PMT signal and adjusts for variations in the zero signal.
HVPS	HVPS	V	The PMT high voltage power supply.
RCELL TEMP	REACTION CELL TEMP	°C	The current temperature of the reaction cell.
BOX TEMP	BOX TEMPERATURE	°C	The ambient temperature of the inside of the analyzer case.
PMT TEMP	PMT TEMPERATURE	°C	The current temperature of the PMT.
IZS TEMP	IZS TEMPERATURE[1]	°C	The current temperature of the internal zero/span option. Only appears when IZS option is enabled.
MOLY TEMP	CONV TEMPERATURE	°C	The current temperature of the NO_2 converter.
RCEL	REACTION CELL PRESSURE	in-Hg-A	The current gas pressure of the reaction cell as measured at the vacuum manifold. This is the vacuum pressure created by the external pump.
SAMP	SAMPLE PRESSURE	in-Hg-A	The current pressure of the sample gas as it enters the reaction cell, measured between the NO/NO_x and Auto-Zero valves.
NOX SLOPE	NO_x SLOPE	- -	The slope of the current NO_x calibration as calculated from a linear fit during the analyzer's last zero/span calibration.
NOX OFFS	NO_x OFFSET	MV	The offset of the current NO_x calibration as calculated from a linear fit during the analyzer's last zero/span calibration.
NO SLOPE	NO SLOPE	- -	The slope of the current NO calibration as calculated from a linear fit during the analyzer's last zero/span calibration.
NO OFFS	NO OFFSET	MV	The offset of the current NO calibration as calculated from a linear fit during the analyzer's last zero/span calibration.
NO2	NO_2 concentration	PPB, PPM, UGM, MGM	The current NO_2 concentration in the chosen unit.
NOX	NO_x concentration	PPB, PPM, UGM, MGM	The current NO_x concentration in the chosen unit.
NO	NO concentration	PPB, PPM, UGM, MGM	The current NO concentration in the chosen unit.
TEST	TEST SIGNAL[2]	MV	Signal of a user-defined test function on output channel A4.
TIME	CLOCK TIME	hh:mm:ss	The current day time for iDAS records and calibration events.

6.2.2. Warning Messages

The most common instrument failures will be reported as a warning on the analyzer's front panel and through the COM ports. Section 11.1 explains how to use these messages to troubleshoot problems. Section 3.5.3 shows how to view and clear warning messages. Table 0-3 lists all warning messages of firmware C.4.

Table 0-3: List of Warning Messages Revision C.4

Message	Meaning
ANALOG CAL WARNING	The instruments analog-to-digital converter (A/D) circuitry or one of the analog outputs are not calibrated.
AZERO WRN XXX.X MV	The reading taken during the Auto-zero cycle is outside the specified limits. The value shown here as "XXX.X" indicates the actual auto-zero reading at the time of the warning.
BOX TEMP WARNING	The temperature inside the M9110E chassis is outside the specified limits.
CANNOT DYN SPAN	Remote span calibration failed while the dynamic span feature was ON.
CANNOT DYN ZERO	Remote zero calibration failed while the dynamic zero feature was ON.
CONFIG INITIALIZED	Configuration storage was reset to factory configuration or was erased.
CONV TEMP WARNING	NO_2 converter temperature is outside of specified limits.
DATA INITIALIZED	iDAS data storage was erased.
HVPS WARNING	High voltage power supply for the PMT is outside of specified limits.
IZS TEMP WARNING	On units with IZS option installed: The IZS temperature is outside of specified limits.
OZONE FLOW WARNING	Ozone flow is outside of specified limits.
OZONE GEN OFF	Ozone generator is off. This is the only warning message that automatically clears itself when the ozone generator is turned on.
PMT TEMP WARNING	PMT temperature is outside of specified limits.
RCELL PRESS WARN	Reaction cell pressure is outside of specified limits.
RCELL TEMP WARNING	Reaction cell temperature is outside of specified limits.
REAR BOARD NOT DET	The firmware is unable to communicate with the motherboard.
RELAY BOARD WARN	The firmware is unable to communicate with the relay board.
SAMPLE FLOW WARN	The flow rate of the sample gas is outside the specified limits.
SYSTEM RESET	The computer rebooted or was powered up.

6.2.3. Calibration Functions

Pressing the **CAL** key switches the M9110E into calibration mode. In this mode, the user can calibrate the instrument with the use of calibrated zero or span gases.

If the instrument includes either the zero/span valve option or IZS option, the display will also include **CALZ** and **CALS** keys. Pressing either of these keys also puts the instrument into multipoint calibration mode.

The **CALZ** key is used to initiate a calibration of the zero point.

The **CALS** key is used to calibrate the span point of the analyzer. It is recommended that this span calibration is about 80-90% of full scale of the analyzer's operating range.

Chapter 7 details all calibration operations, Chapter 1 describes the zero/span valve and IZS options.

6.3. Calibration Mode

Owing to its importance, calibration is described separately in Chapter 7, EPA protocol calibration in Chapter 8.

6.4. Setup Mode

The **SETUP** mode contains a variety of choices that are used to configure the analyzer's hardware and software features and to read or configure the internal data acquisition system (iDAS). For a visual representation of the software menu trees, refer to Appendix A-1.

NOTE
Any changes made to a variable during one of the following procedures is not acknowledged by the instrument until the ENTR Key is pressed

If the EXIT key is pressed before the ENTR key, the analyzer will beep, alerting the user that the newly entered value has not been accepted.

Some of the functions of the SETUP mode are described in separate sections following this section. In particular, the RNGE function can be found in Section 6.5, the ACAL function in Section 7.8.

6.4.1. Password (PASS)

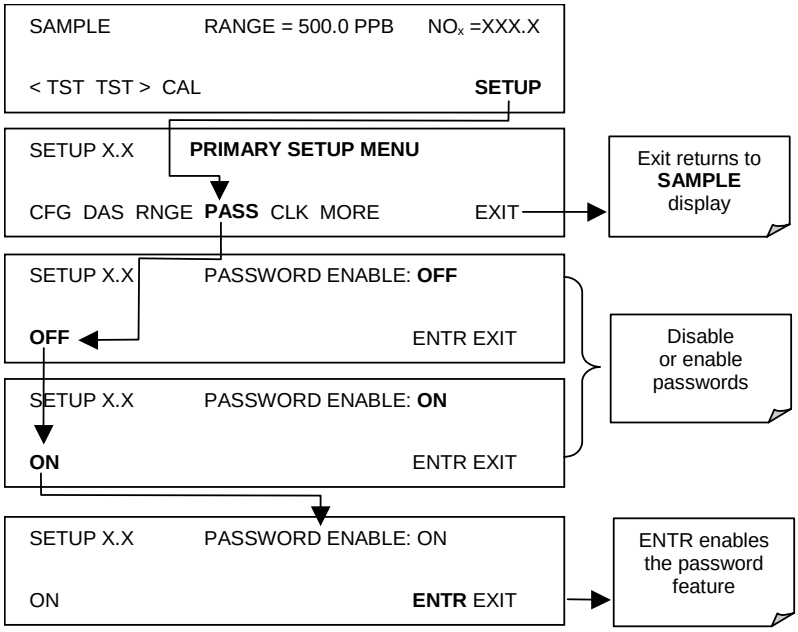
The M9110E provides password protection of the calibration and setup functions to prevent unauthorized adjustments. When the passwords have been enabled in the **PASS** menu item, the system will prompt the user for a password anytime a password-protected function is requested.

There are three levels of password protection, which correspond to operator, maintenance, and configuration functions. Each level allows access to all of the functions in the previous level.

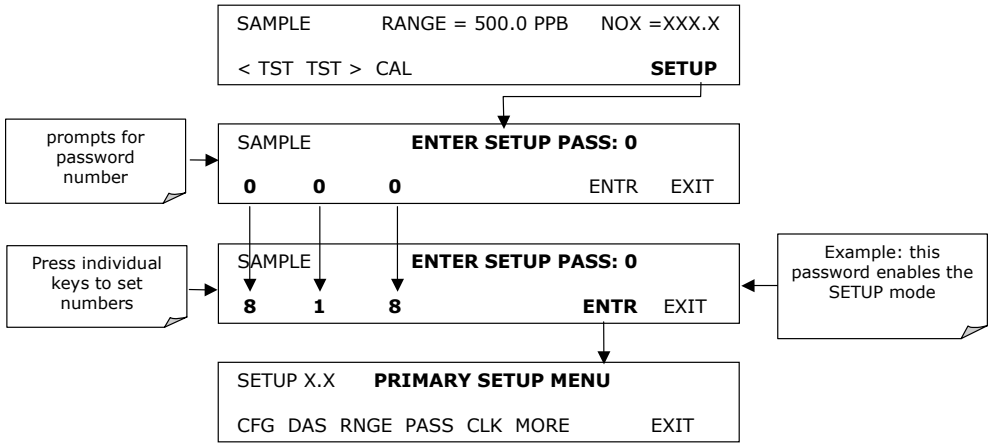
Table 0-4: Password Levels

Password	Level	Menu Access Allowed
No password	Operator	TEST, MSG, CLR
101	Maintenance	CAL, CALZ, CALS
818	Configuration	SETUP, VARS, DIAG

To enable or disable passwords, press the following keystroke sequence:



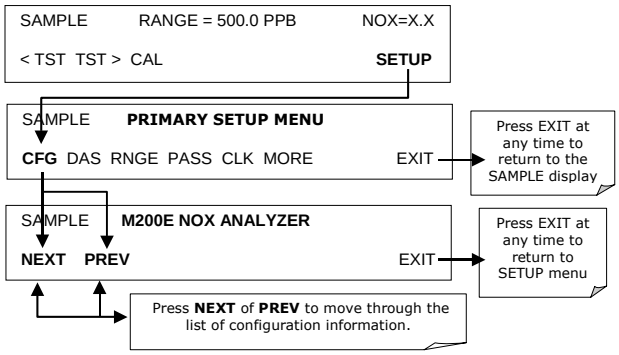
Example: If all passwords are enabled, the following keypad sequence would be required to enter the SETUP menu:



Note that the instrument still prompts for a password when entering the VARS and DIAG menus, even if passwords are disabled, but it displays the default password (818) upon entering these menus. The user only has to press ENTR to access the password protected menus but does not have to enter the required number code.

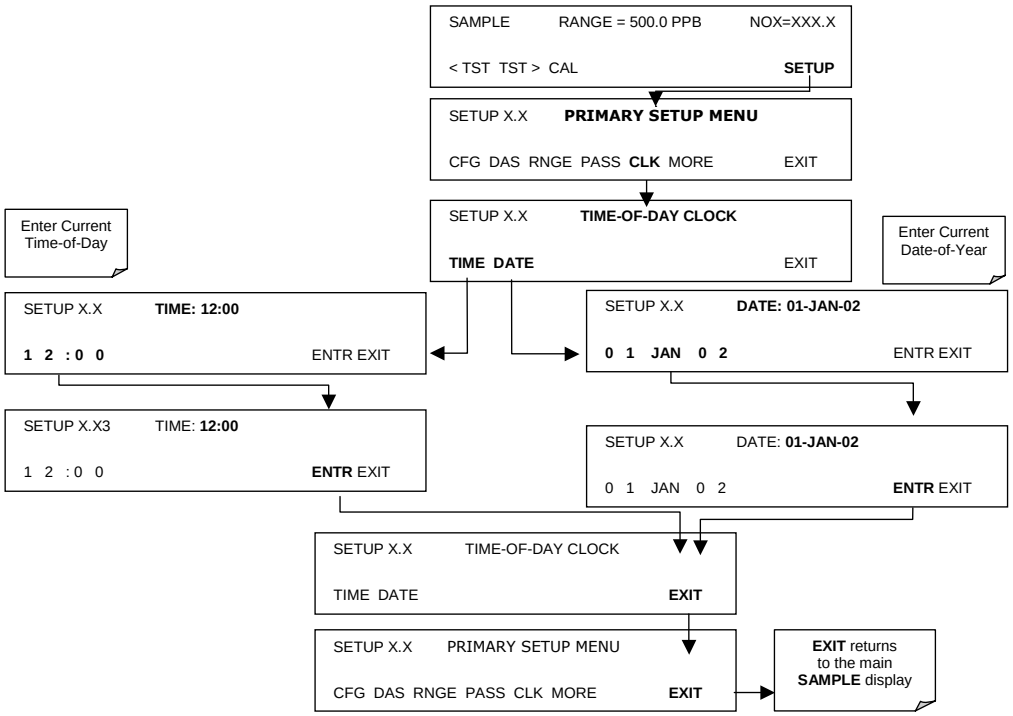
6.4.2. Configuration Information (CFG)

Pressing the CFG key displays the instrument configuration information. This display lists the analyzer model, serial number, firmware revision, software library revision, operating system and other information. Use this information to identify the software and hardware when contacting customer service. Special instrument or software features or installed options may also be listed here.

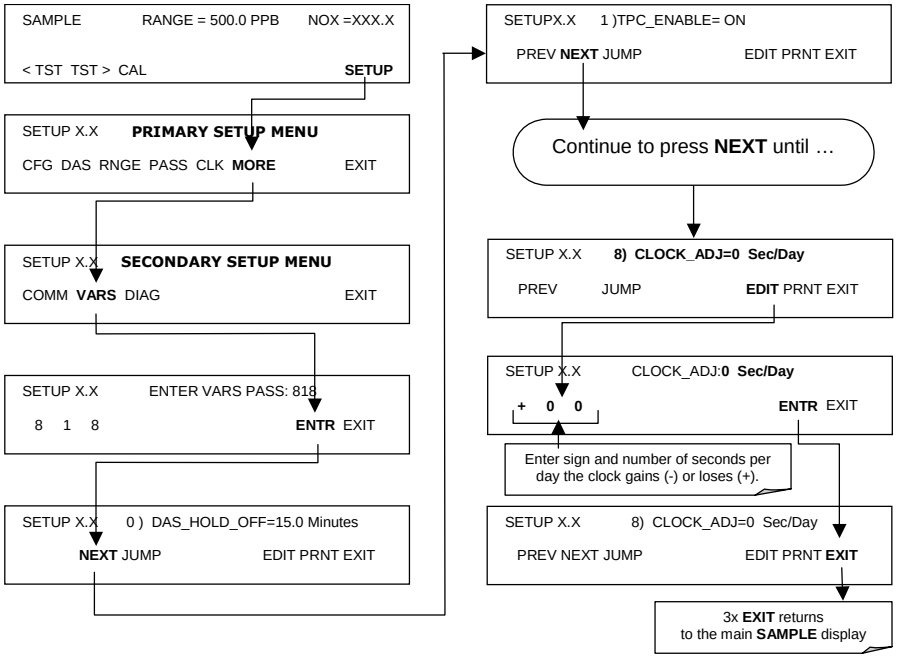


6.4.3. Clock (CLK)

The M9110E has a built-in clock for the AutoCal timer, Time **TEST** function, and time stamps on COM port messages and iDAS data entries. To set the time-of-day, press:



In order to compensate for CPU clocks which run fast or slow, there is a variable to speed up or slow down the clock by a fixed amount every day. To change this variable, press:



6.5. Setup - Range Configuration (RNGE)

The analyzer has four analog output signals, accessible through a connector on the rear panel.

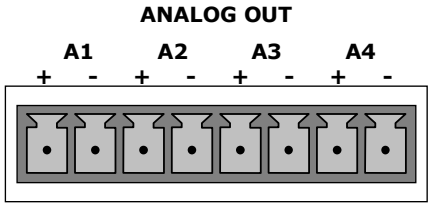


Figure 0-1: Analog Output Connector Key

All of these outputs can be configured either at the factory or by the user for full scale outputs of 0.1 V, 1V, 5V or 10V. Additionally **A1, A2** and**A3** may be equipped with optional 0-20 mA current loop drivers and configured for any current output within that range (e.g. 0-20, 2-20, 4-20, etc.).

Channels **A1**, **A2** and **A3** report analog signals that are proportional to the NO_x, NO and NO_2 concentrations of the sample gas, respectively. Analog output voltage or current can be scaled independently. Here is one configuration example for independent ranges:

A1 OUTPUT (NO_x): Output Signal = 0-5 V

A2 OUTPUT (NO): Output Signal = 4-20 mA (with current loop option)

A3 OUTPUT(NO_2): Output Signal = 0 - 1 V

Output **A4** can be set by the user to report one of many of the parameters accessible through the **<TST>** keys of the unit's SAMPLE mode display. **A4** is not available for the current loop option.

6.5.1. Physical and Analog Output Ranges

Functionally, the model 9110E NO_x analyzer has two physical ranges for determining NO_x, NO and NO_2 concentrations. The difference between the two physical ranges is the resolution of the output signals from the preamplifier board. Internally, the analyzer's signal resolution is about 16-bit or 72000 counts per 5 V PMT signal. The low range spans 0 to 2000 ppb NO_X (2000 ppb = 5 V) whereas the high range spans 0-20000 ppb NO_X (20000 ppb = 5 V). Both ranges need to be calibrated independently to the same span gases in order to allow switching back and forth between high and low ranges. Once properly calibrated, the analyzer's front panel will accurately report concentrations between 0 and 20000 ppb, regardless of the selected analog range. To switch between physical ranges, the user has to specify an appropriate analog output range from the front panel. Any analog range between 0 and 2000 ppb will cause the analyzer to remain in the low physical range. Any upper analog range limit between 2001 and 20000 ppb will cause the instrument to operate in its high physical range.

For applications using chart recorders or other analog recording devices, such a wide range can usually not be resolved on the output. For example, in an application where the expected concentrations of NO, NO_2 and NO_x are typically less than 500 ppb, the full scale of expected values is only 0.25% of the instrument's 20000 ppb physical range. The corresponding output signal would then only be recorded across 0.25% of the range of the recording device.

The M9110E solves this problem by allowing the user to select a reporting range for the analog outputs that only includes that portion of the physical range that covers the specific application. Note that only the reporting range of the analog outputs is scaled, the physical ranges of the analyzer remain unaltered with the exception of the 2000/2001 ppb split. This increases the reliability and accuracy of the analyzer by avoiding additional gain-amplification circuitry. If properly calibrated, both the iDAS values and the concentration values on the front panel are also unaffected by any change in analog output ranges.

6.5.2. Reporting Range Modes

The M9110E provides three analog output range modes to choose from.

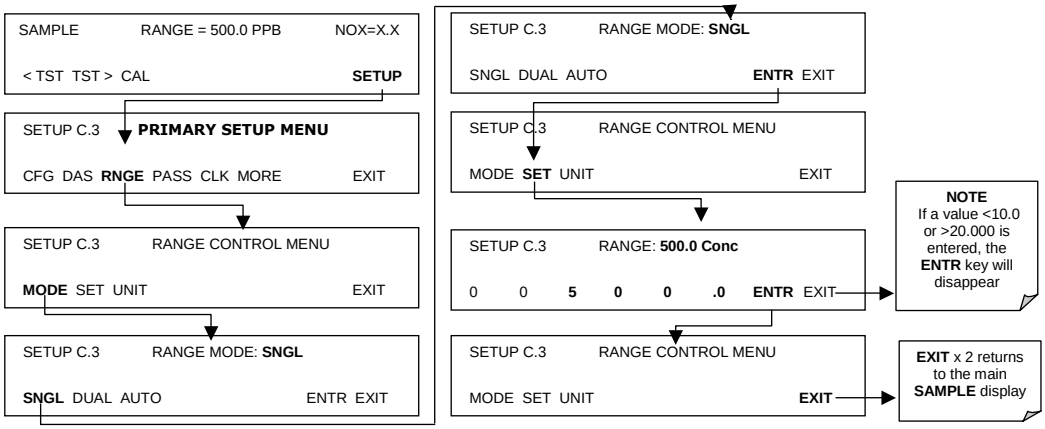
- Single range mode (**SNGL**) sets all measured gases to the same output reporting range.
- Independent range mode (**IND**) allows the reporting ranges for all gases to be different.
- Automatic range mode (**AUTO**) gives the analyzer the ability to report data through a low range and high range by automatically switching into the appropriate range as the concentrations change.

Only one of the above range modes can be active at any time. To select output range types, use the following key sequences.

6.5.3. Single Range mode (SNGL)

The default range mode for the analyzer is single range, in which all analog concentration outputs (usually **A1, A2 and A3**) are set to the same reporting range. This reporting range can be set to any value between 100 ppb and 20000 ppb. However, the electronic signal ranges of the analog outputs may still be configured for different values (e.g., 0-10 V and 0-0.1 V).

To select **SNGLE** range mode and to set the upper limit of the range, press:

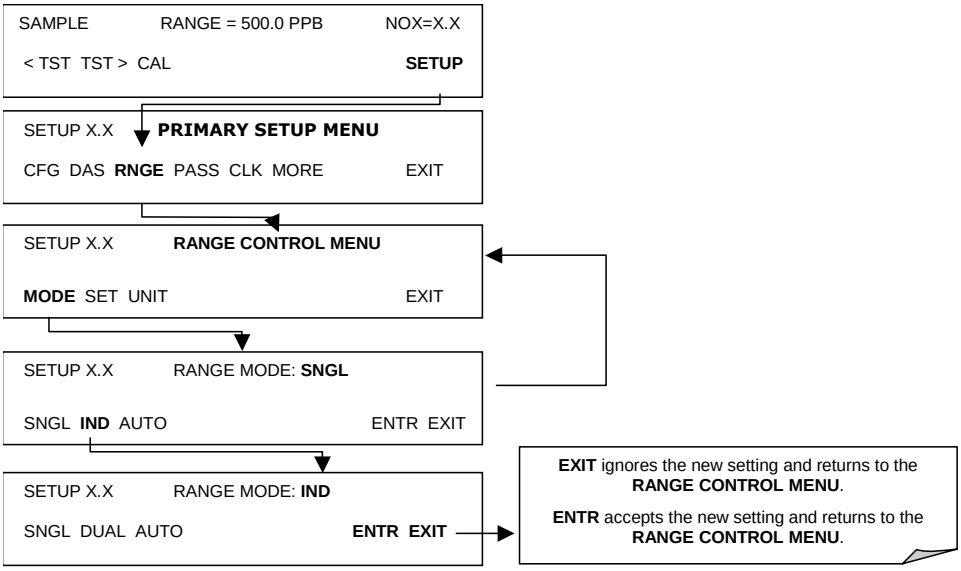


6.5.4. Independent Range Mode (IND)

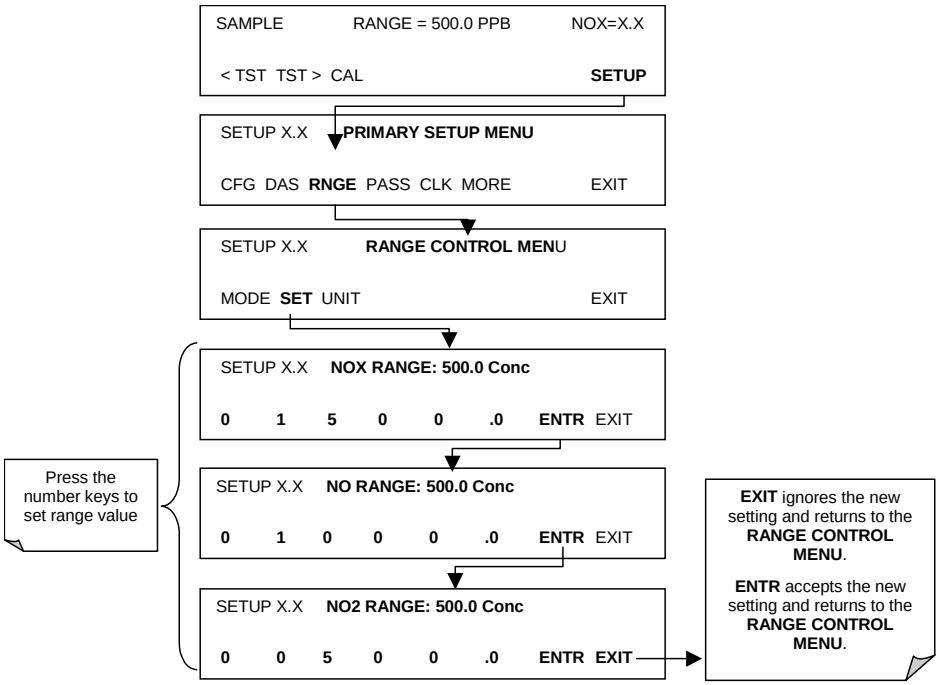
The independent range mode allows the concentration outputs **A1, A2** and **A3** to be configured with a different range value. In **IND** range mode the **RANGE** test function displayed on the front panel will then be replaced by three separate functions:

- **RANGE1**: Range value for output **A1** (NO_x), e.g., 0-10 V for 0-1500 ppm NO_X.
- **RANGE2**: Range value for output **A2** (NO), e.g., 0-10 V for 0-1000 ppm NO.
- **RANGE3**: Range value for output **A3** (NO_2), e.g., 0-10 V for 0-500 ppm NO_2.

Setting analog range limits to different values does not affect the instrument's calibration. To select the **IND** range mode, press the following keys:



To set the range value for each independent range, press:



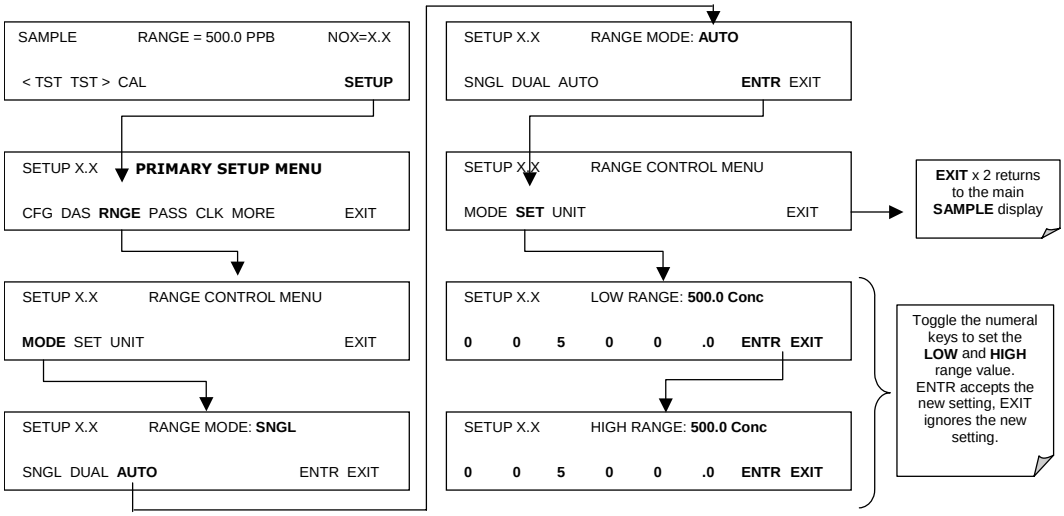
6.5.5. Auto Range Mode (AUTO)

In AUTO range mode, the analyzer automatically switches the reporting range between two user-defined ranges (low and high). The same low and high span settings are applied equally to NO, NO_2 and NO_X readings. The unit will switch from low range to high range when either the NO, or NO_X concentration exceeds 98% of the low range span. The unit will return from high range back to low range once both the NO and NO_X concentrations fall below 75% of the low range span.

In **AUTO** range mode the **RANGE** test function displayed on the front panel will be replaced by two separate functions:

- **RANGE1**: The **LOW** range setting for all analog outputs.
- **RANGE2**: The **HIGH** range setting for all analog outputs.

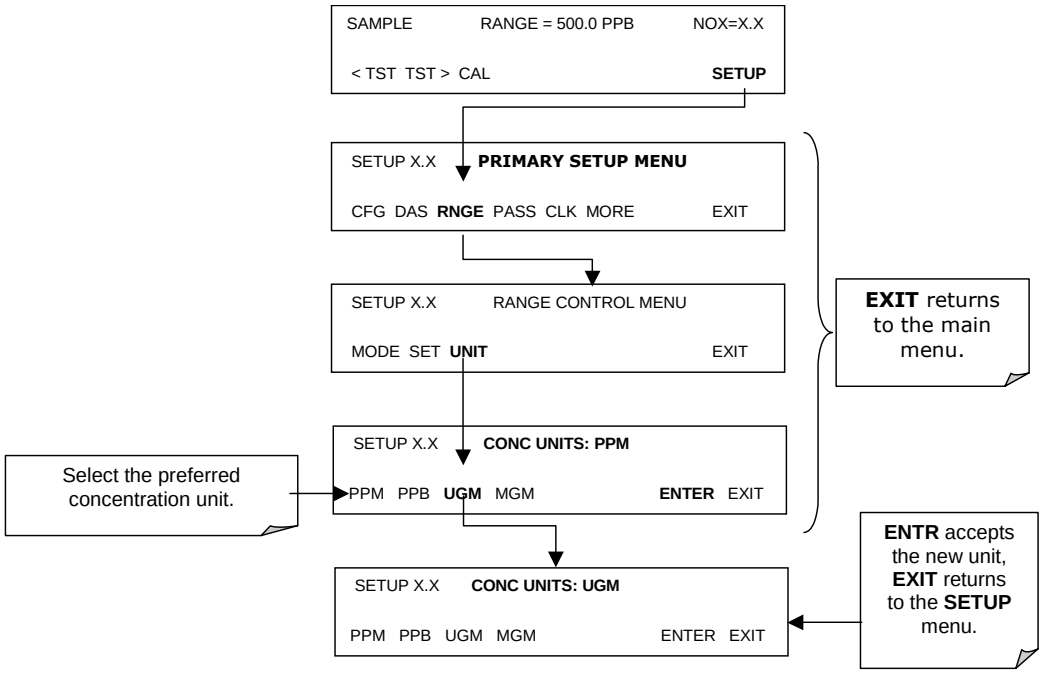
The high/low range status is also reported through the external, digital status bits (Section 6.9.1). To set individual ranges press the following keystroke sequence.



NOTE
Low and high ranges have separate slopes and offsets for computing the NO and NOx concentrations. Hence, the two ranges must be calibrated independently.

6.5.6. Range Units

The M9110E can display concentrations in parts per billion (10^9 mols per mol, PPB), parts per million (10^6 mols per mol, PPM), micrograms per cubic meter ($\mu g/m^3$, UG) or milligrams per cubic meter (mg/m^3, MG). Changing units affects all of the display, COM port and iDAS values for all reporting ranges regardless of the analyzer's range mode. To change the concentration units:



Conversion factors from volumetric to mass units used in the M9110E:

NO: ppb x 1.34 = µg/m^3; ppm x 1.34 = mg/m^3

NO_2: ppb x 2.05 = µg/m^3; ppm x 2.05 = mg/m^3

Concentrations displayed in mg/m^3 and µg/m^3 use 0° C and 760 Torr as standard temperature and pressure (STP). Consult your local regulations for the STP used by your agency. EPA protocol applications, for example, use 25° C as the reference temperature. Changing the units may cause a bias in the measurements if standard temperature and pressure other than 0°C and 760 Torr are used. This problem can be avoided by recalibrating the analyzer after any change from a volumetric to a mass unit or vice versa.

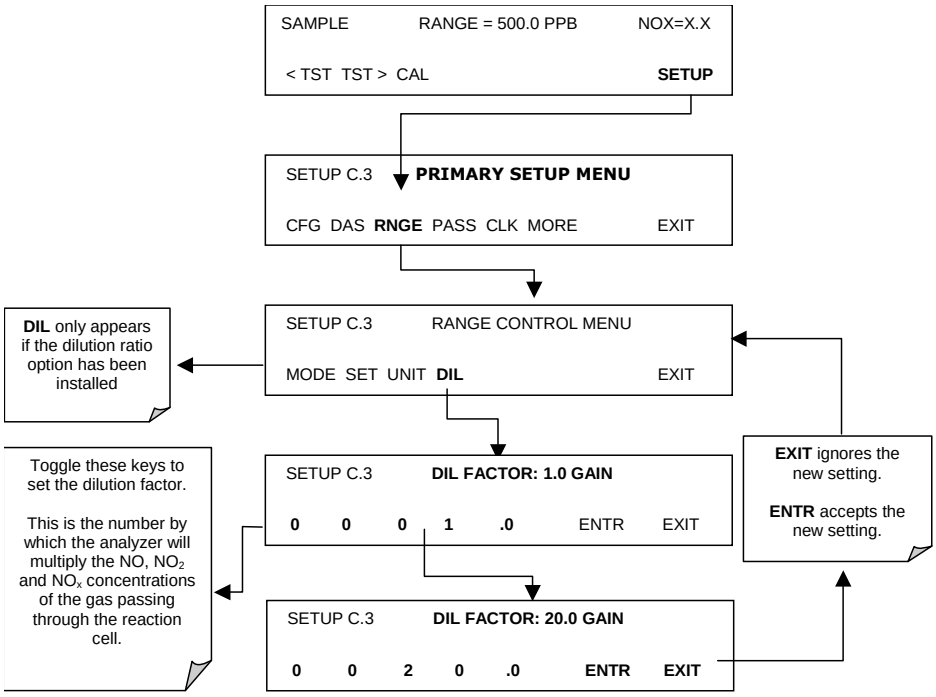
CAUTION
In order to avoid a reference temperature bias, the analyzer must be recalibrated after every change in reporting units.

6.5.7. Dilution Ratio

The dilution ratio is a software option that allows the user to compensate for any dilution of the sample gas before it enters the sample inlet. Using the dilution ratio option is a 4-step process:

- Select concentration units: Follow the procedure in Section 6.5.6.

- Select the range: Use the procedures in Section 6.6. Make sure that the **SPAN** value entered is the maximum expected concentration of the undiluted calibration gas and that the span gas is either supplied through the same dilution inlet system as the sample gas or has an appropriately lower actual concentration. For example, with a dilution set to 100, a 1 ppm gas can be used to calibrate a 100 ppm sample gas if the span gas is not routed through the dilution system. On the other hand, if a 100 ppm span gas is used, it needs to pass through the same dilution steps as the sample gas.
- Set the dilution factor as a gain (e.g., a value of 20 means 20 parts diluent and 1 part of sample gas):



The analyzer multiplies the measured gas concentrations with this dilution factor and displays the result.

Calibrate the analyzer. Once the above settings have been entered, the instrument needs to be recalibrated using one of the methods discussed in Chapter 7.

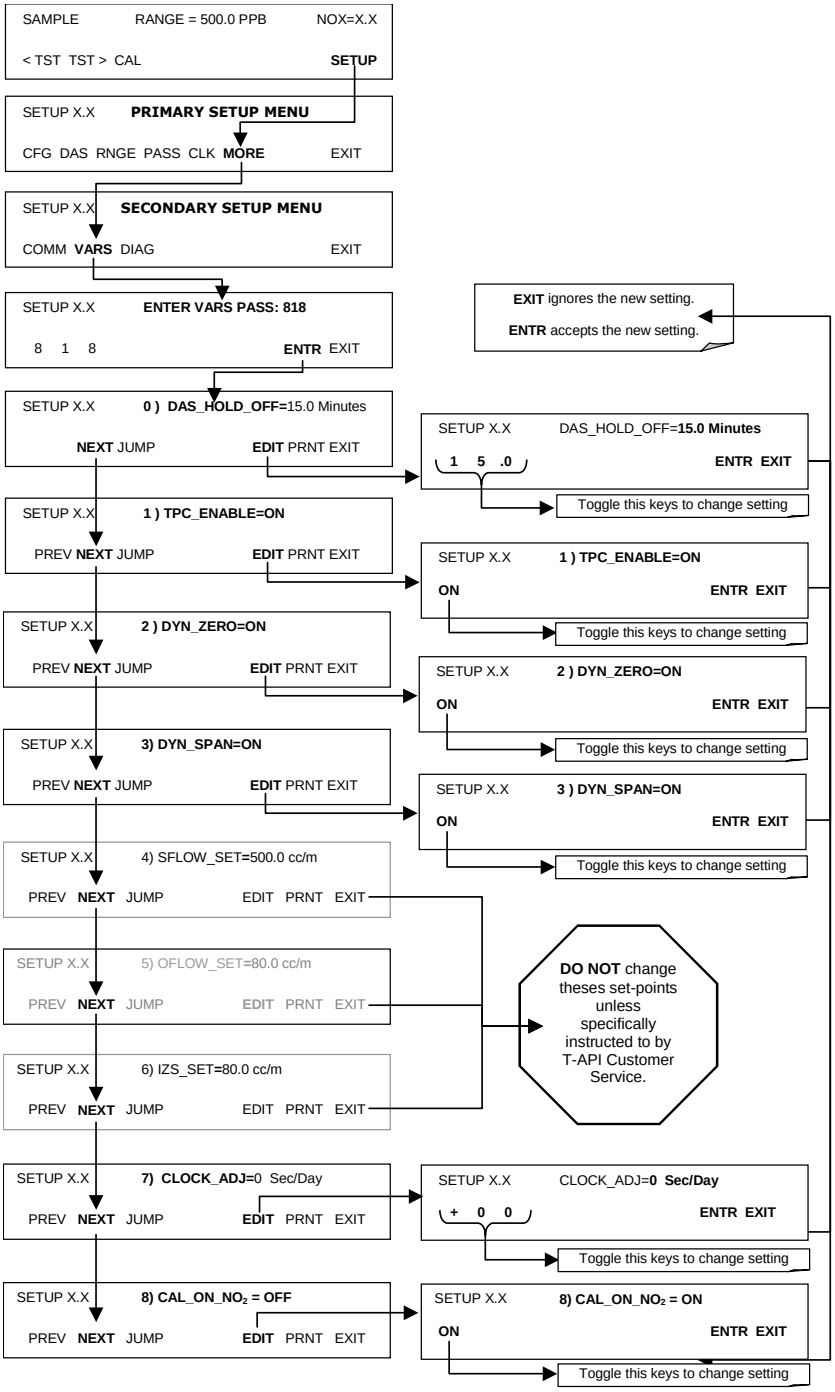
6.6. Setup - Internal Variables (VARS)

The M9110E has several-user adjustable software variables, which define certain operational parameters. Usually, these variables are automatically set by the instrument's firmware, but can be manually re-defined using the VARS menu. Table 0-5 lists all variables that are available within the 818 password protected level. See Appendix A2 for a detailed listing of all of the M9110E variables that are accessible through the remote interface.

Table 0-5: Variable Names (VARS) Revision C.4

Variable	Description	Allowed Values
DAS_HOLD_OFF	Duration of no data storage in the iDAS. This is the time when the analyzer returns from one of its calibration modes to the SAMPLE mode. The DAS_HOLD_OFF can be disabled in each iDAS channel.	Can be between 0.5 and 20 minutes Default=15 min.
TPC_ENABLE	Enables or disables the temperature and pressure compensation (TPC) feature (Section 10.4.3).	ON/OFF Default=ON
DYN_ZERO	Dynamic zero automatically adjusts offset and slope of the NO and NO_X response when performing a zero point calibration during an AutoCal (Chapter 7).	ON/OFF Default=OFF
DYN_SPAN	Dynamic span automatically adjusts the offsets and slopes of the NO and NOx response when performing a zero point calibration during an AutoCal (Chapter 7). Note that the DYN_ZERO and DYN_SPAN features are not allowed for applications requiring EPA equivalency.	ON/OFF Default=OFF
SFLOW_SET	Adjusts the displayed value of the sample flow rate to the actual flow rate, which was measured by the user. Changing this value does not alter the actual sample gas flow rate!	0-1000 cm^3/min Default= 500 cm^3/min
OFLOW_SET	Adjusts the displayed value of the ozone flow rate to its actual flow rate, which was measured by the user. Changing this value does not alter the actual ozone gas flow rate!	10-1000 cm^3/min Default= 80 cm^3/min
IZS_SET	Sets the IZS oven temperature. Increasing or decreasing this temperature will increase or decrease the NO_2 permeation rate of the IZS source (Section 5.6.3).	30°C - 70°C Default= 50°C
CONC_PRECISION	Allows to set the number of decimal points of the concentration and stability parameters displayed on the front panel.	AUTO, 1, 2, 3, 4 Default=AUTO
CLOCK_ADJ	Adjusts the speed of the analyzer's clock. Choose the + sign if the clock is too slow, choose the - sign if the clock is too fast.	-60 to +60 s/day Default=0
CAL_ON_NO_2	Allows to turn ON and OFF the ability to span the analyzer with NO_2, in which case the instrument acts as if NO and NO_X are spanned, even though it is supplied with NO_2. The NO_2 concentration is then zero by default. This feature is not permitted for EPA protocol applications.	ON or OFF Default=OFF

To access and navigate the VARS menu, use the following key sequence:



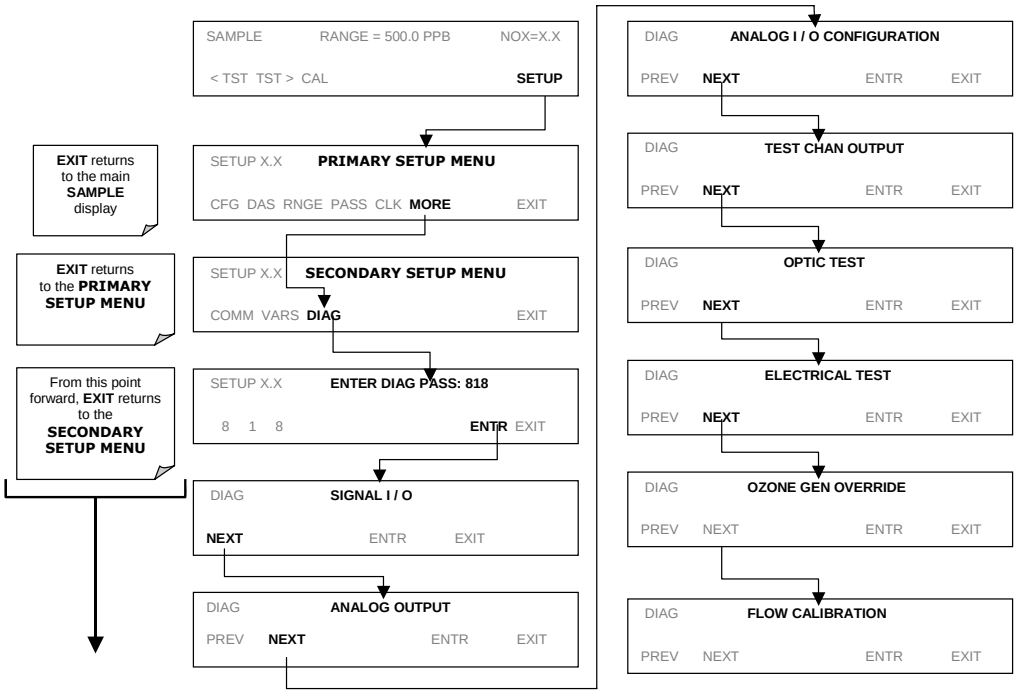
6.7. Setup - Diagnostics (DIAG)

A series of diagnostic tools is grouped together under the **SETUP-MORE-DIAG** menu. As these parameters are dependent on firmware revision, the menu trees are listed in detail in Appendix A. The individual parameters, however, are explained in more detail in the following section, indicated in Table 0-6. These tools can be used in a variety of trouble-shooting and diagnostic procedures and are referred to in many places of the maintenance and trouble-shooting sections.

Table 0-6: M9110E Diagnostic (DIAG) Functions

Diagnostic Function and Meaning	Front Panel Mode Indicator	Section
SIGNAL I/O: Allows observation of all digital and analog signals in the instrument. Allows certain digital signals such as valves and heaters to be toggled ON and OFF.	DIAG I/O	6.7.1
ANALOG I/O: When entered, the analyzer performs an analog output step test. This can be used to calibrate a chart recorder or to test the analog output accuracy.	DIAG AOUT	6.7.2
ANALOG I/O CONFIGURATION: Analog input/output parameters are available for viewing and configuration.	DIAG AIO	6.7.3
TEST CHAN OUTPUT: Configures the **A4** analog output channel.	DIAG TCHN	6.7.2
OPTIC TEST: When activated, the analyzer performs an optic test, which turns on an LED located inside the sensor module near the PMT (Fig. 10-15). This diagnostic tests the response of the PMT without having to supply span gas.	DIAG OPTIC	6.7.5
ELECTRICAL TEST: When activated, the analyzer performs an electric test, which generates a current intended to simulate the PMT output to verify the signal handling and conditioning of the PMT preamp board.	DIAG ELEC	6.7.6
OZONE GEN OVERRIDE: Allows the user to manually turn the O_3 generator on or off. This setting is retained when exiting **DIAG**.	DIAG OZONE	6.7.7
FLOW CALIBRATION: This function is used to calibrate the gas flow output signals of sample gas and ozone supply. These settings are retained when exiting **DIAG**.	DIAG FCAL	6.7.8

To access the DIAG functions press the following keys:

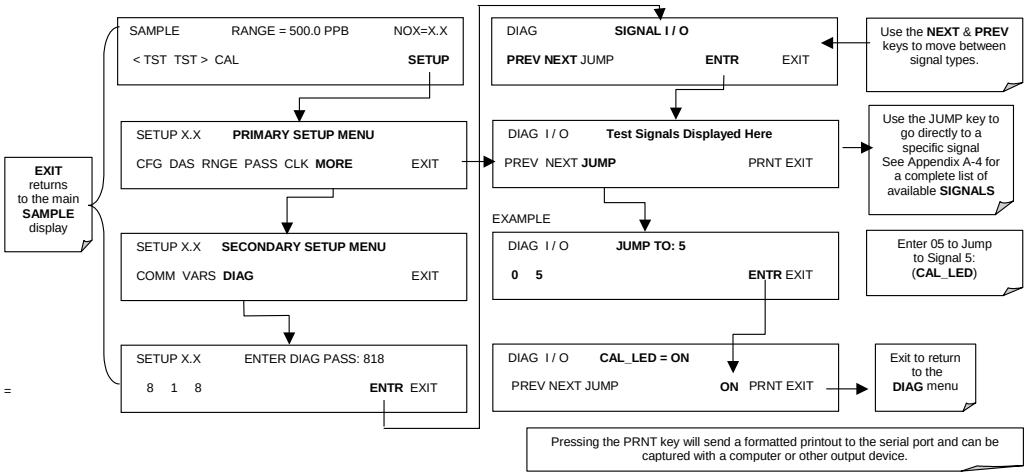


6.7.1. Signal I/O

The signal I/O diagnostic mode allows to review and change the digital and analog input/output functions of the analyzer. See Appendix A-4 for a complete list of the parameters available for review under this menu.

NOTE
Any changes of signal I/O settings will remain in effect only until the signal I/O menu is exited. Exceptions are the ozone generator override and the flow sensor calibration, which remain as entered when exiting.

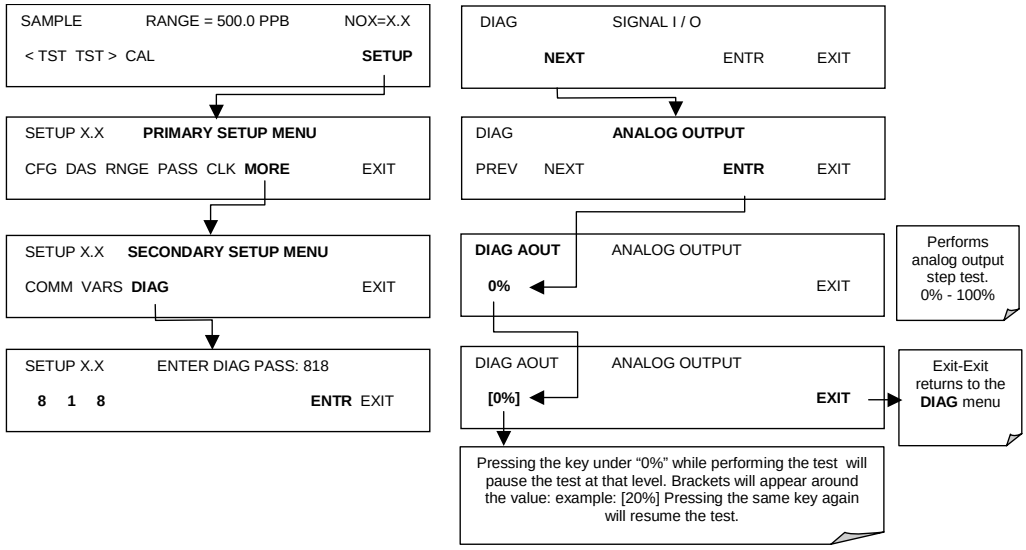
To enter the signal I/O test mode, press:



6.7.2. Analog Output Step Test

This test can be used to check the accuracy and proper operation of the analog outputs. The test forces all four analog output channels to produce signals ranging from 0% to 100% of the full scale range in 20% increments. This test is useful to verify the operation of the data logging/recording devices attached to the analyzer.

To begin the Analog Output Step Test press:



6.7.3. Analog I/O Configuration

Table 0-7 lists the analog I/O functions that are available in the M9110E.

Table 0-7: DIAG - Analog I/O Functions

Sub Menu	Function
AOUTS CALIBRATED:	Shows the status of the analog output calibration (YES/NO) and initiates a calibration of all analog output channels.
CONC_OUT_1	Sets the output voltage of the A1 analog output (NO_X) . **Range**: Selects the signal type (voltage or current loop) and full scale value of the output. **REC_OFS**: Sets a voltage offset (not available when **RANGE** is set to **CURR**ent loop. **Auto_CAL**: Performs the same calibration as AOUT CALIBRATED, but on this one channel only. NOTE: Changes to **RANGE** or **REC_OFS** require recalibration of this output.
CONC_OUT_2	Same as for CONC_OUT_1 but for analog channel 2 (NO)
CONC_OUT_3	Same as for CONC_OUT_1 but for analog channel 3 (NO_2)
TEST OUTPUT	Same as for CONC_OUT_1 but for analog channel 4 (TEST)
AIN CALIBRATED	Shows the calibration status (YES/NO) and initiates a calibration of the analog to digital converter circuit on the motherboard.

To configure the analyzer's four analog outputs, set the electronic signal type of each channel and calibrate the outputs. This consists of:

Selecting an output type (voltage or current, if an optional current output driver has been installed) and the signal level that matches the input requirements of the recording device attached to the channel.

Calibrating the output channel. This can be done automatically or manually for each channel, see Sections 6.7.4 through 6.7.8.

Adding a bipolar recorder offset to the signal, if required (Section 6.7.5).

In its standard configuration, the analyzer's outputs can be set for the following DC voltages. Each range is usable from -5% to + 5% of the nominal range.

Table 0-8: Analog Output Voltage Ranges

Range	Minimum Output	Maximum Output
0-0.1 V	-5 mV	+105 mV
0-1 V	-0.05 V	+1.05 V
0-5 V	-0.25 V	+5.25 V
0-10 V	-0.5 V	+10.5 V
The default offset for all ranges is 0 VDC.		

The following DC current output limits apply to the current loop modules:

Table 0-9: Analog Output Current Loop Range

Range	Minimum Output	Maximum Output
0-20 mA	0 mA	20 mA
These are the physical limits of the current loop modules, typical applications use 2-20 or 4-20 mA for the lower and upper limits. Please specify desired range when ordering this option. The default offset for all ranges is 0 mA.		

Pin assignments for the ANALOG output connector at the rear panel of the instrument:

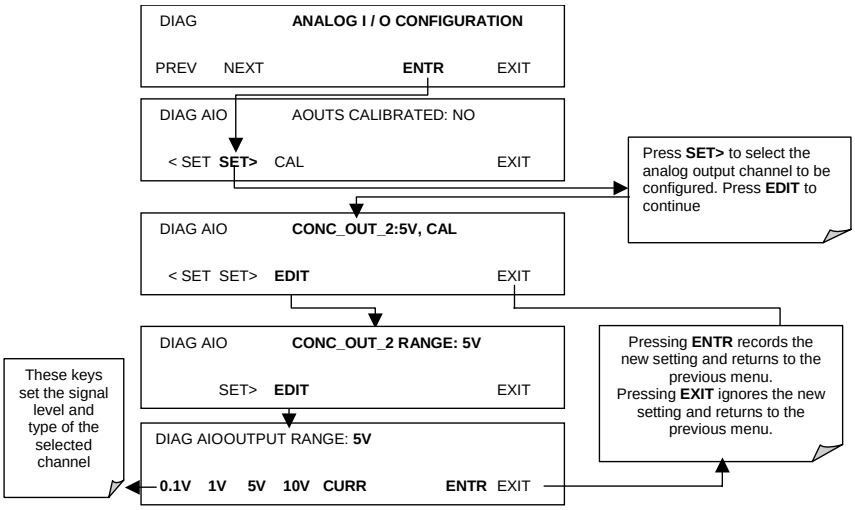
Table 0-10: Analog Output Pin Assignments

Pin	Analog output	VOLTAGE Signal	CURRENT Signal
1	A1	V Out	I Out +
2		Ground	I Out -
3	A2	V Out	I Out +
4		Ground	I Out -
5	A3	V Out	I Out +
6		Ground	I Out -
7	A4	V Out	not available
8		Ground	not available

See Figure 0-1 for a visual representation and location of the analog output connector.

6.7.3.1. Analog Output Signal Type and Range Selection

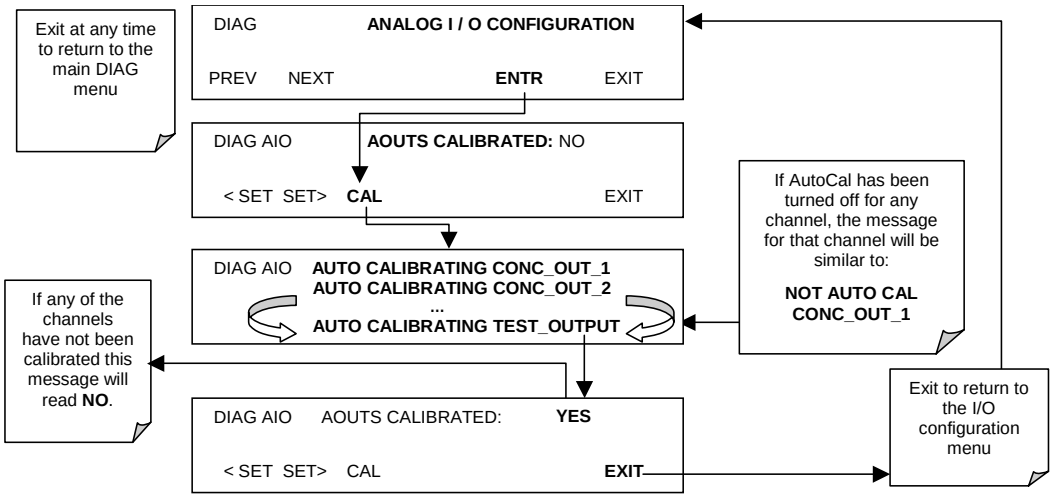
To select an output signal type (DC Voltage or current) and level for one output channel press **SETUP - MORE - DIAG - ENTR - NEXT - NEXT** and then:



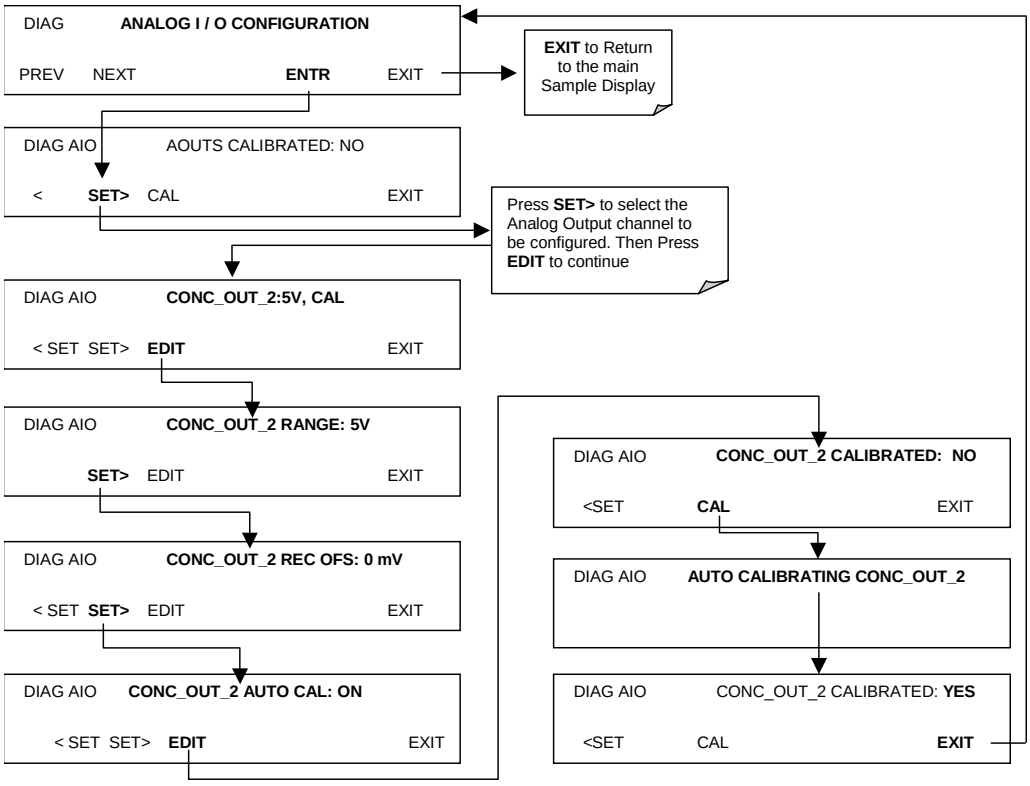
6.7.3.2. Analog Output Calibration Mode

The analog outputs can be calibrated automatically or manually. In its default mode, the instrument is configured for automatic calibration of all channels. Manual calibration should be used for the 0.1V range or in cases where the outputs must be closely matched to the characteristics of the recording device. Outputs configured for automatic calibration can be calibrated as a group or individually. Analog calibration needs to be carried out on first startup of the analyzer (performed in the factory as part of the configuration process) or whenever re-calibration is required.

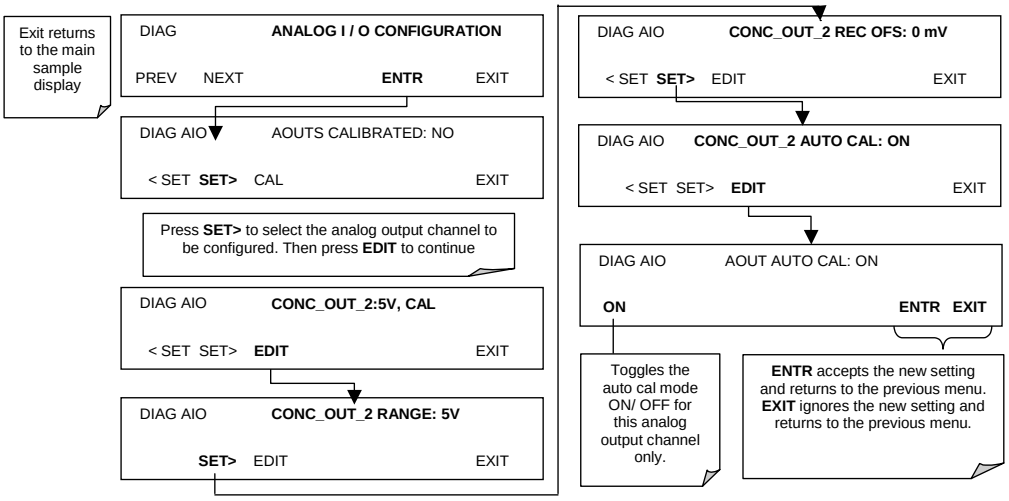
To calibrate the outputs as a group press **SETUP-MORE-DIAG-ENTR-NEXT-NEXT** and then the following keys:



To automatically calibrate an analog channel, press SETUP-MORE-DIAG-ENTR-NEXT-NEXT and then the following keys:



To select manual output calibration for a particular channel press **SETUP-MORE-DIAG-ENTR-NEXT-NEXT** and then the following keys:



Now the analog output channels should either be automatically calibrated or they should be set to manual calibration, which is described next.

6.7.3.3. Manual Analog Output Calibration

For highest accuracy, the voltages of the analog outputs can be manually calibrated. Note that outputs configured for 0.1V full scale should always be calibrated manually. Calibration is done through the instrument software with a voltmeter connected across the output terminals (Figure 0-3). Adjustments are made using the front panel keys by setting the zero-point first and then the span-point (Table 0-11). The software allows this adjustment to be made in 100, 10 or 1 count increments.

Table 0-11: Voltage Tolerances for Analog Output Calibration

Full Scale	Zero Tolerance	Span Voltage	Span Tolerance
0.1 VDC	±0.0005V	90 mV	±0.001V
1 VDC	±0.001V	900 mV	±0.001V
5 VDC	±0.002V	4500 mV	±0.003V
10 VDC	±0.004V	4500 mV	±0.006V

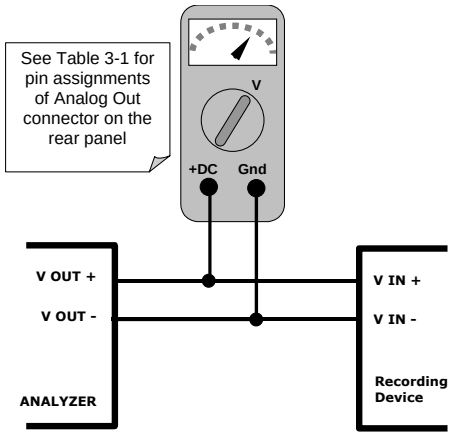
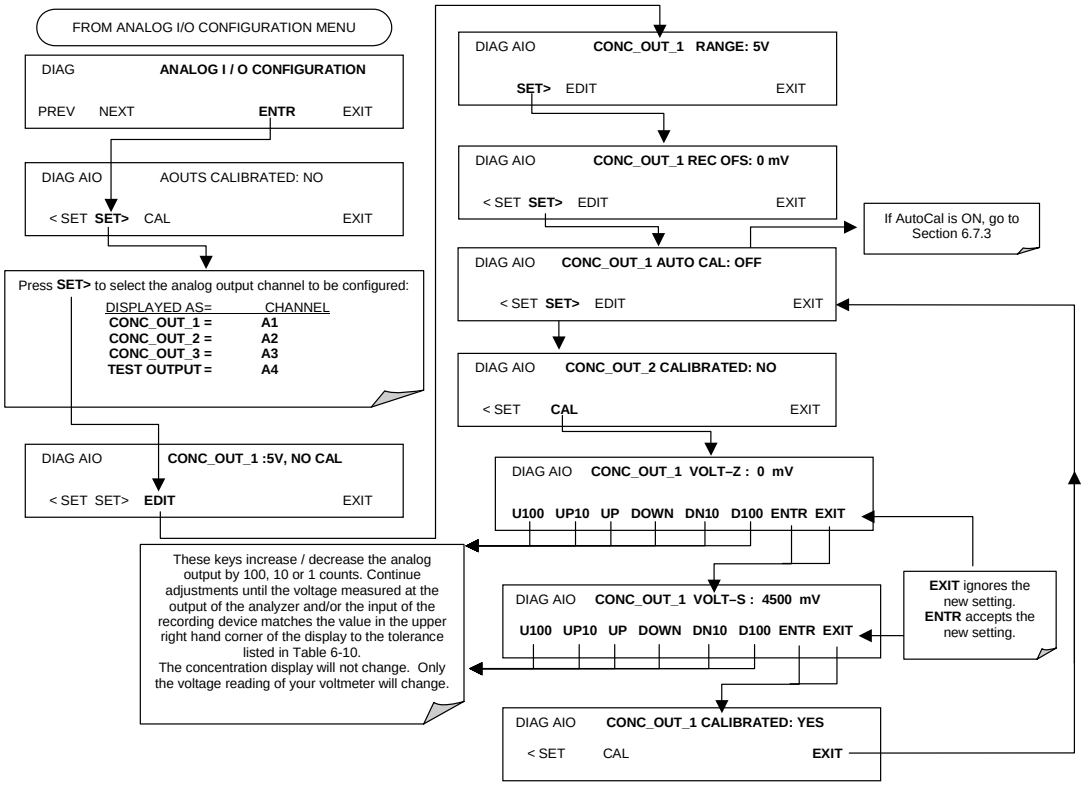


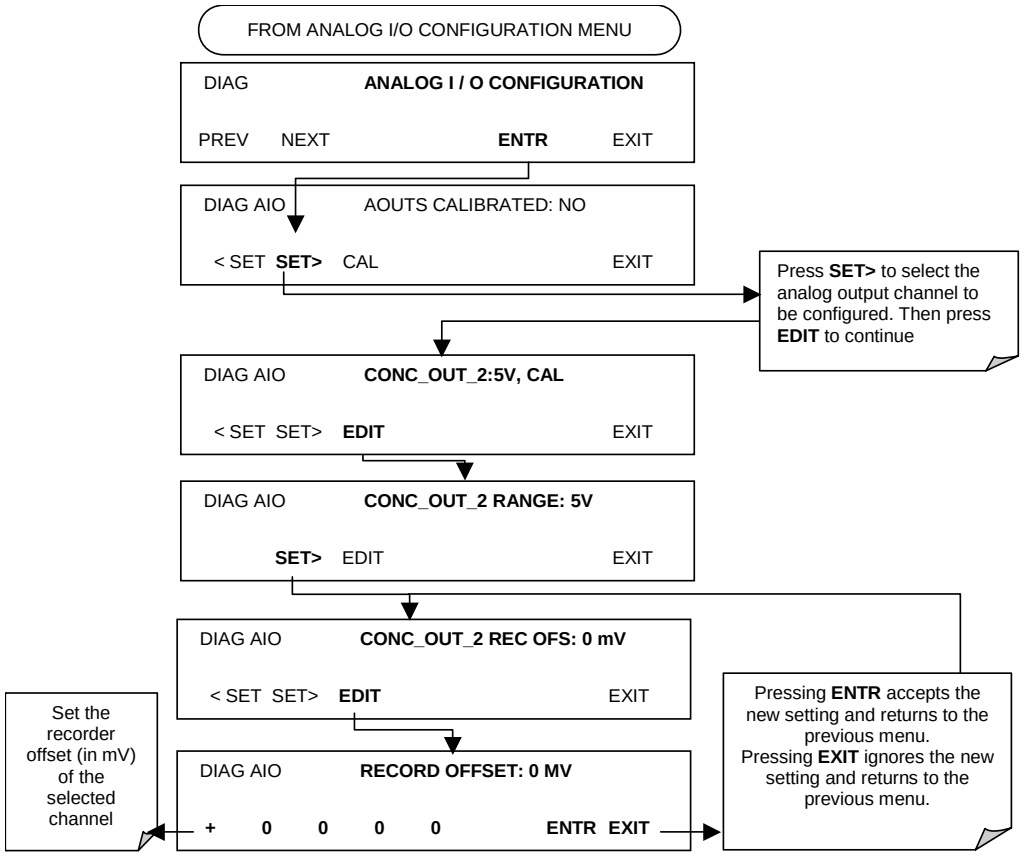
Figure 0-2: Setup for Calibrating Analog Outputs

To make these adjustments, the **AOUT** auto-calibration feature must be turned off (Section 6.7.3). Then press SETUP-MORE-DIAG-ENTR-NEXT-NEXT and the following keys:



6.7.3.4. Analog Output Offset Adjustment

Some analog signal recorders require that the zero signal is significantly different from the baseline of the recorder in order to record slightly negative readings from noise around the zero point. This can be achieved in the M9110E by defining a zero offset, a small voltage (e.g., 10% of span), which can be added to the signal of individual output channels just like a strip chart recorder can be set to have a 10% offset by moving the pens. Set the offset by pressing SETUP-MORE-DIAG-ENTR-NEXT-NEXT and the following keys:



6.7.3.5. Current Loop Output Adjustment

A current loop option is available and can be installed as a retrofit for each of the analog outputs of the analyzer (Section 5.3). This option converts the DC voltage analog output to a current signal with 0-20 mA output current. The outputs can be scaled to any set of limits within that 0-20 mA range. However, most current loop applications call for either 2-20 mA or 4-20 mA range. All current loop outputs have a +5% over-range. Ranges with the lower limit set to more than 1 mA (e.g., 2-20 or 4-20 mA) also have a -5% under-range.

To switch an analog output from voltage to current loop, follow the instructions in Section 6.7.1 and select **CURR** from the list of options on the "Output Range" menu.

Adjusting the signal zero and span values of the current loop output is done by raising or lowering the voltage of the respective analog output. This proportionally raises or lowers the current produced by the current loop option.

Similar to the voltage calibration, the software allows this current adjustment to be made in 100, 10 or 1 count increments. Since the exact current increment per voltage count varies from output to output and from instrument to instrument, you will need to measure the change in the current with a current meter placed in series with the output circuit (Figure 0-4).

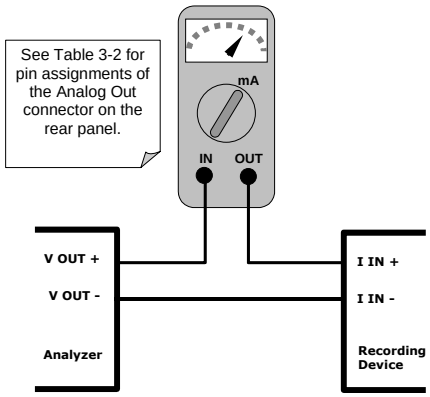
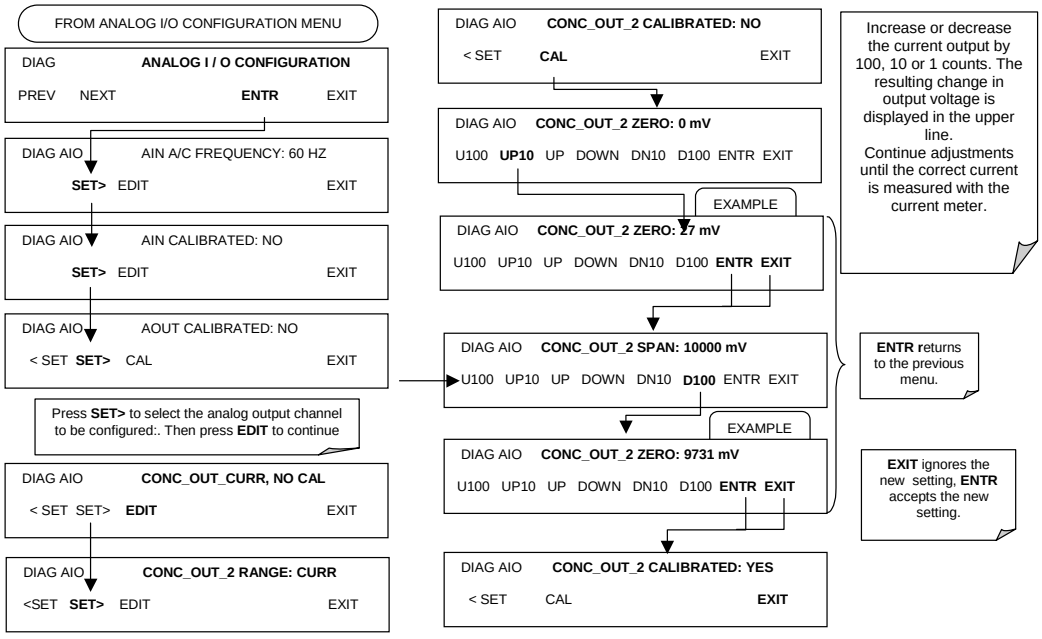


Figure 0-3: Setup for Calibrating Current Outputs

CAUTION
Do not exceed 60 V between current loop outputs and instrument ground.

To adjust the zero and span values of the current outputs, press SETUP-MORE-DIAG-ENTR-NEXT-NEXT and then:



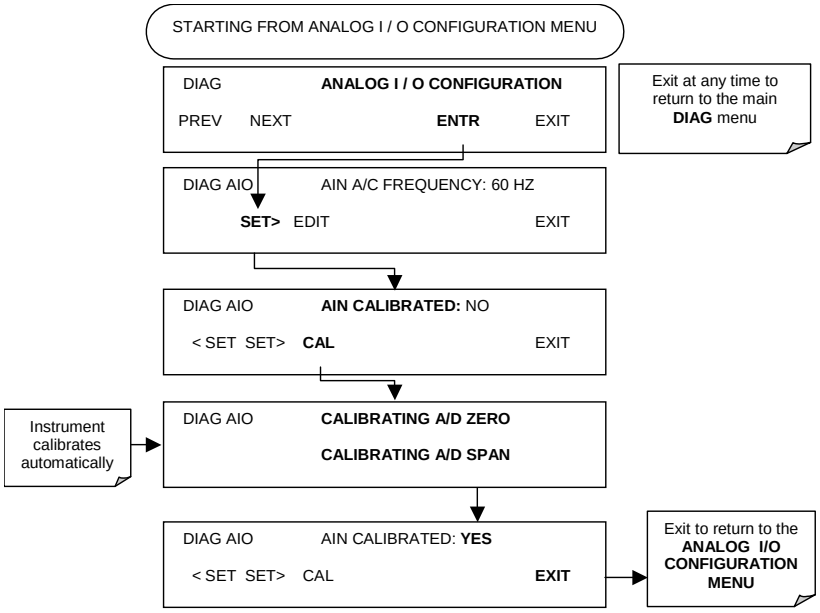
If a current meter is not available, an alternative method for calibrating the current loop outputs is to connect a 250 Ω ±1% resistor across the current loop output. Using a voltmeter, connected across the resistor, follow the procedure above but adjust the output to the following values:

Table 0-12: Current Loop Output Calibration with Resistor

Full scale	Voltage for 2-20 mA (measured across resistor)	Voltage for 4-20 mA (measured across resistor)
0%	0.5 V	1.0 V
100%	5.0 V	5.0 V

6.7.3.6. AIN Calibration

This is the sub-menu to conduct the analog input calibration. This calibration should only be necessary after major repair such as a replacement of CPU, motherboard or power supplies.



6.7.4. Test Channel Output

When activated, output channel **A4** can be used to report one of the test functions viewable from the SAMPLE mode display.

To activate the A4 channel and select a test function, follow this key sequence:

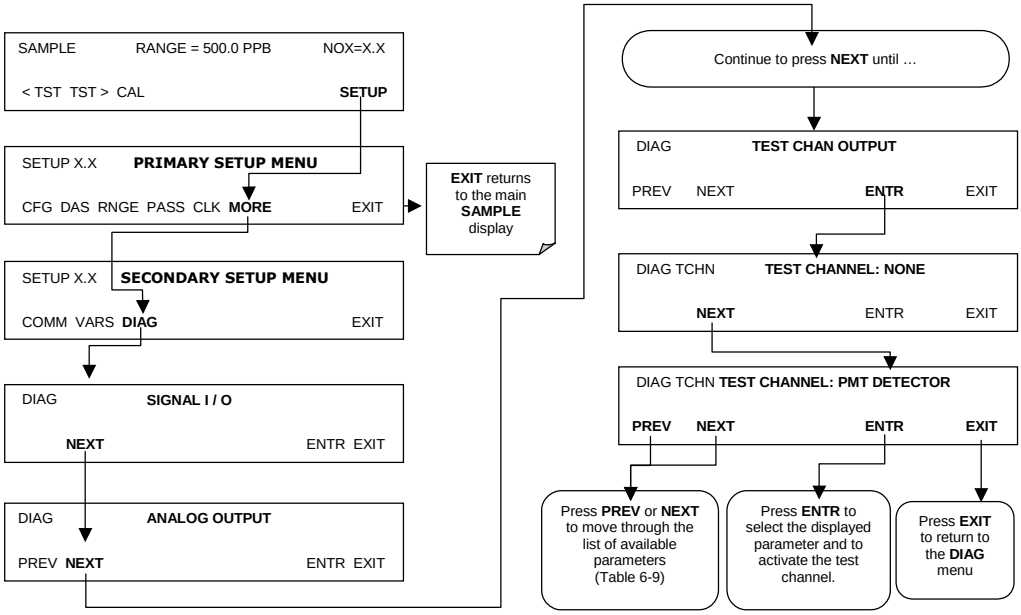


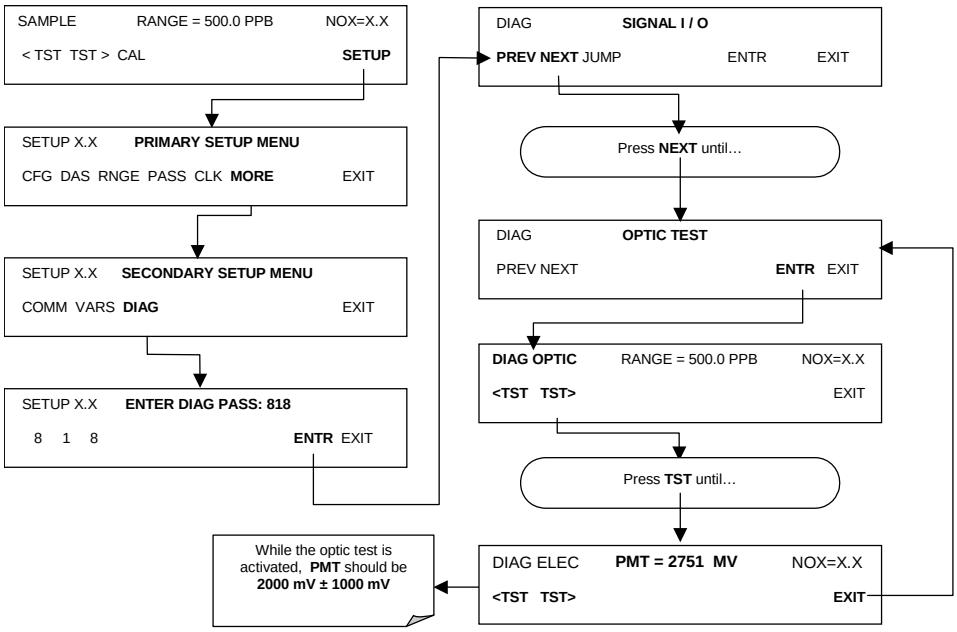
Table 0-13: Test Parameters Available for Analog Output A4

Test Channel	Test parameter range [1]
NONE	Test channel is turned off
PMT DETECTOR	0-5000 mV
Ozone flow	0-1000 cm³/min
sample flow	0-1000 cm³/min
SAMPLE PRESSure	0-40 in-Hg-A
rcell pressure	0-40 in-Hg-A
rcell temp	0-70° C
manifold temp	0-70° C
izs temp	0-70° C
conv temp	0-500° C
pmt temp	0-50° C
CHASSIS TEMP	0-70° C
HVPS VOLTAGE	0-5000 V
[1] This refers to the voltage range of the parameter and not the output signal of the test channel.	

Once a TEST function is selected, the instrument begins to report a signal on the **A4** output and adds **TEST=** to the list of test functions viewable on the display (just before the TIME display).

6.7.5. Optic Test

The optic test function tests the response of the PMT sensor by turning on an LED located in the cooling block of the PMT (Fig. 10-15). The analyzer uses the light emitted from the LED to test its photo-electronic subsystem, including the PMT and the current to voltage converter on the pre-amplifier board. To make sure that the analyzer measures only the light coming from the LED, the analyzer should be supplied with zero air. The optic test should produce a PMT signal of about 2000±1000 mV. To activate the electrical test press the following key sequence.

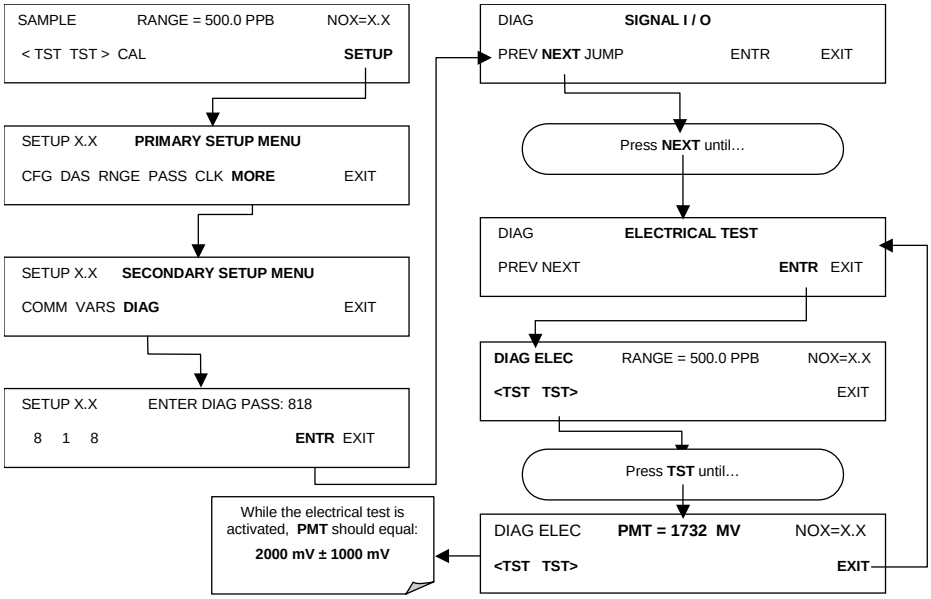


NOTE
This is a coarse test for functionality and not an accurate calibration tool. The resulting PMT signal can vary significantly over time and also changes with low-level calibration.

6.7.6. Electrical Test

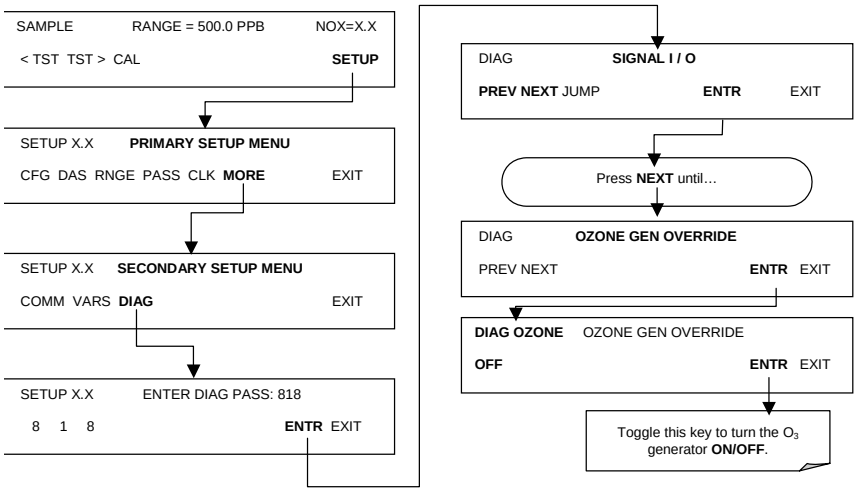
The electrical test function creates a current, which substitutes the PMT signal, and feeds it into the preamplifier board. This signal is generated by circuitry on the pre-amplifier board itself and tests the filtering and amplification functions of that assembly along with the A/D converter on the motherboard. It does not test the PMT itself. The electrical test should produce a PMT signal of about 2000 ±1000 mV.

To activate the electrical test press the following keys.



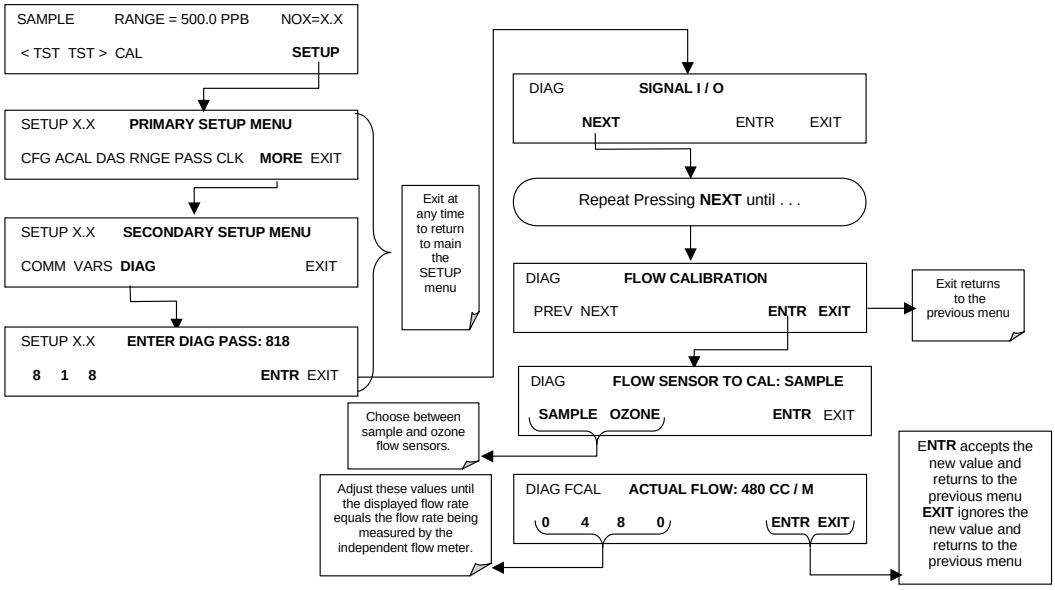
6.7.7. Ozone Generator Override

This feature allows the user to manually turn the ozone generator off and on. This can be done before disconnecting the generator, to prevent ozone from leaking out, or after a system restart if the user does not want to wait for 30 minutes during warm-up time. Note that this is one of the two settings in the **DIAG** menu that is retained after you exit the menu. To access this feature press the following keys. Also note that the ozone generator does not turn on if the ozone flow conditions are out of specification (e.g., if there is no flow through the system or the pump is broken).



6.7.8. Flow Calibration

The flow calibration allows the user to adjust the values of the sample and ozone flow rates as they are displayed on the front panel and reported through COM ports to match the actual flow rate measured at the respective pneumatic ports. This does not change the hardware measurement of the flow sensors, only the software calculated values. This is one of the two parameters in the **DIAG** menu that is retained after you exit the menu. To carry out this adjustment, connect an external, sufficiently accurate flow meter to the respective test port (Chapter 11 contains more details on this setup). Once the flow meter is attached and measures the actual flow, follow this key sequence:



6.8. Digital Inputs and Outputs

6.8.1. Status Outputs

The status output signals report analyzer conditions through optically isolated transistors which can sink up to 50 mA of DC current to ground. These outputs can be used with interface devices that accept logic-level digital inputs, such as programmable logic controllers (PLC).

NOTE
Most PLC devices have internal provisions for limiting the current that the output can draw from an external device. When connecting the M9110E status outputs to a unit that does not have this feature, a 120 Ω external pull-up resistors must be used to limit the current through the transistor output to 50 mA or less. Refer to the motherboard schematic 04069 in Appendix D.

The status outputs are accessed through a 12 pin connector on the analyzer's rear panel labeled STATUS. The function of each pin is defined in Table 0-14.

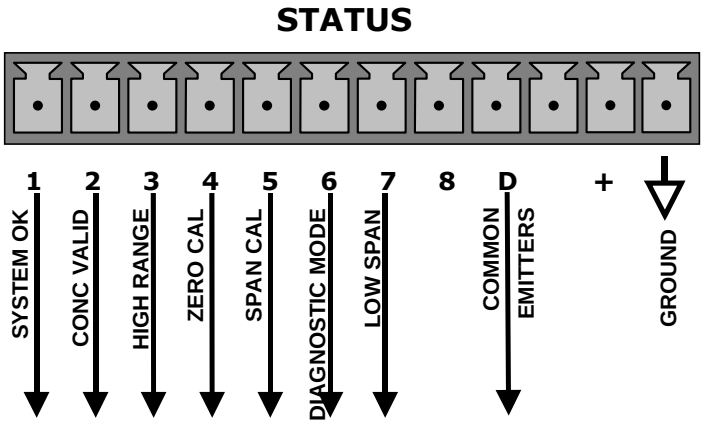


Figure 0-4: Status Output Connector

Table 0-14: Status Output Pin Assignments

Connector Pin	Status	Condition (ON=conducting)
1	SYSTEM OK	ON if no faults are present.
2	CONC VALID	ON if concentration measurement is valid, OFF when invalid.
3	HIGH RANGE	ON if unit is in high range of any AUTO range mode.
4	ZERO CAL	ON whenever the instrument is in ZERO calibration mode.
5	SPAN CAL	ON whenever the instrument is in SPAN calibration mode.
6	DIAG MODE	ON whenever the instrument is in DIAGNOSTIC mode.
7	LOW RANGE	ON if unit is in low range of any AUTO range mode.
8		Unused.
D	EMITTER BUS	The emitters of the transistors on pins 1-8 are bussed together. For most applications, this pin should be connected to the circuit ground of the receiving device.
+	DC POWER	+ 5 VDC, 30 mA maximum (combined rating with Control Inputs).
⏚	DIGITAL GROUND	The ground from the analyzer's internal, 5/±15 VDC power supply.

6.8.2. Control Inputs

Control inputs allow the user to remotely initiate ZERO and SPAN calibration modes are provided through a 10-pin connector labeled CONTROL IN on the analyzer's rear panel. These are opto-isolated, digital inputs that are activated when a 5 VDC signal from the "U" pin is connected to the respective input pin.

Table 0-15: Control Input Pin Assignments

Input	Status	Condition when enabled
A	EXTERNAL ZERO CAL	Zero calibration mode is activated. The mode field of the display will read **ZERO CAL R**.
B	EXTERNAL SPAN CAL	Span calibration mode is activated. The mode field of the display will read **SPAN CAL R**.
C	EXTERNAL LOW SPAN CAL	Low span (mid-point) calibration mode is activated. The mode field of the display will read **LO CAL R**.
D		Unused
E		Unused
F		Unused
⏚	DIGITAL GROUND	Provided to ground an external device (e.g., recorder).
U	DC power for Input pull ups	Input for +5 VDC required to activate inputs A - F. This voltage can be taken from an external source or from the "+" pin.
+	Internal +5V Supply	Internal source of +5V which can be used to activate inputs when connected to pin U.

There are two methods to activate control inputs. The internal +5V available from the "+" pin is the most convenient method (see figure). However, to ensure that these inputs are truly isolated, a separate, external 5 VDC power supply should be used.

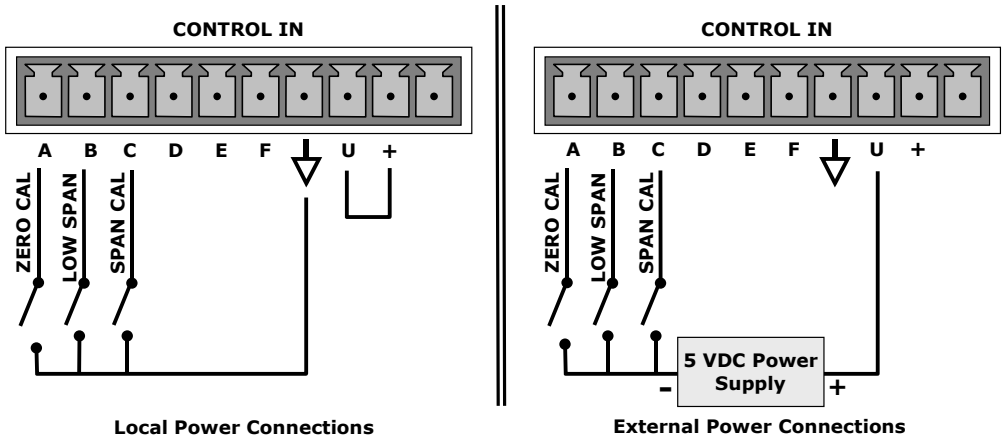


Figure 0-5: Control Inputs with Local and External 5 V Power Supply

6.9. Setup - Communication Ports (COMM)

The M9110E is equipped with two serial communication ports located on the rear panel (Figure 3-3). Both ports operate similarly and give the user the ability to communicate with, issue commands to, and receive data from the analyzer through an external computer system or terminal. By default, both ports operate on the RS-232 protocol. The COM2 port,

however, can be configured for half-duplex RS-485 communication or can be used for the TAI Ethernet interface card (optional equipment, Section 5.7.3).

There are two options to connect multiple analyzers to a single computer terminal or data logging device over a single serial communications line. Either port can be equipped with an optional RS-232 multidrop assembly (Section 5.7.2), or up to eight analyzers can be connected using COM2 configured for RS-485 operation (contact the factory for further information). A third option is to use a code-activated switch (CAS), which can connect typically between 2 and 16 analyzers to one communications hub. Contact TAI sales for more information on CAS systems.

When equipped with the optional Ethernet interface (Section 5.8.3), the analyzer can be connected to any standard 10BaseT Ethernet network via low-cost network hubs, switches or routers. The interface operates as a standard TCP/IP device on port 3000. This allows a remote computer to connect through the internet to the analyzer using APIcom, terminal emulators or other programs.

6.9.1. Analyzer ID

The first entry in the **COMM** menu is for configuration of the analyzer ID number, a numerical value of up to 4 digits. As a factory default, the M9110E is configured with ID number "200". The ID number is only important if more than one analyzer is connected to the same communications channel (e.g., a multi-drop setup), in which case each analyzer needs to be addressed with a unique ID number. Different models of TAI analyzers have different ID numbers, but if two identical models are used on one channel (for example, two M9110E instruments), the ID of one instrument needs to be changed. The ID can also be used for internal identification of same model analyzers in different locations.

For the *Hessen* protocol (a configuration option listed in Table 0-17 and briefly described in Section 6.9.10), the M9110E assigns different numbers to identify its reported gases. When this protocol is enabled, the analyzer behaves and reports as three separate instruments, one for each gas.

6.9.2. COM Port Default Settings

As received from the factory, the analyzer is set up to emulate a DCE or modem, with pin 3 of the DB-9 connector designated for receiving data and pin 2 designated for sending data.

- **COM1**: RS-232 (fixed), DB-9 male connector.
  - **Baud rate**: 19200 bits per second (baud).
  - **Data Bits**: 8 data bits with 1 stop bit, no start bit.
  - **Parity**: None.
- **COM2**: RS-232 (configurable), DB-9 female connector.
  - **Baud rate**: 115000 bits per second (baud).
  - **Data Bits**: 8 data bits with 1 stop bit, no start bit.
  - **Parity**: None.

CAUTION
Cables that appear to be compatible because of matching connectors may incorporate internal wiring that make the link inoperable. Check cables acquired from sources other than TAI for pin assignments before using.

6.9.3. COM Port Cable Connections

There are two DB-9 connectors on the M9110E rear panel. COM1 is a male connector, COM2 a female connector (Table 0-16 lists pin assignments). TAI offers two mating cables, one of which should be applicable for your use.

- Part number WR000077, a DB-9 female to DB-9 female cable, 6 feet long. Allows connection of COM1 with the serial port of most personal computers. Also available as Option 60 (Section 5.8.1).
- Part number WR0000024, a DB-9 female to DB-25 male cable. Allows connection to the most common styles of modems (e.g. Hayes-compatible) and code activated switches.

Both cables are configured with straight-through wiring and should require no additional adapters.

To assist in properly connecting the serial ports to either a computer or a modem, there are activity indicators just above each COM port. When power is applied to the analyzer, the red LED should be illuminated. If this LED is dark, it indicates a communications error between serial port and CPU.

Once a cable is connected between the analyzer and a computer or modem, both the red and green LEDs should be on. If not, COM1 can be switched between DTE and DCE modes using a small switch on the rear panel to exchange the receive and transmit lines (emulating a cross-over or null-modem cable). If both LEDs are still not illuminated, check the cable for proper wiring. For COM2 it may be necessary to install a null-modem cable (contact customer service for information).

6.9.4. COM2 Configuration

As delivered from the factory, COM2 is configured for RS-232 communications. This port can be re-configured for operation as a non-isolated, half-duplex RS-485 port with a 150 Ω termination resistor (Table 0-18 shows the pin assignments of the DB-9 connector).

For RS-485 operation, jumper JP3 on the CPU board should be installed and switch 6 of SW1 should be set to the ON position. For RS-232, remove the jumper and set the switch to OFF (default). JP3 is just to the right of the third connector from the left on the top of the CPU board (as seen from the inside of the analyzer). SW1 is in the middle of the CPU board between disk-on-chip and BIOS. For non-terminated RS-485 operation, remove the jumper on JP3 but leave switch 6 in the ON position. Refer to Figure 3-7 to locate the CPU board.

Table 0-16: COM1 and COM2 DB-9 Pin Assignments

Pin #	COM1 (RS-232)	COM2 (RS-232)	COM2 (RS-485)
1	Not used	Not used	Not used
2	TRANSMIT DATA*	RECEIVE DATA	DATA -
3	RECEIVE DATA*	TRANSMIT DATA	DATA +
4	Not used	Not used	Not used
5	Signal Ground	Signal Ground	Signal Ground
6	Not used	Not used	Not used
7	DATA SET READY*	DATA SET READY	Not used
8	REQUEST TO SEND* (=DTE Ready)	REQUEST TO SEND	Not used
9	Not used	Not used	Not used
* Configurable for COM1 at rear panel using the DTE-DCE switch			

6.9.5. DTE and DCE Communication

RS-232 was developed for allowing communications between data terminal equipment (DTE) and data communication equipment (DCE). Basic terminals always fall into the DTE category whereas modems are always considered DCE devices. The difference between the two is the pin assignment of the Data Receive and Data Transmit functions. DTE devices receive data on pin 2 and transmit data on pin 3, DCE devices receive data on pin 3 and transmit data on pin 2.

To allow the analyzer to be used with terminals (DTE), modems (DCE) and computers (which can be either), a switch mounted below the serial ports on the rear panel allows the user to switch between the two functions (for COM1 only).

6.9.6. COM Port Communication Modes

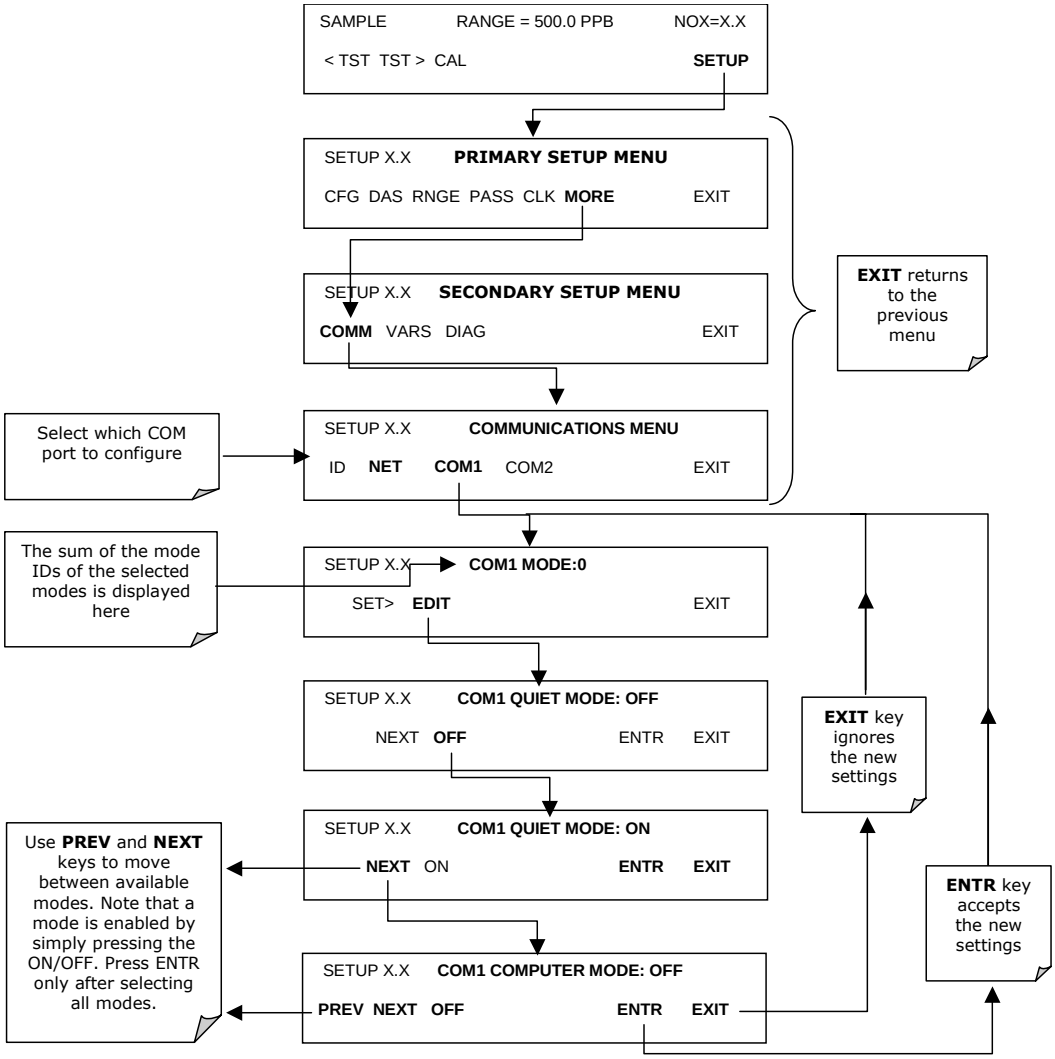
Each of the analyzer's serial ports can be configured to operate in a number of different modes, which are listed in Table 0-17 and which can be combined by adding the Mode ID numbers. For example, quiet mode, computer mode and internet-enabled mode would carry a combined mode ID of 11, the standard configuration for Ethernet functionality on the M9110E COM2 port. Note that each COM port needs to be configured independently.

Table 0-17: COM Port Communication Modes

Mode	ID	Description
Quiet mode	1	Quiet mode suppresses any feedback from the analyzer (iDAS reports, and warning messages) to the remote device and is typically used when the port is communicating with a computer program such as APICOM. Such feedback is still available but a command must be issued to receive them.
Computer mode	2	Computer mode inhibits echoing of typed characters and is used when the port is communicating with a computer program, such as APICOM.
Security mode	4	When enabled, the serial port requires a password before it will respond. The only command that is active is the help screen (? CR). Section 6.4.1 describes the password functionality.
Enable Internet	8	Enables the use and configuration of the Ethernet interface. When enabled, a new menu item INET will appear in the respective COM port menu.
Hessen protocol	16	The Hessen communications protocol is used in some European countries. TAI part number 02252 contains more information on this protocol.
Multidrop Protocol	32	Multidrop protocol allows a multi-instrument configuration on a single communications channel. Multidrop requires the use of instrument IDs.
Enable modem	64	Enables to send a modem initialization string at power-up. Asserts certain lines in the RS-232 port to enable the modem to communicate.
Ignore Errors	128	Fixes certain types of parity errors at certain Hessen protocol installations.
Disable XON/XOFF	256	Disables XON/XOFF data flow control.
	512	Unused
RS-485 mode	1024	Configures the COM2 Port for RS-485 communication. RS-485 mode has precedence over multidrop mode if both are enabled.
E, 7, 1	2048	This setting selects even parity, 7 data bits, and 1 stop bit for this com port; the default setting is always no parity, 8 data bits, and 1 stop bit. Used in conjunction with the Hessen protocol, hence, it is listed after ID 16
Command Prompt	4096	Enables a command prompt when in terminal mode.

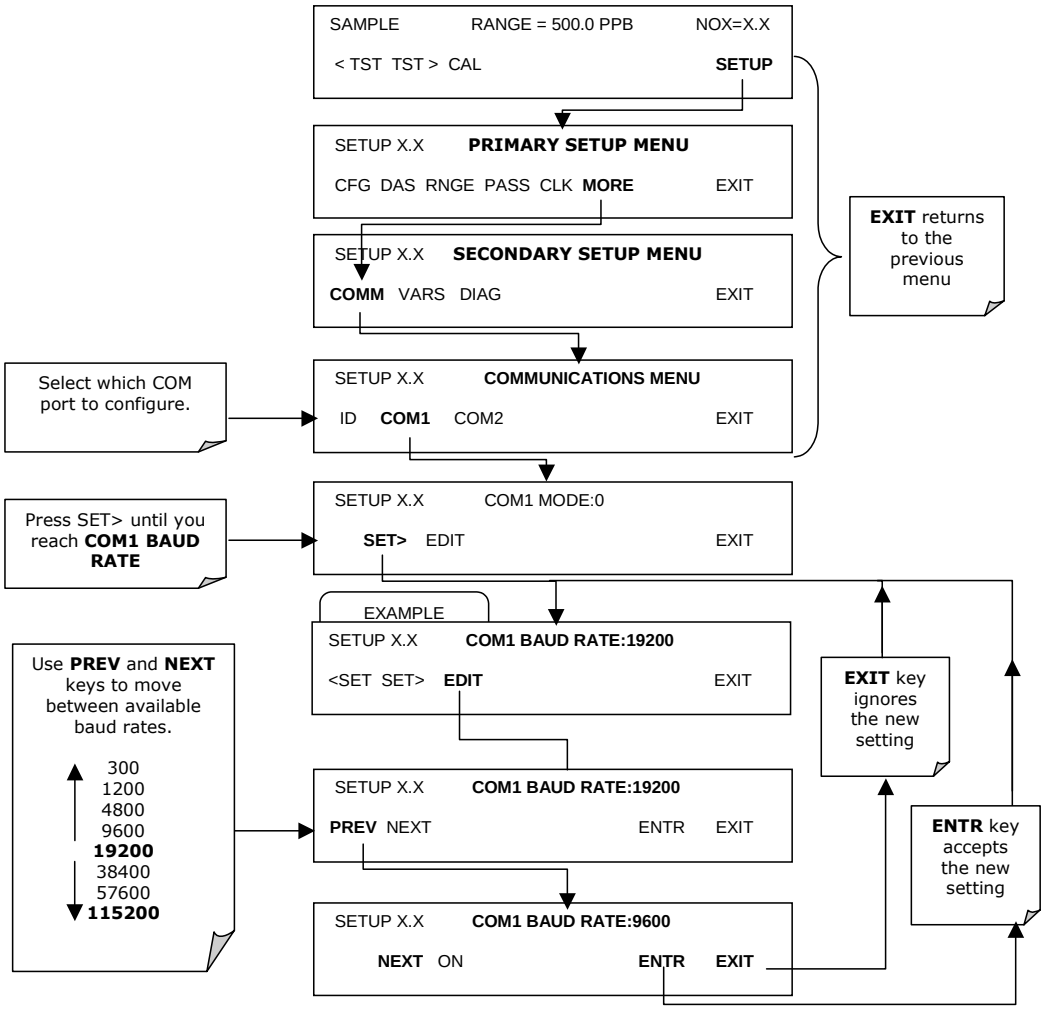
Each Parameter is preceded by a string of either **COM1** or **COM2** depending on the chosen COM port.

To select a set of communication modes for a one of the COMM Ports, press:



6.9.7. COM Port Baud Rate

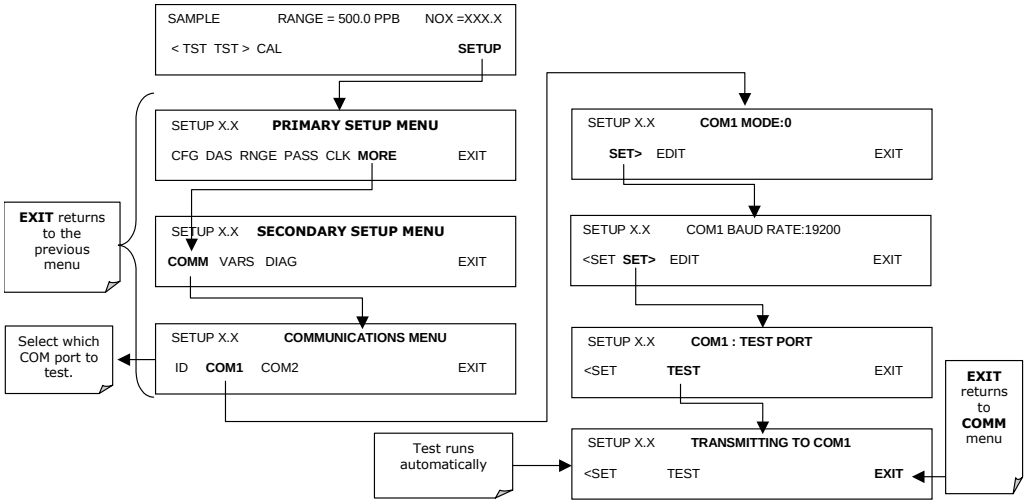
To select the baud rate of one of the COM Ports, press:



6.9.8. COM Port Testing

The serial ports can be tested for correct connection and output in the **COMM** menu. This test sends a string of 256 'w' characters to the selected COM port. While the test is running, the red LED on the rear panel of the analyzer should flicker.

To initiate the test press the following key sequence.



6.9.9. Ethernet Port Configuration

The optional Ethernet port (Section 5.8.3) communicates with the analyzer through the COM2 serial port. Refer to Figure 3-2 and Figure 5-3 for location of this option. The Ethernet board has two operational modes:

- Pass-through mode: This is the normal operation mode in which the board actively passes data between the RS-232 port and the RJ-45 connector on the analyzer's rear panel. This enables all remote commands to be passed to the analyzer.
- Configuration mode: The board stops passing data and is ready to accept and store configuration parameters and firmware upgrades. The use of a terminal window or separate configuration program is needed for these low-level configuration changes. The iChip configuration utility is available at http://www.teledyne-api.com/software/ and provides a convenient, graphical user interface, which runs only on Microsoft Windows™ operating systems. All commands can also be issued via Terminal window using the AT+i protocol. Instructions for AT+i commands are also available at the website along with other pertinent information.

The Ethernet board has four LEDs that are visible on the rear panel of the analyzer, indicating its current operating status (Table 0-18).

Table 0-18: Ethernet Status Indicators

LED	Function
LNK (green)	ON when connection to the LAN is valid.
ACT (yellow)	Flickers on any activity on the LAN.
TA (green)	Flickers when the RS-232 port is transmitting data.
RA (yellow)	Flickers when the RS-232 port is receiving data.

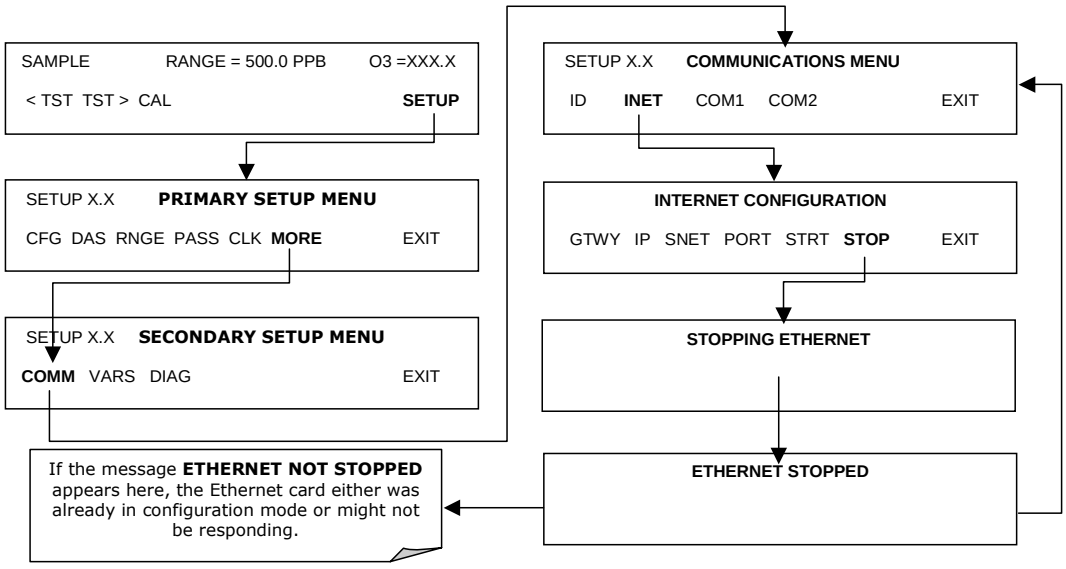
As soon as the Ethernet option is enabled in the COMM menu, a new sub-menu **INET** will appear. This sub-menu is enabled by default when the analyzer was ordered with built-in

Ethernet and is used to set configuration parameters that enable the Ethernet card to communicate with your local area network. To perform this configuration, you will need to get the following information from your network administrator:

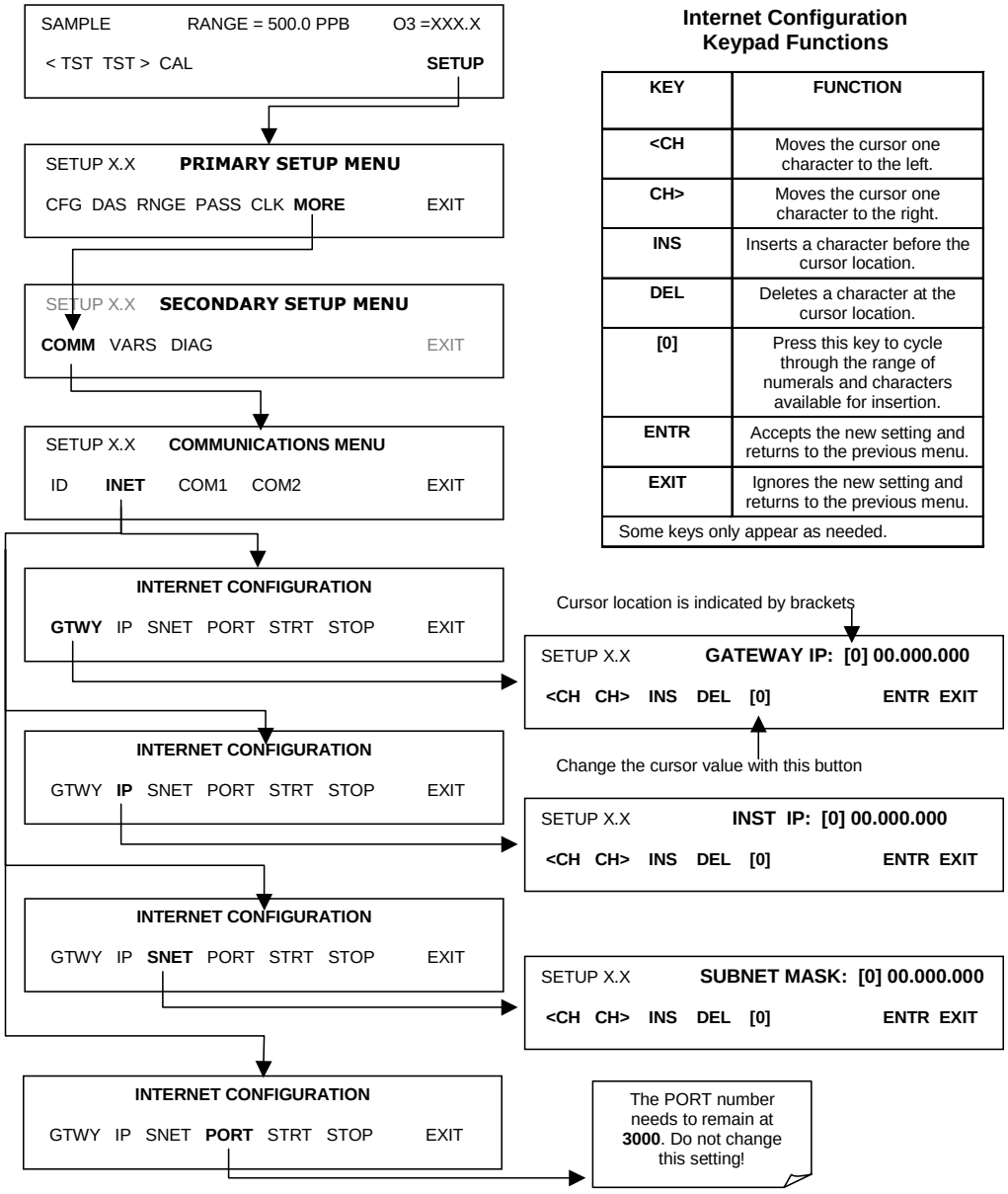
- Gateway IP address, typically a string of numbers with four packets of 1 to 3 numbers each: nnn.nnn.nnn.nnn, for example: 192.168.76.1.
- Instrument IP address, typically a string of numbers very similar to the Gateway IP address, for example: 192.168.76.55. Note that this instrument IP address must be a static address and cannot be a dynamic IP address. DHCP and analyzer host names are not supported at this time.
- Subnet Mask, typically a string of numbers such as 255.255.252.0.
- The communications port number is set to 3000 by default and should not be changed.

The following procedures assume that the Ethernet card is already installed in your analyzer. If you are retro-fitting the analyzer with an Ethernet Option 63, please make sure to enable the internet option as described in Section 6.9.6 and set the baud rate to 115000 as described in Section 6.9.7. Refer to the installation instructions of that option for more information.

Once Ethernet is enabled for the COM2 port, the first step in configuring the Ethernet option is to set the card from pass-through mode to configuration mode, so that TCP/IP parameters can be edited.



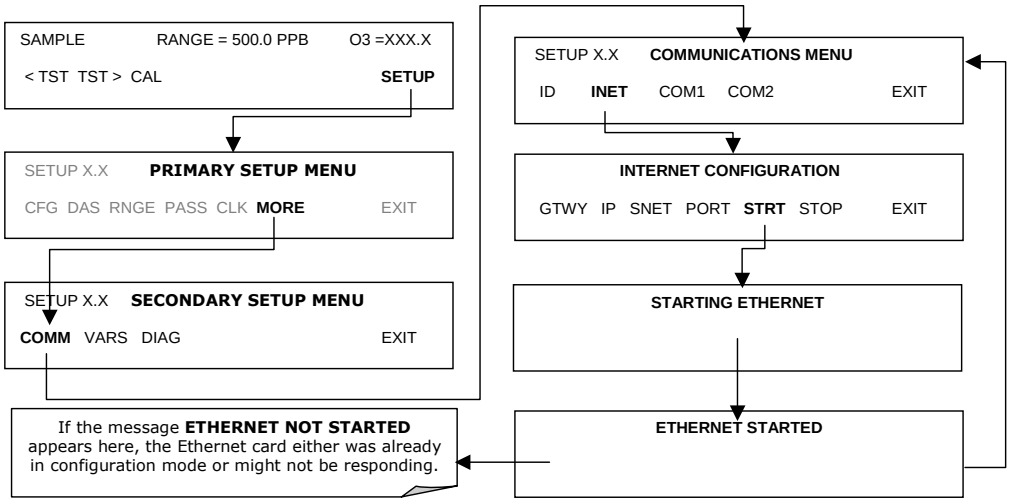
Step two in the configuration process is to edit the TCP/IP parameters.



Internet Configuration Keypad Functions

KEY	FUNCTION
<CH	Moves the cursor one character to the left.
CH>	Moves the cursor one character to the right.
INS	Inserts a character before the cursor location.
DEL	Deletes a character at the cursor location.
[0]	Press this key to cycle through the range of numerals and characters available for insertion.
ENTR	Accepts the new setting and returns to the previous menu.
EXIT	Ignores the new setting and returns to the previous menu.
Some keys only appear as needed.	

Step three in the configuration process is to restart the pass-through mode for normal operation.



6.9.10. Hessen Mode Configuration

The Hessen protocol is used in applications, which adhere to operation protocols originally defined by the German state of Hessen and also applies to the Bavarian protocol.

A Hessen protocol network typically consists of a host computer that monitors the status and controls one or more remote instruments. The remote instruments are regarded as slaves of the host computer, and only respond to commands from the host computer; remote instruments never initiate Hessen protocol messages.

The Hessen protocol is a multidrop application, in which several instruments are connected to a common communications channel (e.g., using hardware Option 62). However, the implementation details of this multidrop bus are handled outside of the instrument. The instruments are unaware that they are connected to a multidrop bus and respond only to commands containing their own unique ID number.

The Hessen protocol is designed to accomplish two things:

- to obtain the status of remote instruments, including the concentrations of all the gases measured and
- to place remote instruments into zero or span calibration or measure mode.

The TAI implementation supports both of these principal features.

From the user's point of view, the RS-232 hardware on TAI instruments supporting the Hessen protocol is not different from that of standard instruments. The RS-232 communication parameters, however, are different from standard configurations. For more information on configuring the Hessen protocol, please download the manual addendum at http://www.teledyne-api.com/manuals/.

6.10. Setup - Data Acquisition System (DAS)

The M9110E analyzer contains a flexible and powerful, internal data acquisition system (iDAS) that enables the analyzer to store concentration and calibration data as well as a host of diagnostic parameters. The iDAS of the M9110E can store up to about one million data points, which can, depending on individual configurations, cover days, weeks or months of valuable measurements. The data are stored in non-volatile memory and are retained even when the instrument is powered off. Data are stored in plain text format for easy retrieval and use in common data analysis programs (such as spreadsheet-type programs).

The iDAS is designed to be flexible, users have full control over the type, length and reporting time of the data. The iDAS permits users to access stored data through the instrument's front panel or its communication ports. Using APICOM, data can even be retrieved automatically to a remote computer for further processing.

The principal use of the iDAS is logging data for trend analysis and predictive diagnostics, which can assist in identifying possible problems before they affect the functionality of the analyzer. The secondary use is for data analysis, documentation and archival in electronic format.

To support the iDAS functionality, TAI offers APICOM, a program that provides a visual interface for remote or local setup, configuration and data retrieval of the iDAS (Section 6.11). The APICOM manual, which is included with the program, contains a more detailed description of the iDAS structure and configuration, which is briefly described in this section.

The M9110E is configured with a basic iDAS configuration, which is enabled by default. New data channels are also enabled by default but each channel may be turned off for later or occasional use. Note that iDAS operation is suspended while its configuration is edited through the front panel. To prevent such data loss, it is recommended to use the APICOM graphical user interface for iDAS changes.

The green SAMPLE LED on the instrument front panel, which indicates the analyzer status, also indicates certain aspects of the iDAS status:

Table 0-19: Front Panel LED Status Indicators for iDAS

LED State	iDAS Status
Off	System is in calibration mode. Data logging can be enabled or disabled for this mode. Calibration data are typically stored at the end of calibration periods, concentration data are typically not sampled, diagnostic data should be collected.
Blinking	Instrument is in hold-off mode, a short period after the system exits calibrations. IDAS channels can be enabled or disabled for this period. Concentration data are typically disabled whereas diagnostic should be collected.
On	Sampling normally.

The iDAS can be disabled only by disabling or deleting its individual data channels.

6.10.1. iDAS Structure

The iDAS is designed around the feature of a "record". A record is a single data point of one parameter, stored in one (or more) data channels and generated by one of several triggering event. The entire iDAS configuration is stored in a script, which can be edited from the front panel or downloaded, edited and uploaded to the instrument in form of a string of plain-text lines through the communication ports.

iDAS data are defined by the PARAMETER type and are stored through different triggering EVENTS in data CHANNELS, which relate triggering events to data parameters and define certain operational functions related to the recording and reporting of the data.

6.10.1.1. iDAS Channels

The key to the flexibility of the iDAS is its ability to store a large number of combinations of triggering events and data parameters in the form of data channels. Users may create up to 20 data channels and each channel can contain one or more parameters. For each channel one triggering event is selected and up to 50 data parameters are allowed (the M9110E has around 25), which can be the same or different between channels. Each data channel has several properties that define the structure of the channel (Table 0-20).

Table 0-20: iDAS Data Channel Properties

Property	Description	Default	Setting Range
NAME	The name of the data channel.	"NONE"	Up to 6 letters and digits are displayed on the front panel (use more with APICOM).
TRIGGERING EVENT	The event that triggers the data channel to measure and store its data parameters. See APPENDIX A-5 for a list of available triggering events.	ATIMER	Any allowed event.
NUMBER AND LIST OF PARAMETERS	A User-configurable list of data types to be recorded in any given channel. See APPENDIX A-5 for a list of available parameters.	PMTDET	Any available concentration, temperature, pneumatic or diagnostic parameter.
STARTING DATE	The starting date when a channel starts collecting fata	01-JAN-03	Any actual date in the past or future.
SAMPLE PERIOD	The amount of time between each data point that is averaged into one mean reported every REPORT PERIOD.	000:01:00	000:00:01 to 366:23:59 (Days:Hours:Minutes)
REPORT PERIOD	The amount of time between each channel data point.	000:01:00	000:00:01 to 366:23:59 (Days:Hours:Minutes)
NUMBER OF RECORDS	The number of reports that will be stored in the data file. Once the specified limit has been exceeded, the oldest data are over-written to make space for new data.	100	1 to 1 million, limited by available storage space.
RS-232 REPORT	Enables the analyzer to automatically report	OFF	OFF or ON

Property	Description	Default	Setting Range
	channel values to the RS-232 ports.		
COMPACT REPORT	Enables a compact version of the RS-232 reporting with up to five parameters sharing the same output line.	OFF	OFF or ON
CHANNEL ENABLED	Enables or disables the channel. Provides a convenient means to temporarily disable a data channel.	ON	OFF or ON
CAL HOLD OFF	Disables sampling of data parameters while instrument is in calibration mode. Note that - when enabled here - there is also a length of the DAS HOLD OFF after calibration mode, which is set in the VARS menu. (Section 6.5.)	OFF	OFF or ON

6.10.1.2. iDAS Parameters

Data parameters are types of data that may be measured and stored by the iDAS. For each TAI analyzer model, the list of available data parameters is different, fully defined and not customizable. Appendix A-5 lists firmware specific data parameters for the M9110E. The most common parameters are concentrations of measured gases (NO_X, NO and NO_2), temperatures of heated zones (NO_2 converter, reaction cell, box temperature…), pressures and flows of the pneumatic subsystem and other diagnostic measurements as well as calibration data (slope and offset) for each gas.

Most data parameters have associated measurement units, such as mV, ppb, cm^3/min, etc., although some parameters have no units. The only units that can be changed are those of the concentration readings according to the **SETUP-RANGE** settings. Note that the iDAS does not keep track of the unit of each concentration value and iDAS data files may contain concentrations in multiple units if the unit was changed during data acquisition.

Each data parameter has user-configurable functions that define how the data are recorded (Table 0-21).

Table 0-21: iDAS Data Parameter Functions

Function	Effect
PARAMETER	Instrument-specific parameter name.
SAMPLE MODE	INST: Records instantaneous reading. AVG: Records average reading during reporting interval. MIN: Records minimum (instantaneous) reading during reporting interval. MAX: Records maximum (instantaneous) reading during reporting interval.
PRECISION	Decimal precision of parameter value(0-4).
STORE NUM. SAMPLES	OFF: stores only the average (default). ON: stores the average and the number of samples in each average for a parameter. This property is only useful when the AVG sample mode is used. Note that the number of samples is the same for all parameters in one channel and needs to be specified only for one of the parameters.

Users can specify up to 50 parameters per data channel (the M9110E has about 30 parameters). The number of parameters and channels is also limited by analyzer memory.

6.10.1.3. iDAS Triggering Events

Triggering events define when and how the iDAS records a measurement of any given data channel. Triggering events are firmware-specific and are listed in Appendix A-5. The most common triggering events are:

- ATIMER: Sampling at regular intervals specified by an automatic timer. Most trending information is usually stored at such regular intervals, which can be instantaneous or averaged.
- EXITZR, EXITSP, SLPCHG (exit zero, exit span, slope change): Sampling at the end of (irregularly occurring) calibrations or when the response slope changes. These triggering events create instantaneous data points for the new slope and offset (concentration response) values at the end of a calibration. Zero and slope values can be used to monitor response drift and to document when the instrument was calibrated.
- WARNINGS: Some data may be useful when stored if one of several warning messages appears. This is helpful for trouble-shooting by monitoring when a particular warning occurred.

6.10.2. Configuring the iDAS

6.10.2.1. Default M9110E iDAS Configuration

A set of default data channels has been included in the analyzer's software for logging nitrogen oxides concentrations, calibration and predictive diagnostic data. These default channels are listed in Table 0-22 and are defined as follows:

CONC: Hourly averages of NO_X, NO and NO_2 concentrations and the NO_X stability (standard deviation). These data are recorded at one minute intervals and stored every full hour with a time and date stamp. Readings during calibration and the calibration hold off period are not included in the averages. By default, the last 800 hourly averages are stored, which covers more than one month of continuous data acquisition. This channel also logs the number of (1-minute) samples within each average for statistical evaluation of the concentration means.

CALDAT: Logs concentration, slope and offset values for NO_X and NO every time a zero or span calibration is performed (triggering event: SLPCHG). The NO_X stability (to evaluate if the calibration value was stable) as well as the converter efficiency (for trend reference) are also stored. This data channel will store data from the last 200 calibrations and can be used to document analyzer calibration and detect trends in slope and offset (instrument response). As with all data channels, a date and time stamp is recorded for every logged data point.

CALCHECK: This channel logs concentrations and the stability each time a zero or span *check* (not calibration) is finished (triggered by exiting any calibration menu). The data of this channel enable the user to track the quality of zero and span responses over time and assist in evaluating the quality of zero and span gases and the analyzer's noise specifications. The STABIL figure documents if the analyzer response was stable at the point of the calibration check reading. The last 200 data points are retained.

Table 0-22: M9110E Default iDAS Configuration, Revision C.7.

List of Channels	List of Parameters NAME – MODE/EVENT - PRECISION - NUM SAMPLES
Name: CONC Event: ATIMER Sample Period: 000:00:01 Report Period: 000:01:00 Number of Records: 800 RS-232 report: OFF Channel enabled: ON DAS HOLDOFF: ON	NOXCNC1 - AVG - 4 - ON
	NOCNC1 - AVG - 4 - OFF
	N2CNC1 - AVG - 4 - OFF
	STABIL - AVG - 4 - OM
Name: CALDAT Event: SLPCHG Number of Records: 200 RS-232 report: OFF Channel enabled: ON DAS HOLDOFF: OFF	NXZSC1 - SLPCHG - 4 - OFF
	NOXSLP1 - SLPCHG - 4 - OFF
	NOXOFFS1 - SLPCHG - 4 - OFF
	NOZSC1 - SLPCHG - 4 - OFF
	NOSLP1 - SLPCHG - 4 - OFF
	NOOFFS1 - SLPCHG - 4 - OFF
	N2ZSC1 - SLPCHG - 4 - OFF
	CNVEF1 - SLPCHG - 4 - OFF
	STABIL - SLPCHG - 4 - OFF
Name: CALCHECK Event: EXITMP Number of Records: 200 RS-232 report: OFF Channel enabled: ON DAS HOLDOFF: OFF	NXZSC1 - EXITMP - 4 - OFF
	NOZSC1 - EXITMP - 4 - OFF
	N2ZSC1 - EXITMP - 4 - OFF
	STABIL - EXITMP - 4 - OFF
Name: DIAG Event: ATIMER Sample Period: 000:00:30 Report Period: 001:00:00 Number of Records: 1100 RS-232 report: OFF Channel enabled: ON DAS HOLDOFF: OFF	SMPFLW - AVG – 2 - OFF
	O3FLOW – AVG – 2 - OFF
	RCPRESS – AVG – 2 - OFF
	SMPPRES – AVG – 2 - OFF
	RCTEMP - AVG – 2 - OFF
	PMTTMP - AVG – 2 - OFF
	CNVTMP - AVG – 2 - OFF
	BOXTMP - AVG – 2 - OFF
	HVPS - AVG – 2 - OFF
	AZERO - AVG – 2 - OFF
Name: HIRES Event: ATIMER Sample Period: 000:00:01 Report Period: 000:00:01 Number of Records: 1500 RS-232 report: OFF Channel enabled: OFF DAS HOLDOFF: OFF	NOXCNC1 - AVG - 4 - OFF
	NOCNC1 – AVG - 4 - OFF
	N2CNC1 - AVG – 4 - OFF
	STABIL - AVG – 4 - OFF
	SMPFLW - AVG – 2 - OFF
	O3FLOW - AVG – 2 - OFF
	RCPRESS - AVG – 2 - OFF
	SMPPRES - AVG – 2 - OFF
	RCTEMP - AVG – 2 - OFF
	PMTTMP - AVG – 2 - OFF
	CNVTMP - AVG – 2 - OFF
	BOXTMP - AVG – 2 - OFF
	HVPS - AVG – 1 - OFF
	AZERO - AVG – 2 - OFF
	REFGND - AVG – 1 - OFF
	REF4096 - AVG - 1 - OFF

DIAG: Daily averages of temperature zones, flow and pressure data as well as some other diagnostic parameters (HVPS, AZERO). These data are intended for predictive diagnostics and maintenance described in Chapter 9. The last 1100 daily averages are stored to cover more than four years of analyzer performance, a major portion of the analyzer's lifetime. If these parameters are required for data analysis, this channel can easily be duplicated (e.g.,

by using APICOM) to obtain hourly averages, which could be synchronized with the CONC data.

HIRES: One minute, instantaneous data of all available parameters in the M9110E that are actively used. This data channel is disabled by default but may be turned on for trouble-shooting or when the application requires a high resolution of data. Short-term trends as well as signal noise levels can be detected and documented this way. Readings during calibration and the calibration hold off period are included in the averages. By default, the last 1500 data points are stored, which covers a little more than one day of continuous data acquisition.

Please be aware that all stored data will be erased if the analyzer's disk-on-chip, CPU board or configuration is replaced/reset.

Teledyne Analytical Instruments recommends to download and store CONC, CALDAT and ENGDAT data once per month for permanent documentation and future data analysis. Data can be most conveniently downloaded, graphed and stored using the APICOM remote control program. Channel properties, triggering events and parameters for the default channels are listed in Table 0-22.

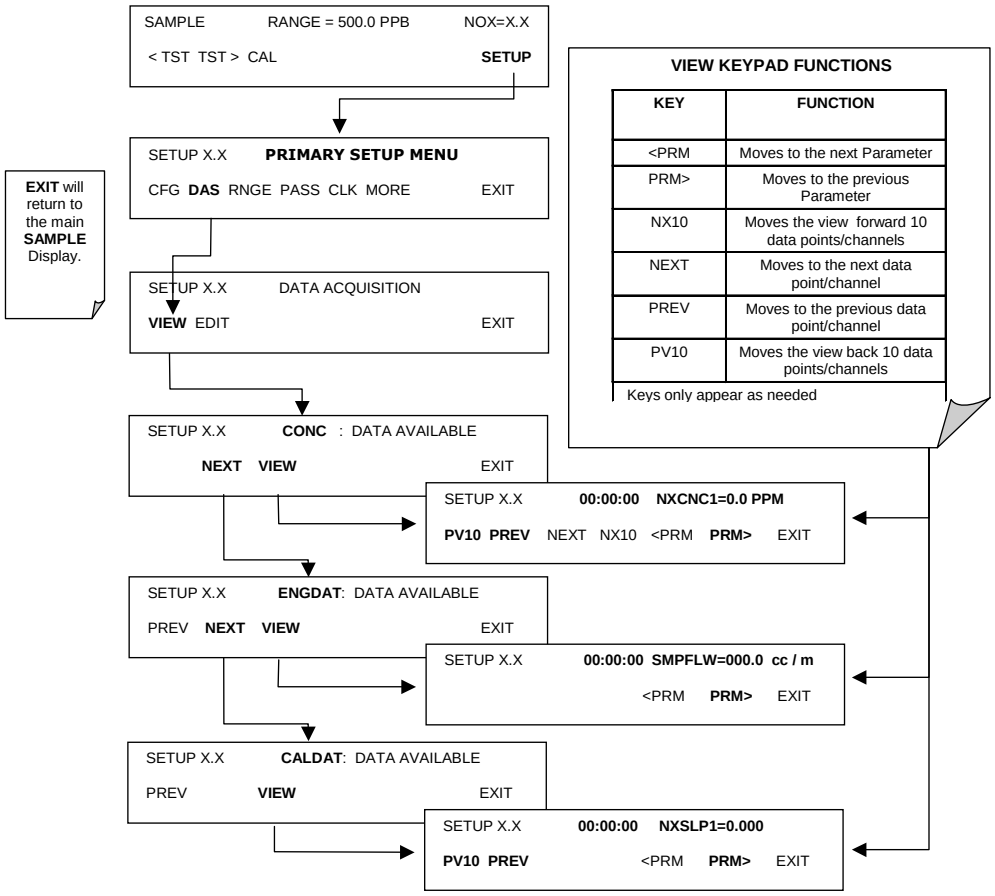
The default data channels can be used as they are, or they can be customized from the front panel or through APICOM to fit a specific application. The TAI website contains this default and other sample iDAS scripts for free download. We recommend that the user backs up any iDAS configuration and its data before altering it.

Appendix A-5 lists the firmware-specific iDAS configuration in plain-text format. This text file can either be loaded into APICOM and then modified and uploaded to the instrument or can be copied and pasted into a terminal program to be sent to the analyzer.

WARNING
Sending an iDAS configuration to the analyzer through its COM ports will replace the existing configuration and will delete all stored data. Back up any existing data and the iDAS configuration before uploading new settings.

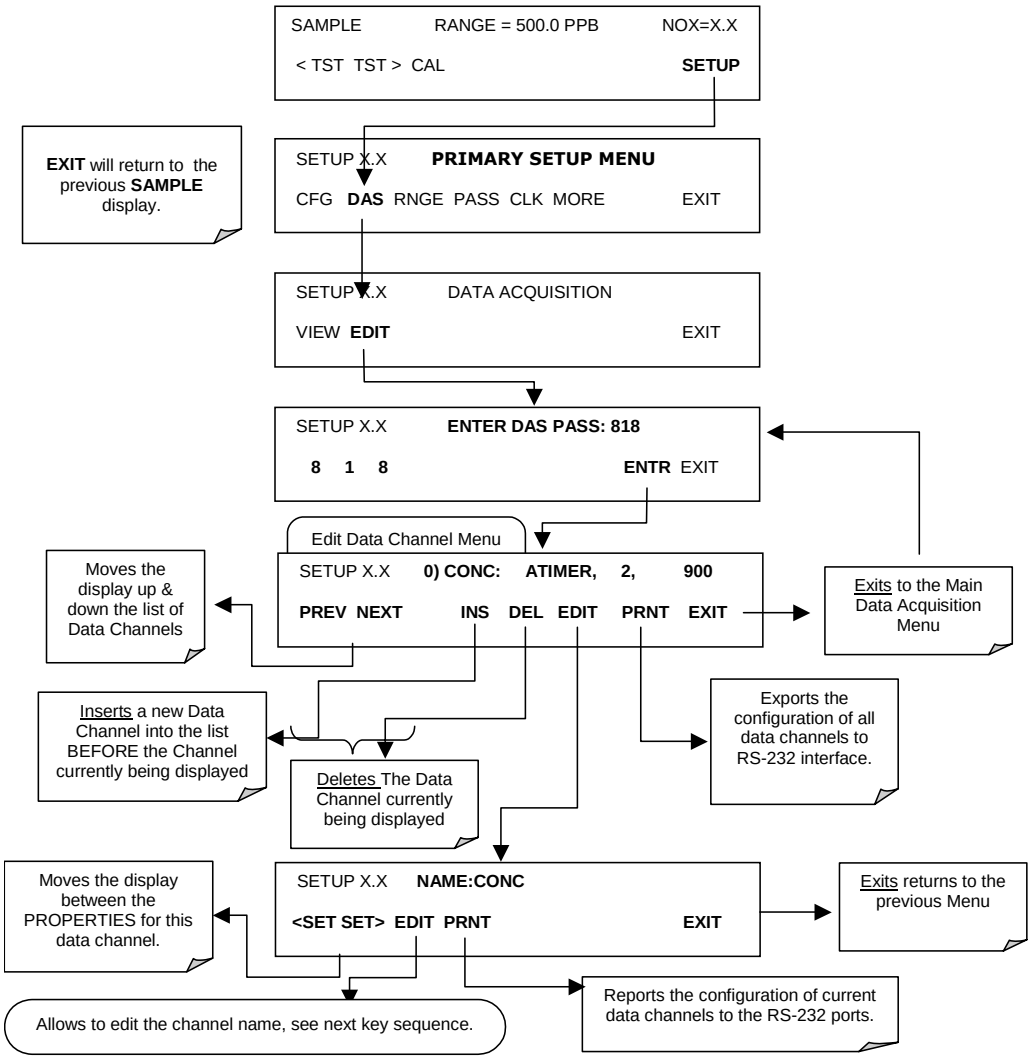
6.10.2.2. Viewing iDAS Data and Settings

IDAS data and settings can be viewed on the front panel through the following keystroke sequence.



6.10.2.3. Editing iDAS Data Channels

IDAS configuration is most conveniently done through the APICOM remote control program. The following list of key strokes shows how to edit using the front panel.



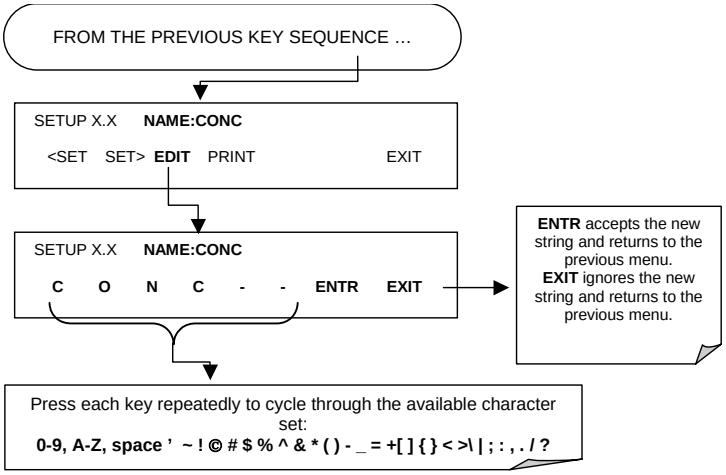
When editing the data channels, the top line of the display indicates some of the configuration parameters. For example, the display line:

```
0) CONC : ATIMER, 4, 800
```

Translates to the following configuration:

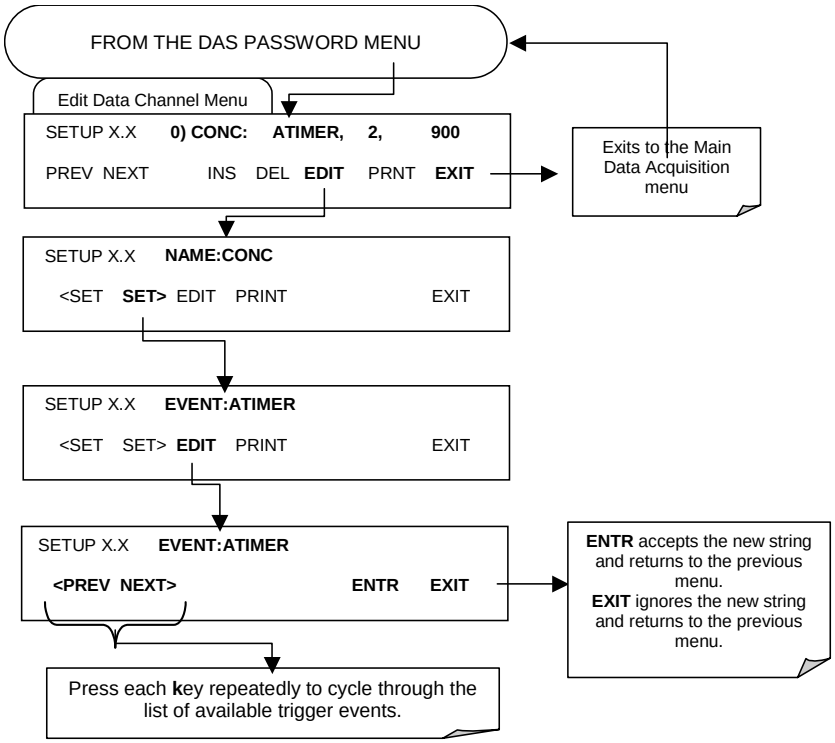
Channel No.: 0
NAME: CONC
TRIGGER EVENT: ATIMER
PARAMETERS: Four parameters are included in this channel
EVENT: This channel is set up to record 800 data points.

To edit the name of a data channel, follow the above key sequence and then press:



6.10.2.4. Trigger Events

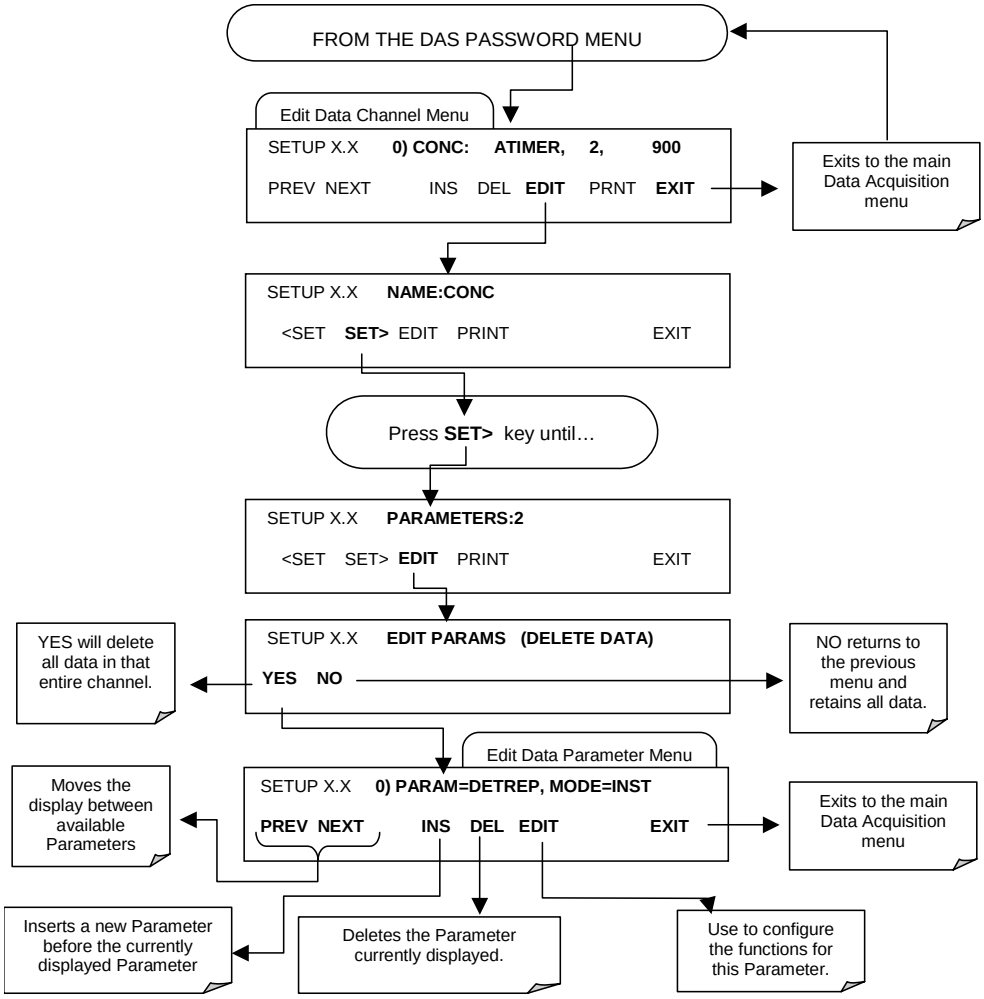
To edit the list of data parameters associated with a specific data channel, press:



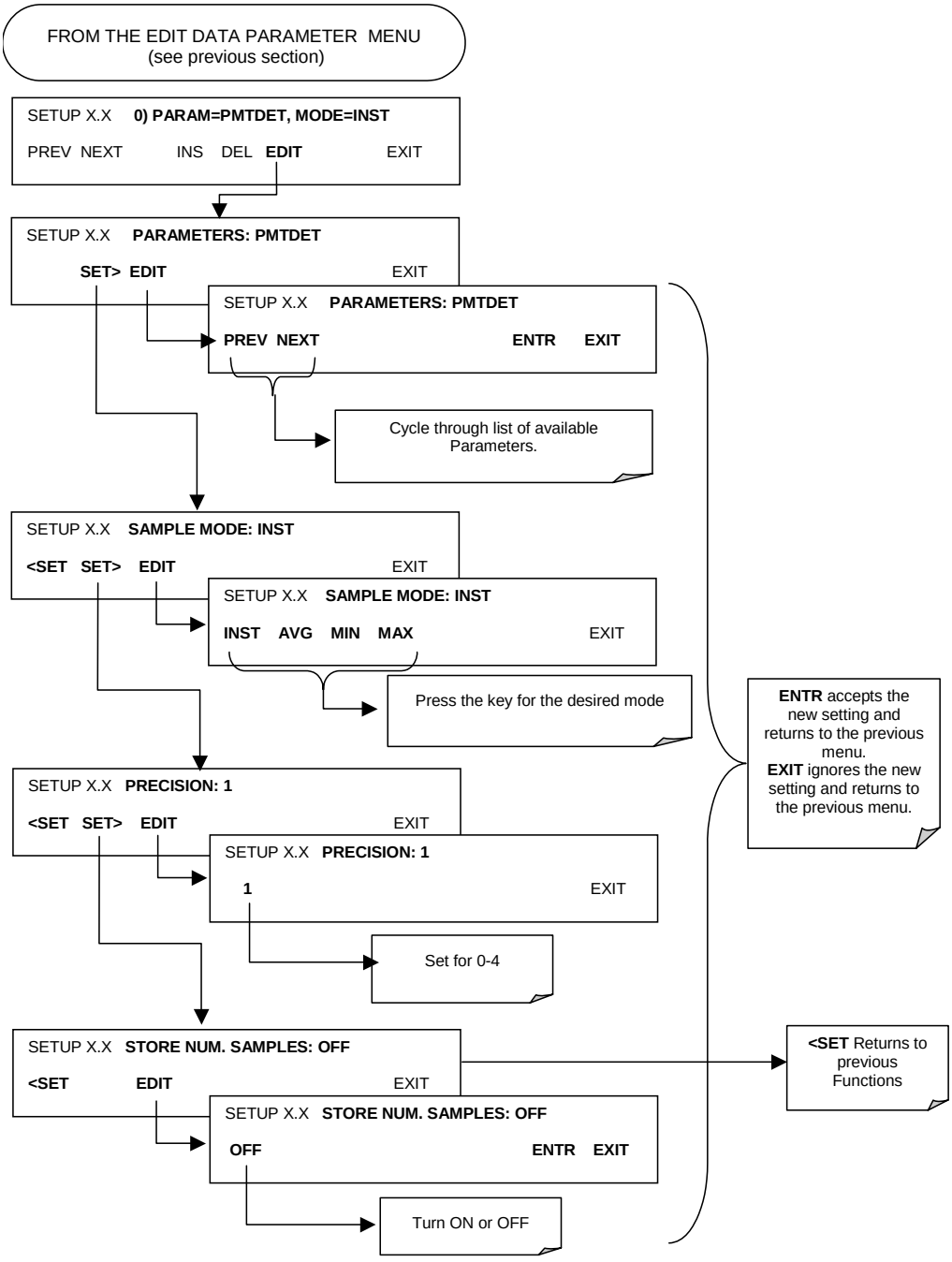
6.10.2.5. Editing iDAS Parameters

Data channels can be edited individually from the front panel without affecting other data channels. However, when editing a data channel, such as during adding, deleting or editing parameters, all data for that particular channel will be lost, because the iDAS can store only data of one format (number of parameter columns etc.) for any given channel. In addition, an iDAS configuration can only be uploaded remotely as an entire set of channels. Hence, remote update of the iDAS will always delete all current channels and stored data.

To modify, add or delete a parameter, press SETUP-DAS-ENTR and then:



To configure the parameters for a specific data parameter, press:



6.10.2.6. Sample Period and Report Period

The iDAS defines two principal time periods, the **SAMPLE PERIOD**, which is the time interval at which data are sampled (in volatile memory; not stored permanently), and the **REPORT PERIOD**, which is the time interval of which data are permanently stored to the Disk-on-Chip data storage and reported to the communication ports.

The **REPORT PERIOD** is typically used as the time interval between two permanently stored data points. The **SAMPLE PERIOD** is set to one minute by default and determines the frequency of data collection, i.e. how many times the iDAS records a parameter and stores it in a (volatile) data array for further processing and averaging. In conjunction with the **REPORT PERIOD**, the **SAMPLE PERIOD** determines the number of data points in each average value.

If, for example, the NO_X concentration parameter is configured with a **SAMPLE PERIOD** set to once per minute (default setting) and the **REPORT PERIOD** set to once per hour, the resulting data will be hourly, arithmetic means calculated from N=60 data points. Calibration and hold-off procedures as well as power-outs during that one hour will reduce the number of records per concentration average. For statistical analysis, the number of records per average data point for any given parameter within one data channel can also be stored.

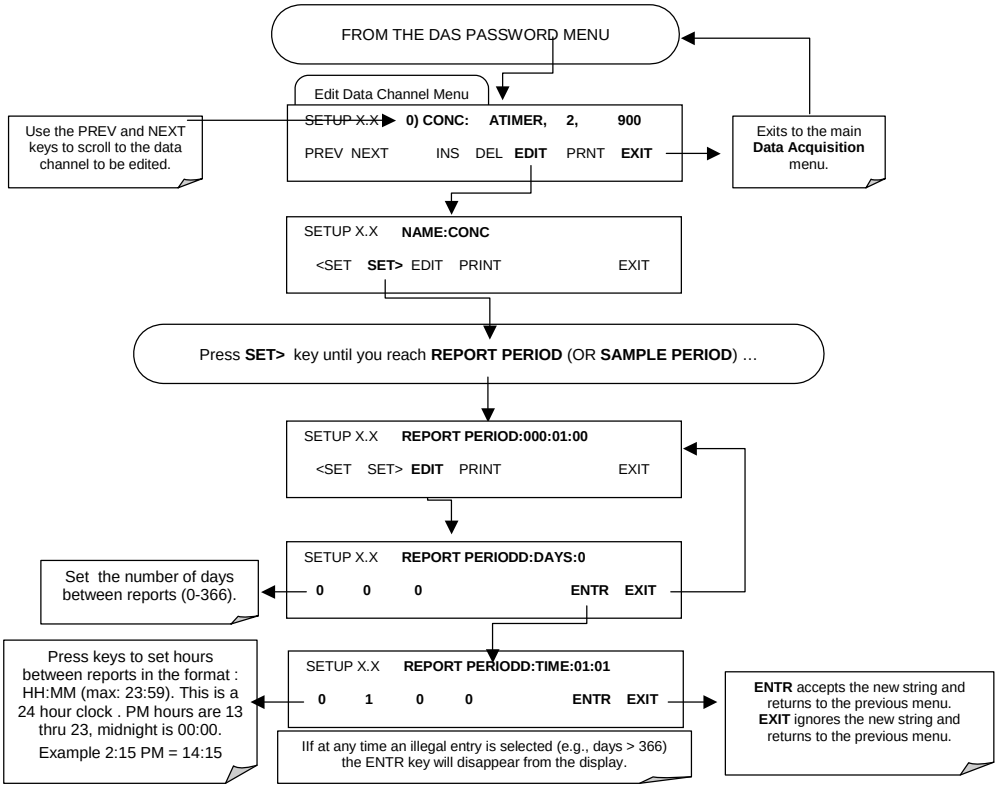
Configuring the **SAMPLE PERIOD** and the **REPORT PERIOD** for the same value, for example once per hour, will result in an instantaneous reading once per hour. This value would be the same as a reading configured for an instantaneous (**INST**) data type once per hour instead of an **AVG** type.

SAMPLE PERIOD and **REPORT PERIOD** are defined to be from the beginning to the end of the respective clock interval. A one-minute period starts and ends with the full minutes of the analyzer clock, an hourly period starts and ends with the full hour of the analyzer's clock and so on, even if the iDAS data collection was started within those periods. A one-minute data point, which is the lowest setting for any period, is always an instantaneous value, even when configured as an **AVG** event (although that data point is internally averaged over about 30 milli-seconds of analog data readings).

Note on averages in progress when instrument is powered off:

The iDAS is capable of averaging parameters over very long time intervals (**REPORT PERIOD** up to 366 days). If the instrument is powered off during an averaging interval and before the average is permanently stored in memory, the samples accumulated so far for that **REPORT PERIOD** are lost. On the other hand, if the instrument is powered up during an averaging interval, the iDAS begins averaging samples from that point onward (or after the hold-off period) until the scheduled end of the **REPORT PERIOD** when the data point is permanently stored.

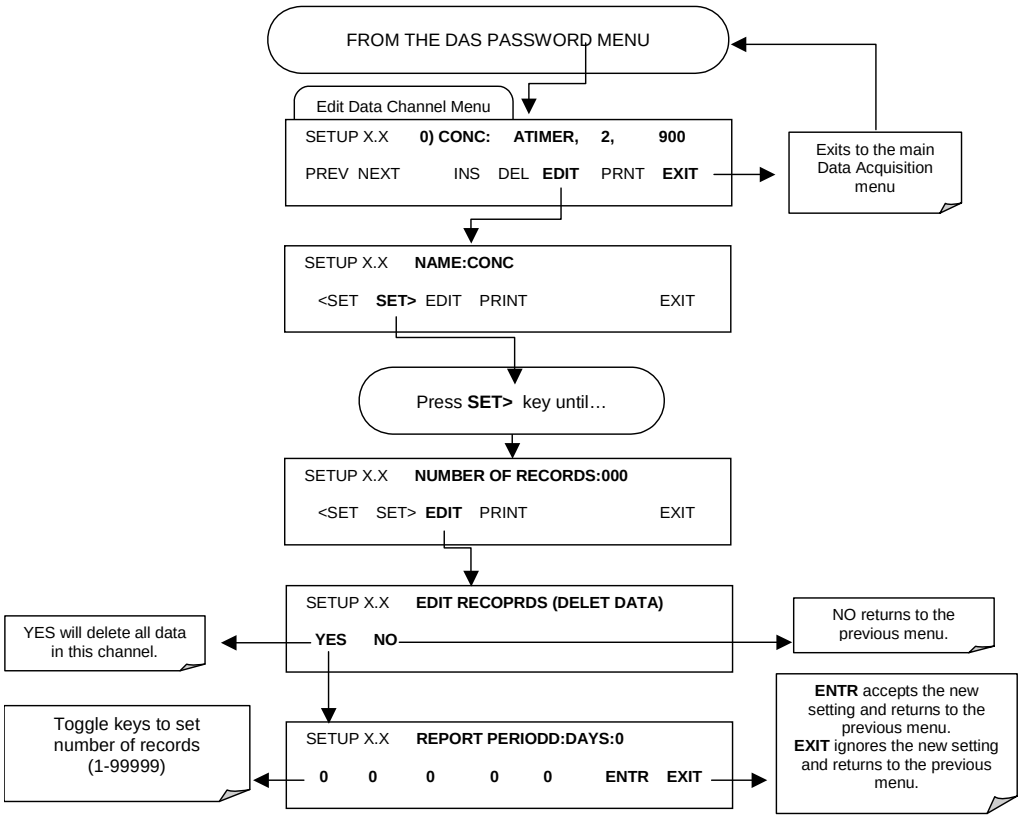
To define the **SAMPLE** or **REPORT PERIOD**, press SETUP-DAS-EDIT-ENTR and the following keys:



6.10.2.7. Number of Records

The number of data records in the M9110E is limited to a cumulative one million data points in all channels (one megabyte of space on the disk-on-chip). However, the actual number of records is also limited by the total number of parameters and channels and other settings in the iDAS configuration. Every additional data channel, parameter, number of samples setting etc. will reduce the maximum amount of data points somewhat. In general, however, the maximum data capacity is divided amongst all channels (max: 20) and parameters (max: 50 per channel).

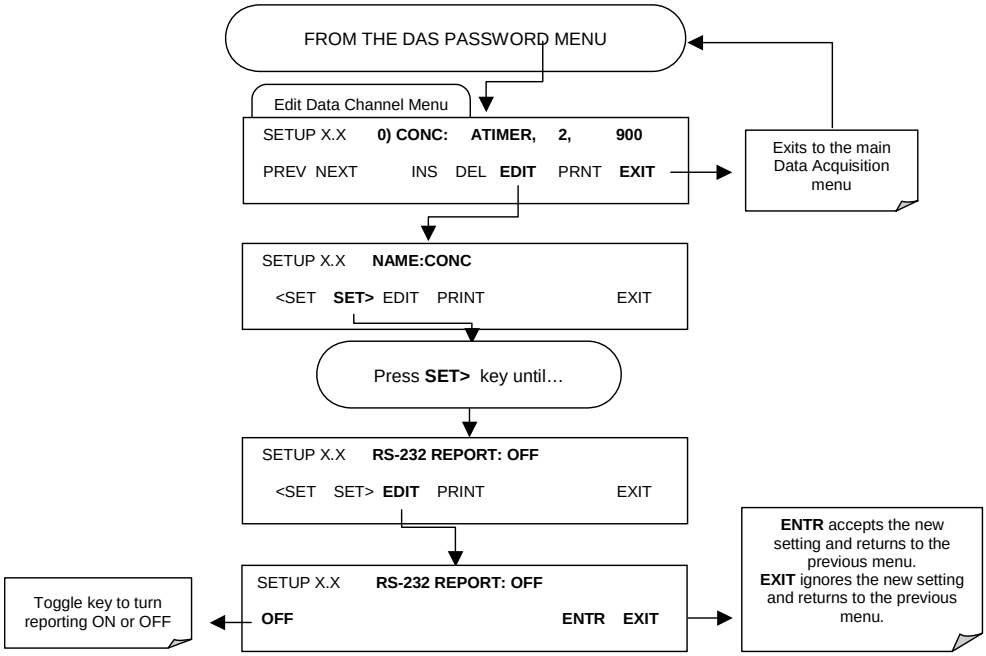
The iDAS will check the amount of available data space and prevent the user from specifying too many records at any given point. If, for example, the iDAS memory space can accommodate 375 more data records, the ENTR key will disappear when trying to specify more than that number of records. This check for memory space may also make an upload of an iDAS configuration with APICOM or a Terminal program fail, if the combined number of records would be exceeded. In this case, it is suggested to either try from the front panel what the maximum number of records can be or use trial-and-error in designing the iDAS script or calculate the number of records using the DAS or APICOM manuals. To set the number of records for one channel from the front panel, press SETUP-DAS-EDIT-ENTR and the following key sequence.



6.10.2.8. RS-232 Report Function

The M9110E iDAS can automatically report data to the communications ports, where they can be captured with a terminal emulation program or simply viewed by the user.

To enable automatic COM port reporting, press SETUP-DAS-ENTR and then:



6.10.2.9. Compact Report

When enabled, this option avoids unnecessary line breaks on all RS-232 reports. Instead of reporting each parameter in one channel on a separate line, up to five parameters are reported in one line, instead. For example, channel DIAG would report its record in two lines (10 parameters) instead of 10 lines. Individual lines carry the same time stamp and are labeled in sequence.

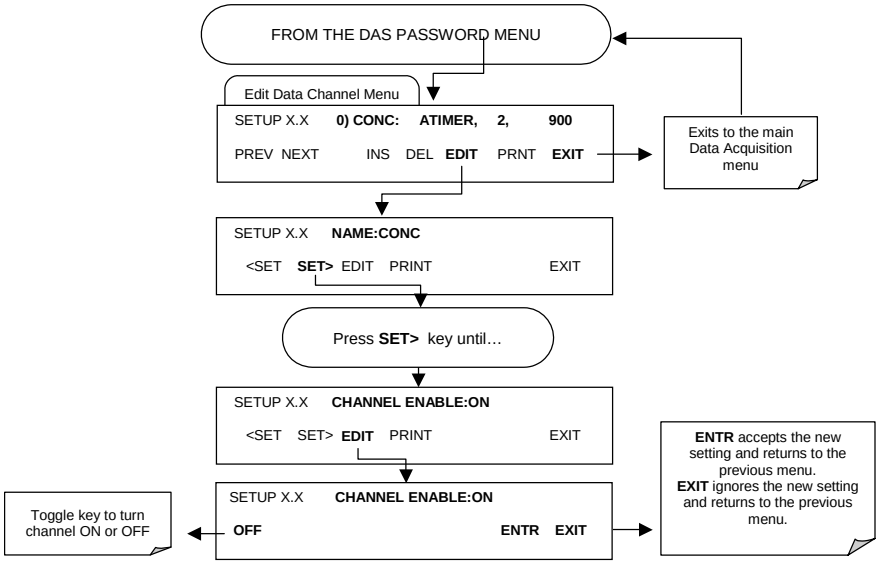
6.10.2.10. Starting Date

This option allows to specify a starting date for any given channel in case the user wants to start data acquisition only after a certain time and date. If the **Starting Date** is in the past, the iDAS ignores this setting.

6.10.2.11. Disabling/Enabling Data Channels

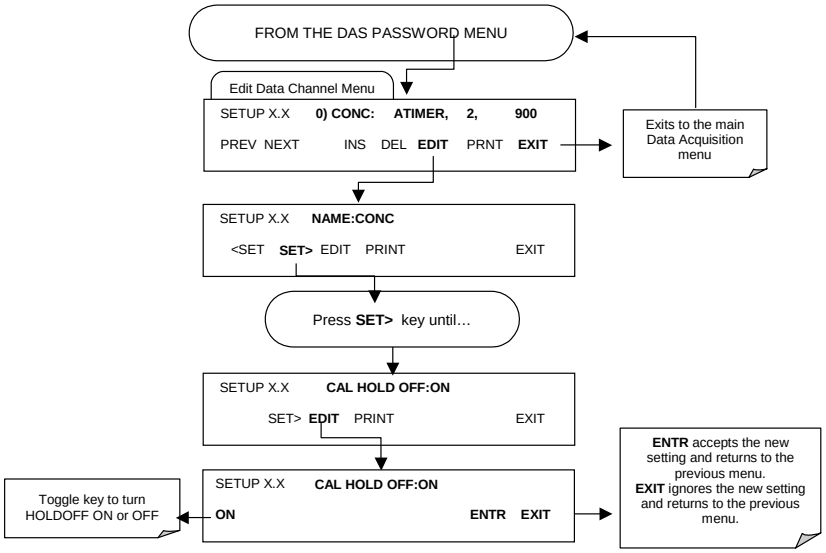
Data channels can be temporarily disabled, which can reduce the read/write wear on the disk-on-chip. The HIRES channel of the M9110E, for example, is disabled by default.

To disable a data channel, press SETUP-DAS-ENTR and the following keys:



6.10.2.12. HOLDOFF Feature

The iDAS HOLDOFF feature allows to prevent data collection during calibrations and during the DAS_HOLDOFF period enabled and specified in the VARS (Section 6.5). To enable or disable the HOLDOFF for any one iDAS channel, press SETUP-DAS-ENTR and then:



6.10.3. Remote iDAS Configuration

Editing channels, parameters and triggering events as described in Section 6.9.10 is much more conveniently done in one step through the APICOM remote control program using the graphical interface shown in Figure 0-6. Refer to the next Section 6.11 for details on remote access to the M9110E analyzer.

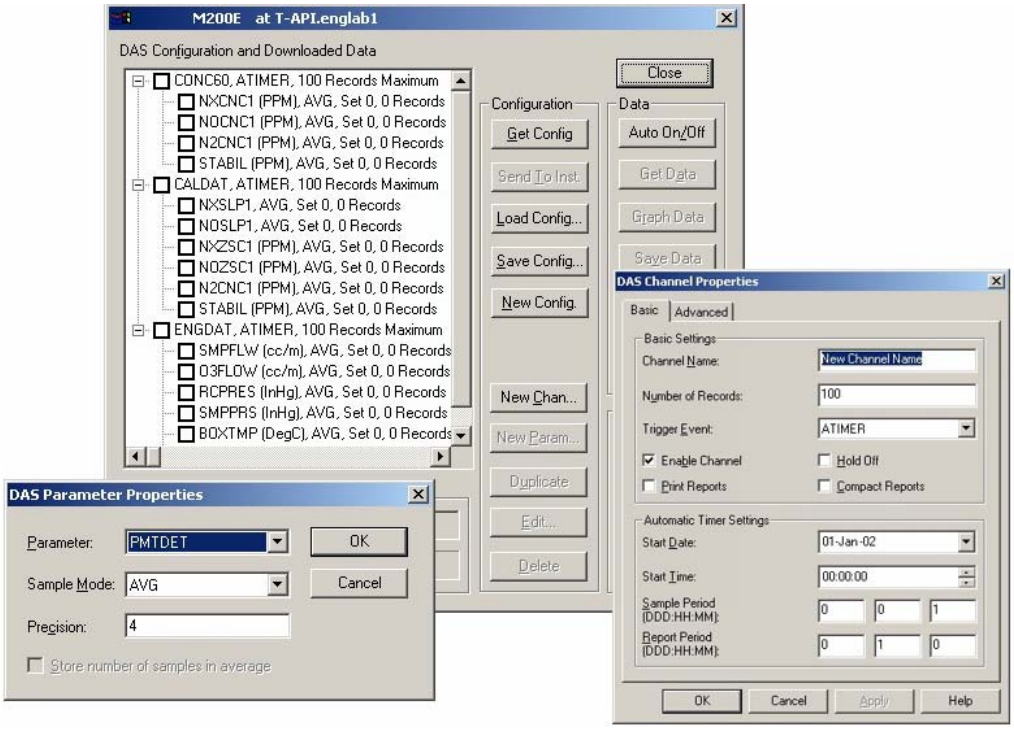


Figure 0-6: APICOM Graphical User Interface for Configuring the iDAS

Once an iDAS configuration is edited (which can be done offline and without interrupting DAS data collection), it is conveniently uploaded to the instrument and can be stored on a computer for later review, alteration or documentation and archival. Refer to the APICOM manual for details on these procedures. The APICOM user manual (TAI part number 039450000) is included in the APICOM installation file, which can be downloaded at http://www.teledyne-ai.com/software/.

Although TAI recommends the use of APICOM, the iDAS can also be accessed and configured through a terminal emulation program such as HyperTerminal (Figure 0-7). However, all configuration commands must be created following a strict syntax or be pasted in from of a text file, which was edited offline and then uploaded through a specific transfer procedure.

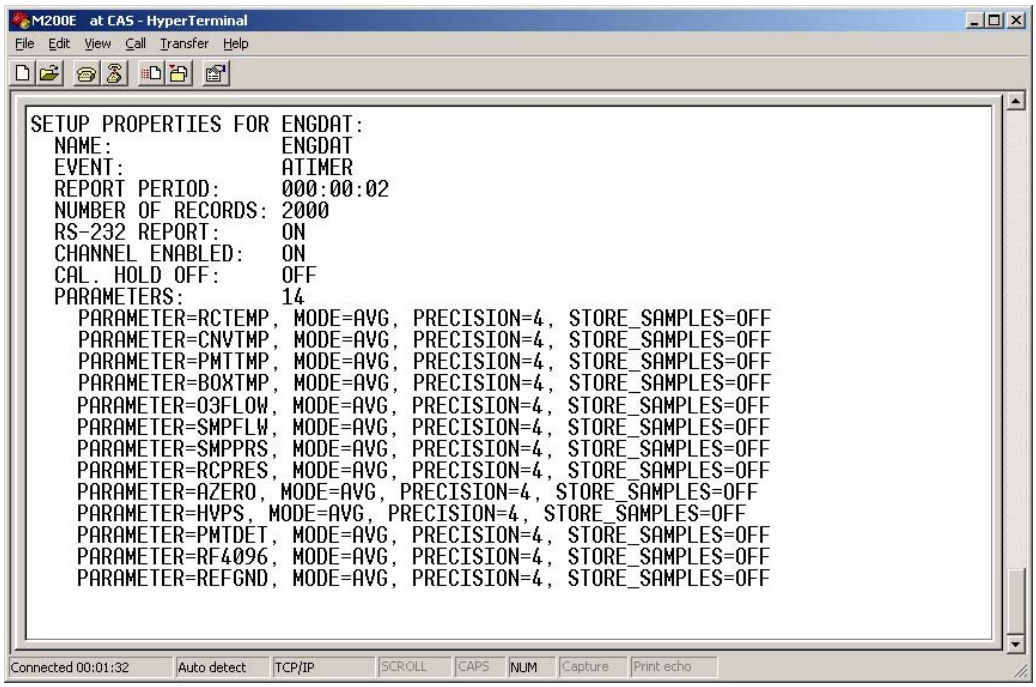


Figure 0-7: iDAS Configuration Through a Terminal Emulation Program

Both procedures are best started by downloading the default iDAS configuration, getting familiar with its command structure and syntax conventions, and then altering a copy of the original file offline before uploading the new configuration.

CAUTION
Whereas the editing, adding and deleting of iDAS channels and parameters of one channel through the front-panel keyboard can be done without affecting the other channels, uploading an iDAS configuration script to the analyzer through its communication ports will erase <u>all</u> data, parameters and channels by replacing them with the new iDAS configuration. It is advised to download and backup all data and the original iDAS configuration before attempting any iDAS changes.

6.11. Remote Operation of the Analyzer

6.11.1. Basic Operation

6.11.1.1. Terminal Operating Modes

The Model 9110E can be remotely configured, calibrated or queried for stored data through the serial ports. As terminals and computers use different communication schemes, the analyzer supports two communicate modes specifically designed to interface with these two types of devices.

Computer mode is used when the analyzer is connected to a computer with a dedicated interface program such as APICOM. More information regarding APICOM can be found in later in this section or on the TAI website at http://www.teledyne-api.com/software/apicom/.

Interactive mode is used with a terminal emulation programs such as HyperTerminal or a "dumb" computer terminal. The commands that are used to operate the analyzer in this mode are listed in Table 0-23.

6.11.1.2. Help Commands in Terminal Mode

Table 0-23: Terminal Mode Software Commands

COMMAND	Function
Control-T	Switches the analyzer to terminal mode (echo, edit). If mode flags 1 & 2 are OFF, the interface can be used in interactive mode with a terminal emulation program.
Control-C	Switches the analyzer to computer mode (no echo, no edit).
CR (carriage return)	A carriage return is required after each command line is typed into the terminal/computer. The command will not be sent to the analyzer to be executed until this is done. On personal computers, this is achieved by pressing the ENTER key.
BS (backspace)	Erases one character to the left of the cursor location.
ESC (escape)	Erases the entire command line.
? [ID] CR	This command prints a complete list of available commands along with the definitions of their functionality to the display device of the terminal or computer being used. The ID number of the analyzer is only necessary if multiple analyzers are on the same communications line, such as the multi-drop setup.
Control-C	Pauses the listing of commands.
Control-P	Restarts the listing of commands.

6.11.1.3. Command Syntax

Commands are not case-sensitive and all arguments within one command (i.e. ID numbers, keywords, data values, etc.) must be separated with a space character.

All Commands follow the syntax:

```
X [ID] COMMAND <CR>
```

Where

X — is the command type (one letter) that defines the type of command. Allowed designators are listed in Table 0-24 and Appendix A-6.

[ID] — is the analyzer identification number (Section 6.10.1). Example: the Command "? 200" followed by a carriage return would print the list of available commands for the revision of software currently installed in the instrument assigned ID Number 200.

COMMAND — is the command designator: This string is the name of the command being issued (LIST, ABORT, NAME, EXIT, etc.). Some commands may have additional arguments that define how the command is to be

executed. Press ? <CR> or refer to Appendix A-6 for a list of available command designators.

<CR> is a carriage return. All commands must be terminated by a carriage return (usually achieved by pressing the ENTER key on a computer).

Table 0-24: Command Types

Command	Command Type
C	Calibration
D	Diagnostic
L	Logon
T	Test measurement
V	Variable
W	Warning

6.11.1.4. Data Types

Data types consist of integers, hexadecimal integers, floating-point numbers, Boolean expressions and text strings.

- Integer data are used to indicate integral quantities such as a number of records, a filter length, etc. They consist of an optional plus or minus sign, followed by one or more digits. For example, *+1*, *-12*, *123* are all valid integers.
- Hexadecimal integer data are used for the same purposes as integers. They consist of the two characters "0x," followed by one or more hexadecimal digits (0-9, A-F, a-f), which is the 'C' programming language convention. No plus or minus sign is permitted. For example, *0x1*, *0x12*, *0x1234abcd* are all valid hexadecimal integers.
- Floating-point numbers are used to specify continuously variable values such as temperature set points, time intervals, warning limits, voltages, etc. They consist of an optional plus or minus sign, followed by zero or more digits, an optional decimal point, and zero or more digits. (At least one digit must appear before or after the decimal point.) Scientific notation is not permitted. For example, *+1.0*, *1234.5678*, *-0.1*, *1* are all valid floating-point numbers.
- Boolean expressions are used to specify the value of variables or I/O signals that may assume only two values. They are denoted by the keywords *ON* and *OFF*.
- Text strings are used to represent data that cannot be easily represented by other data types, such as data channel names, which may contain letters and numbers. They consist of a quotation mark, followed by one or more printable characters, including spaces, letters, numbers, and symbols, and a final quotation mark. For example, *"a"*, *"1"*, *"123abc"*, and *"()[]<>"* are all valid text strings. It is not possible to include a quotation mark character within a text string.
- Some commands allow you to access variables, messages, and other items, such as iDAS data channels, by name. When using these commands, you must type the entire name of the item; you cannot abbreviate any names.

6.11.2. Status Reporting

Reporting of status messages as an audit trail is one of the three principal uses for the RS-232 interface (the other two being the command line interface for controlling the

instrument and the download of data in electronic format). You can effectively disable the reporting feature by setting the interface to quiet mode (Section 6.9.6, Table 0-18).

Status reports include iDAS data (when reporting is enabled), warning messages, calibration and diagnostic status messages. Refer to Appendix A-3 for a list of the possible messages, and this section for information on controlling the instrument through the RS-232 interface.

General Message Format

All messages from the instrument (including those in response to a command line request) are in the format:

```
X DDD:HH:MM [Id] MESSAGE<CRLF>
```

Where:

X	is a command type designator, a single character indicating the message type, as shown in the Table 0-21.
DDD:HH:MM	is the time stamp, the date and time when the message was issued. It consists of the Day-of-year (DDD) as a number from 1 to 366, the hour of the day (HH) as a number from 00 to 23, and the minute (MM) as a number from 00 to 59.
[ID]	is the analyzer ID, a number with 1 to 4 digits.
MESSAGE	is the message content that may contain warning messages, test measurements, iDAS reports, variable values, etc.
<CRLF>	is a carriage return / line feed pair, which terminates the message.

The uniform nature of the output messages makes it easy for a host computer to parse them into an easy structure. Keep in mind that the front panel display does not give any information on the time a message was issued, hence it is useful to log such messages for trouble-shooting and reference purposes. Terminal emulation programs such as HyperTerminal can capture these messages to text files for later review.

6.11.3. Remote Access by Modem

The M9110E can be connected to a modem for remote access. This requires a cable between the analyzer's COM port and the modem, typically a DB-9F to DB-25M cable (available from TAI with part number WR0000024).

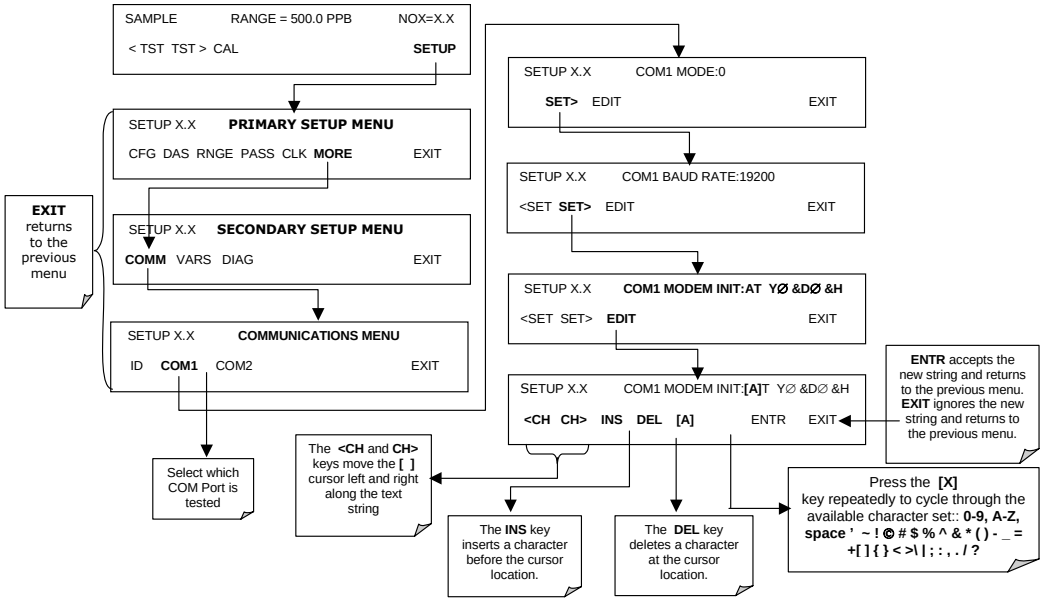
Once the cable has been connected, check to make sure the DTE-DCE is in the correct position. Also make sure the M9110E COM port is set for a baud rate that is compatible with the modem, which needs to operate with an 8-bit word length with one stop bit.

The first step is to turn on the **MODEM ENABLE** communication mode (Mode 64, Section 6.10.2.11). Once this is completed, the appropriate setup command line for your modem can be entered into the analyzer. The default setting for this feature is

```
AT Y0 &D0 &H0 &I0 S0=2 &B0 &N6 &M0 E0 Q1 &W0
```

This string can be altered to match your modem's initialization and can be up to 100 characters long.

To change this setting press:



6.11.4. COM Port Password Security

In order to provide security for remote access of the M9110E, a LOGON feature can be enabled to require a password before the instrument will accept commands. This is done by turning on the **SECURITY MODE** (Mode 4, Section 6.10.2.11). Once the **SECURITY MODE** is enabled, the following items apply.

- A password is required before the port will respond or pass on commands.
- If the port is inactive for one hour, it will automatically logoff, which can also be achieved with the LOGOFF command.
- Three unsuccessful attempts to log on with an incorrect password will cause subsequent logins to be disabled for 1 hour, even if the correct password is used.
- If not logged on, the only active command is the '?' request for the help screen.
- The following messages will be returned at logon:
  - LOGON SUCCESSFUL - Correct password given.
  - LOGON FAILED - Password not given or incorrect.
  - LOGOFF SUCCESSFUL - Connection terminated successfully.

To log on to the model 9110E analyzer with **SECURITY MODE** feature enabled, type:

```
LOGON 940331
```

940331 is the default password. To change the default password, use the variable RS232_PASS issued as follows:

V RS232_PASS=NNNNNN

Where N is any numeral between 0 and 9.

6.11.5. APICOM Remote Control Program

APICOM is an easy-to-use, yet powerful interface program that allows to access and control any of TAI's main line of ambient and stack-gas instruments from a remote connection through direct cable, modem or Ethernet. Section 6.10.3 and Figure 0-6 showed the remote iDAS configuration through APICOM, Figure 0-8 shows the main interface, which resembles and emulates the actual front panel functionality. *Note: 9110E and M200E are used interchangeably.*

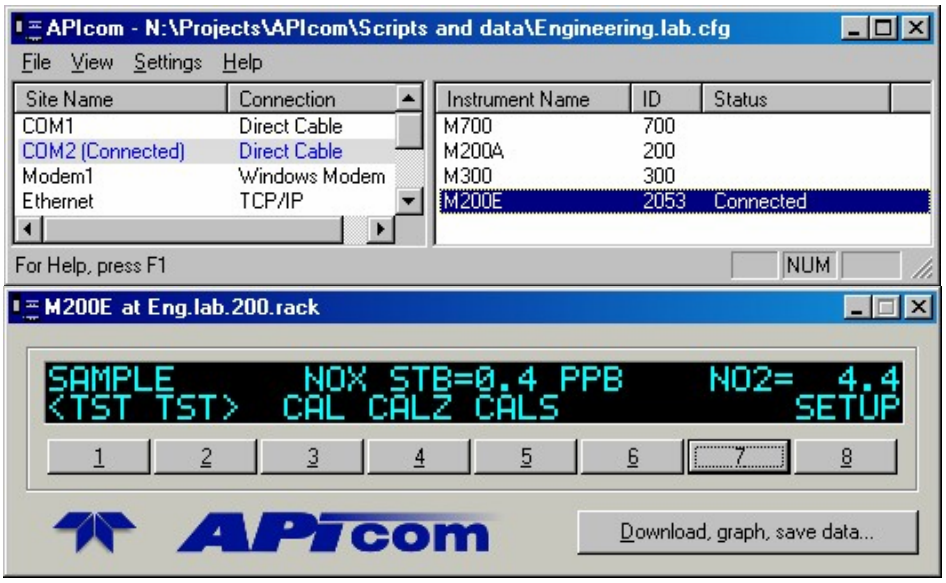


Figure 0-8: APICOM Remote Control Program Interface

Running APICOM, a user can:

- Establish a link from a remote location to the M9110E through direct cable connection via RS-232 modem or Ethernet.
- View the instrument's front panel and remotely access all functions that could be accessed when standing in front of the instrument.
- View multiple instruments (including calibrators) from multiple sites at the same time.
- Check on system parameters for trouble-shooting and quality control.
- Remotely edit system parameters and set points.
- Download, view, graph and save data for predictive diagnostics or data analysis.

- Retrieve, view, edit, save and upload iDAS configurations.

APICOM is very helpful for initial setup, data analysis, maintenance and trouble-shooting. APICOM is included free of cost with the analyzer or can be downloaded for free at http://www.teledyne-api.com/software/apicom/.

6.11.6. Additional Communications Documentation

Table 0-25: Serial Interface Documents

Interface / Tool	Document Title	Part Number	Available Online*
Multi-drop	RS-232 Multi-drop Documentation	021790000	YES
DAS Manual	Detailed description of the iDAS	028370000	YES
APICOM	APICOM User Manual	039450000	YES
Hessen protocol	Hessen Protocol 4.0 Manual Addendum	045850000	YES
* These documents can be downloaded at http://www.teledyne-ai.com/manuals/			

7. CALIBRATION PROCEDURES

This chapter describes calibration procedures for the M9110E. All of the methods described here can be initiated and controlled through the front panel or the COM ports.

NOTE
If you are using the M9110E for US-EPA controlled monitoring, see Chapter 8 for information on the EPA calibration protocol.

7.1. Calibration Preparations

The calibration procedures in this section assume that the range mode, analog range and units of measure have already been selected for the analyzer. If this has not been done, please do so before continuing (Section 6.5 for instructions).

7.1.1. Required Equipment, Supplies, and Expendables

Calibration of the Model 9110E analyzer requires a certain amount of equipment and supplies. These include, but are not limited to, the following:

- Zero-air source (defined in Section 3.3.2).
- Span gas source (defined in Section 3.3.1).
- Gas lines - all gas line materials should be stainless steel or Teflon-type (PTFE or FEP). High concentration NO gas transported over long distances may require stainless steel to avoid oxidation of NO with O_2 diffusing into the tubing.
- A recording device such as a strip-chart recorder and/or data logger (optional). For electronic documentation, the internal data acquisition system can be used.

7.1.2. Zero Air

Zero air is similar in chemical composition to the Earth's atmosphere but scrubbed of all components that might affect the analyzer's readings. For NO_X measuring devices, zero air should be devoid of NO_X and large amounts of CO_2, NH_3 and water vapor. Water vapor and moderate amounts of NH_3 can be removed using a sample gas conditioner (Section 5.9).

Devices such as the API Model 701 zero air generator that condition ambient air by drying and removal of pollutants are available. We recommend this type of device for generating zero air. Please contact our sales department for more information on this.

7.1.3. Span Gas Standards

As explained in detail in Section 3.3.1, span gas is specifically mixed to match the chemical composition of the gas being measured at about 80% of the desired full measurement range. For example, if the measurement range is 500 ppb, the span gas should have an NO concentration of about 400 ppb.

We strongly recommend that span calibration is carried out with NO span gas, although it is possible to use NO_2 or a gas phase titration (GPT) system. Quick span checks may be done with either NO, NO_2 or a mixture of NO and NO_2 as is used in GPT. Span gases should be certified to a specific accuracy to ensure accurate calibration of the analyzer. Typical gas accuracy for NO_X gases is 1 or 2%. NO standards should be mixed in nitrogen (to prevent oxidation of NO to NO_2 over time), whereas NO_2 standards should be mixed in air (to keep it oxidized).

7.1.4. NO_2 Permeation Tubes

TAI offers an internal zero / span (IZS) option operating with an NO_2 permeation device. The accuracy of these devices is only about ±5%. Whereas this may be sufficient for quick, daily calibration checks, we recommend to use certified NO gases for accurate calibration. Note that US-EPA controlled applications do not allow permeation devices to be used for calibration.

7.1.5. Calibration Gas Traceability

All equipment used to produce calibration gases should be verified against standards of the National Institute for Standards and Technology (NIST). To ensure NIST traceability, we recommend to acquire cylinders of working gas that are certified to be traceable to NIST standard reference materials (SRM). These are available from a variety of commercial sources.

7.1.6. Data Recording Devices

A strip chart recorder, data acquisition system or digital data acquisition system should be used to record data from the serial or analog outputs of the M9110E. If analog readings are used, the response of the recording system should be checked against a NIST traceable voltage source or meter. Data recording devices should be capable of bi-polar operation so that negative readings can be recorded. For electronic data recording, the M9110E provides an internal data acquisition system (iDAS), which is described in detail in Section 6.9.10. APICOM, a remote control program, is also provided as a convenient and powerful tool for data handling, download, storage, quick check and plotting.

7.1.7. NO_2 Conversion Efficiency

To ensure accurate operation of the M9110E, it is important to check the NO_2 conversion efficiency (CE) periodically and to update this value as necessary. The default setting for the NO_2 converter efficiency is 1.0000. For the analyzer to function correctly, the converter efficiency must be between 0.9600 and 1.0200 (96-102% conversion efficiency) as per US-EPA requirements. If the converter's efficiency is outside these limits, the NO_2 converter should be replaced. The currently programmed CE is recorded along with the calibration data in the iDAS for documentation and performance analysis (Section 6.10.2.1).

The following procedure will cause the Model 9110E to automatically calculate the current NO_2 conversion efficiency.

Step one is to connect a source of calibrated NO_2 span gas as shown below.

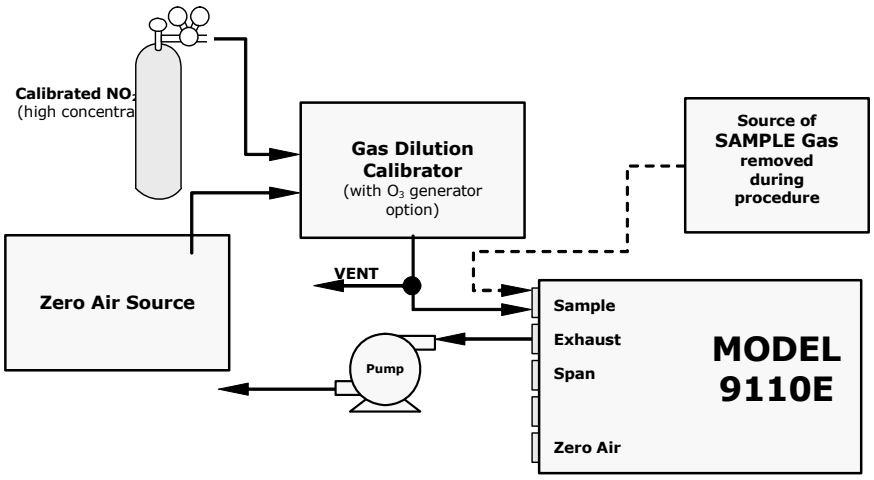
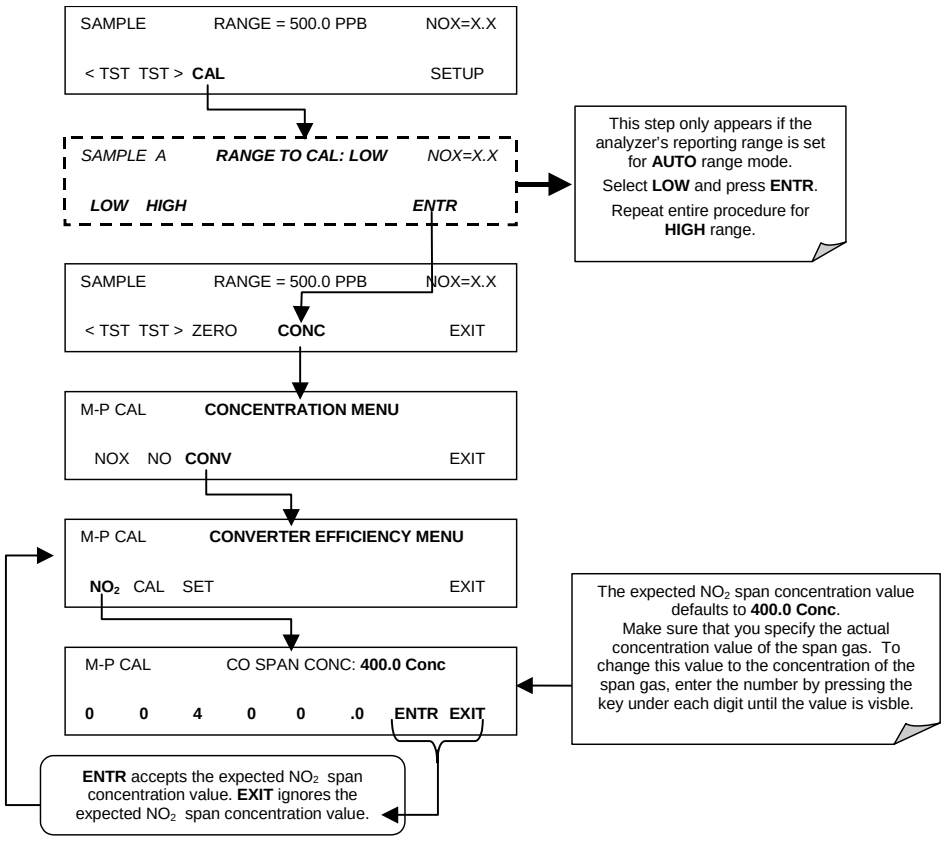
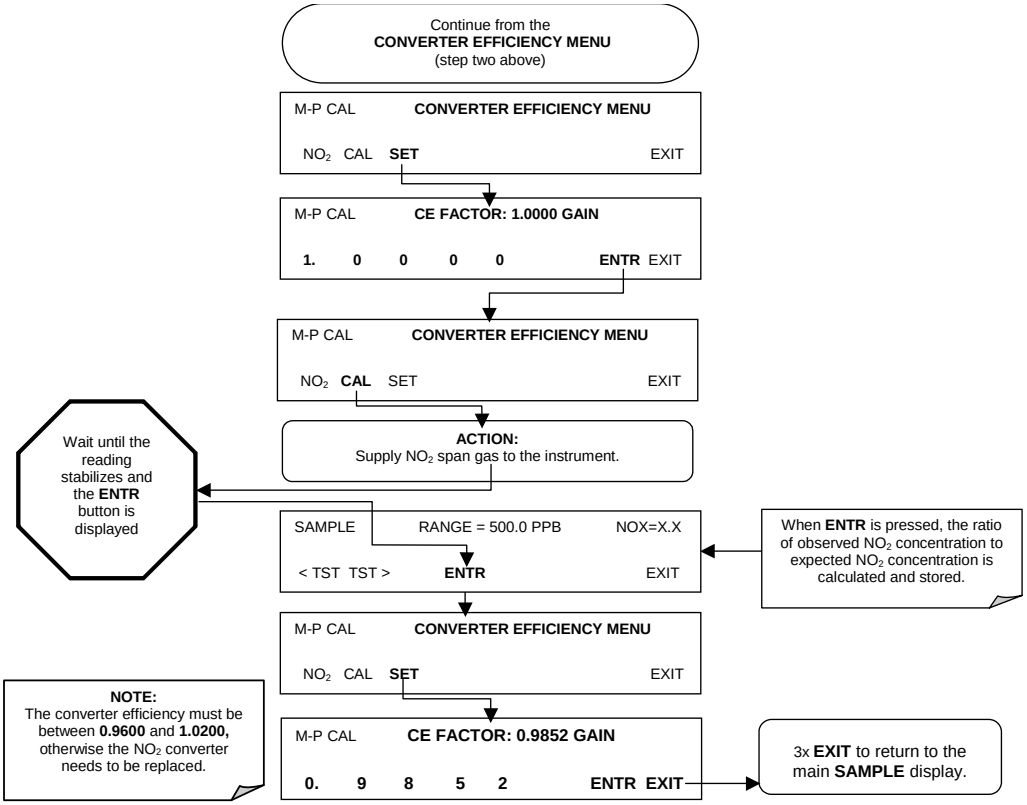


Figure 7-1: Gas Supply Setup for Determination of NO_2 Conversion Efficiency

Step two is to set the expected NO_2 span gas concentration:



Step three is to perform the converter efficiency calculation procedure:



7.2. Manual Calibration

The following section describes the basic method for manually calibrating the Model 9110E NO_X analyzer.

A note on the difference between a calibration and calibration check: pressing the ENTR key during the following procedures recalculates the stored values for OFFSET and SLOPE (instrument response curve) and alters the instrument's calibration. Alternatively, you can check on the current values and response and then EXIT out of any menu before pressing the final ENTR key to leave all settings intact (Section 7.3).

7.2.1. Connect Zero Air and Span Gases to the Analyzer

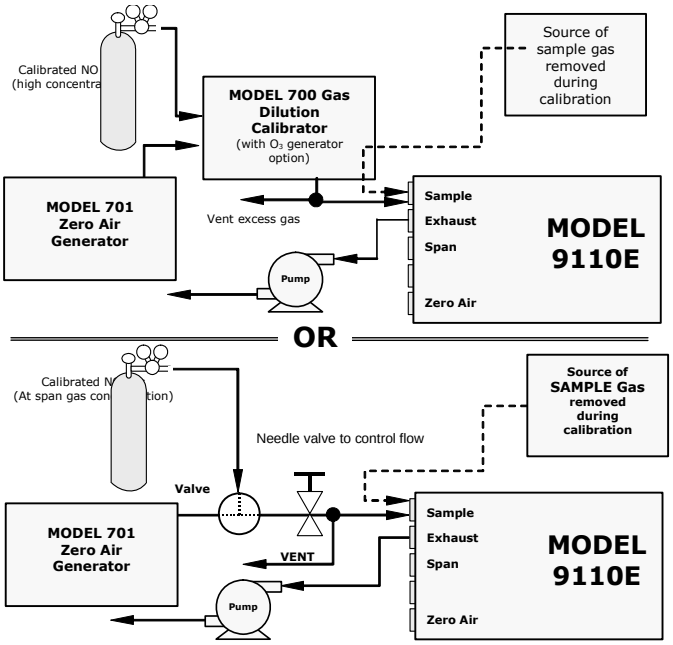
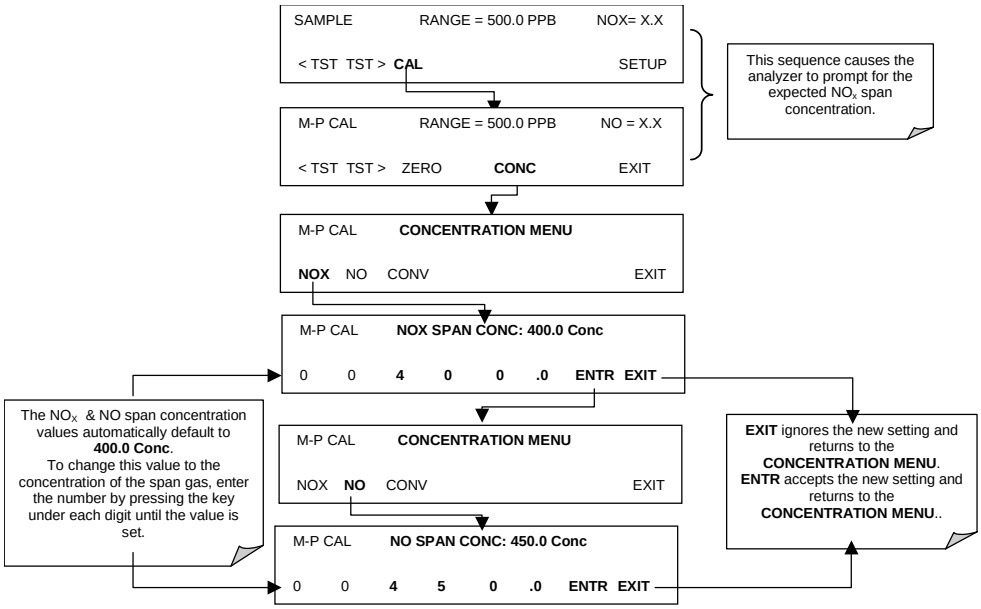


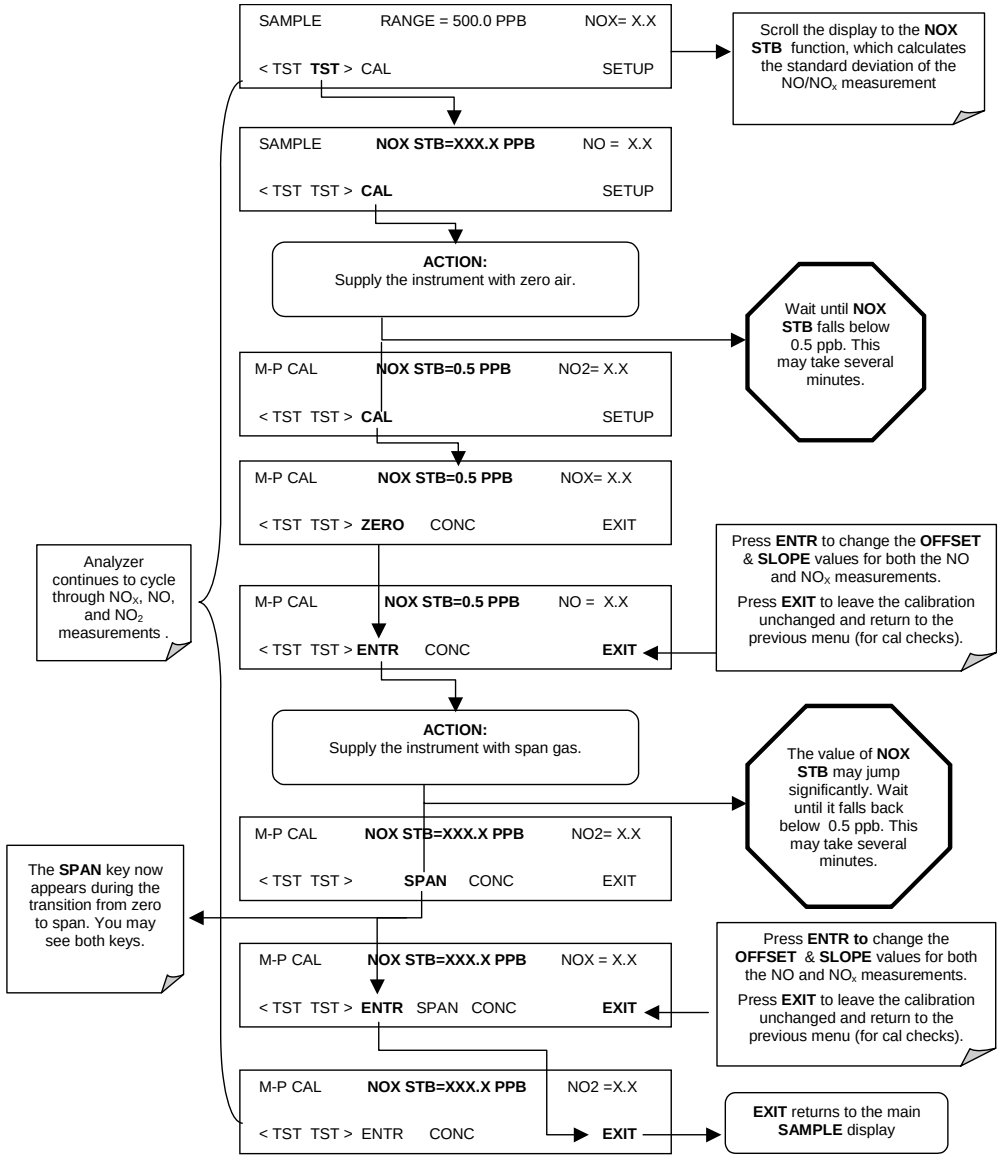
Figure 7-2: Setup for Manual Calibration without Z/S valve or IZS Option

7.2.2. Set Expected NO and NO_X Span Gas Concentrations



NOTE
The expected concentrations for both NO_X and NO are usually set to the same value unless the conversion efficiency is not equal to 1.000 or not entered properly in the conversion efficiency setting. When setting expected concentration values, consider impurities in your span gas source (NO often contains 1-3% NO_2 and vice versa).

7.2.3. Perform Zero/Span Calibration:

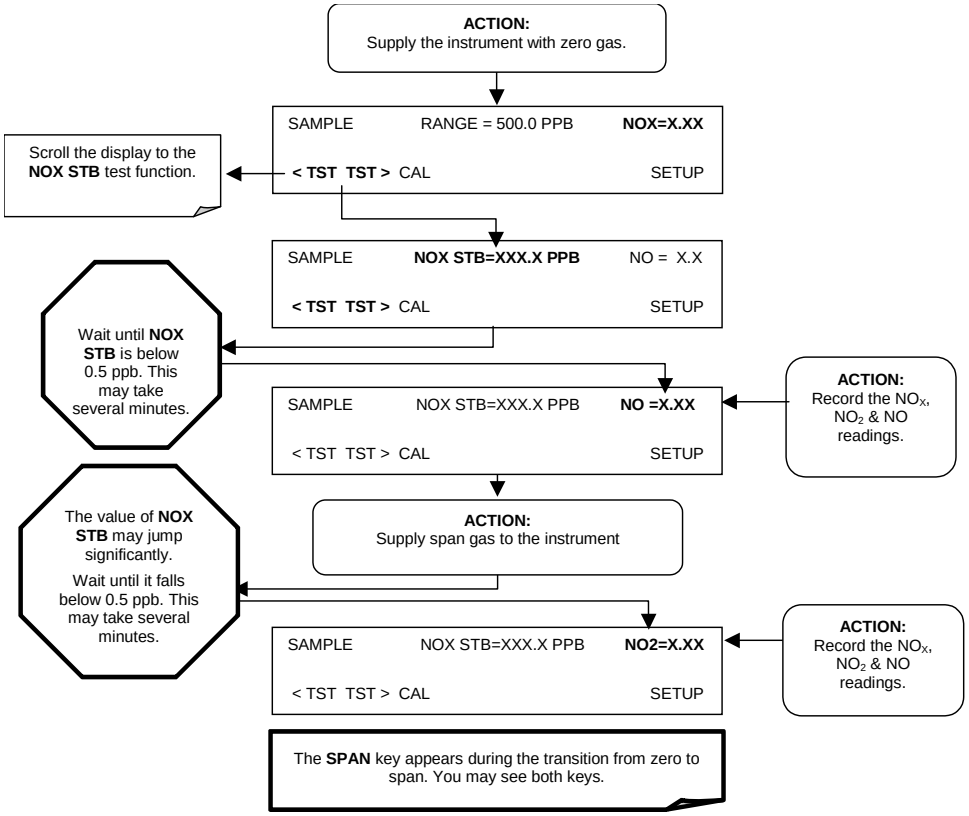


If the **ZERO** or **SPAN** keys are not displayed during zero or span calibration, the measured concentration value is too different from the expected value and the analyzer does not allow to zero or span the instrument. Consult Section 11.3 for calibration problems.

7.3. Calibration Checks

Informal calibration checks, which only evaluate but do not alter the analyzer's response curve, are recommended as a regular maintenance item and in order to monitor the analyzer's performance. To carry out a calibration check rather than a full calibration, follow these steps.

Connect the sources of zero air and span gas as shown in Figure 7-2, then perform the zero/span calibration check procedure:

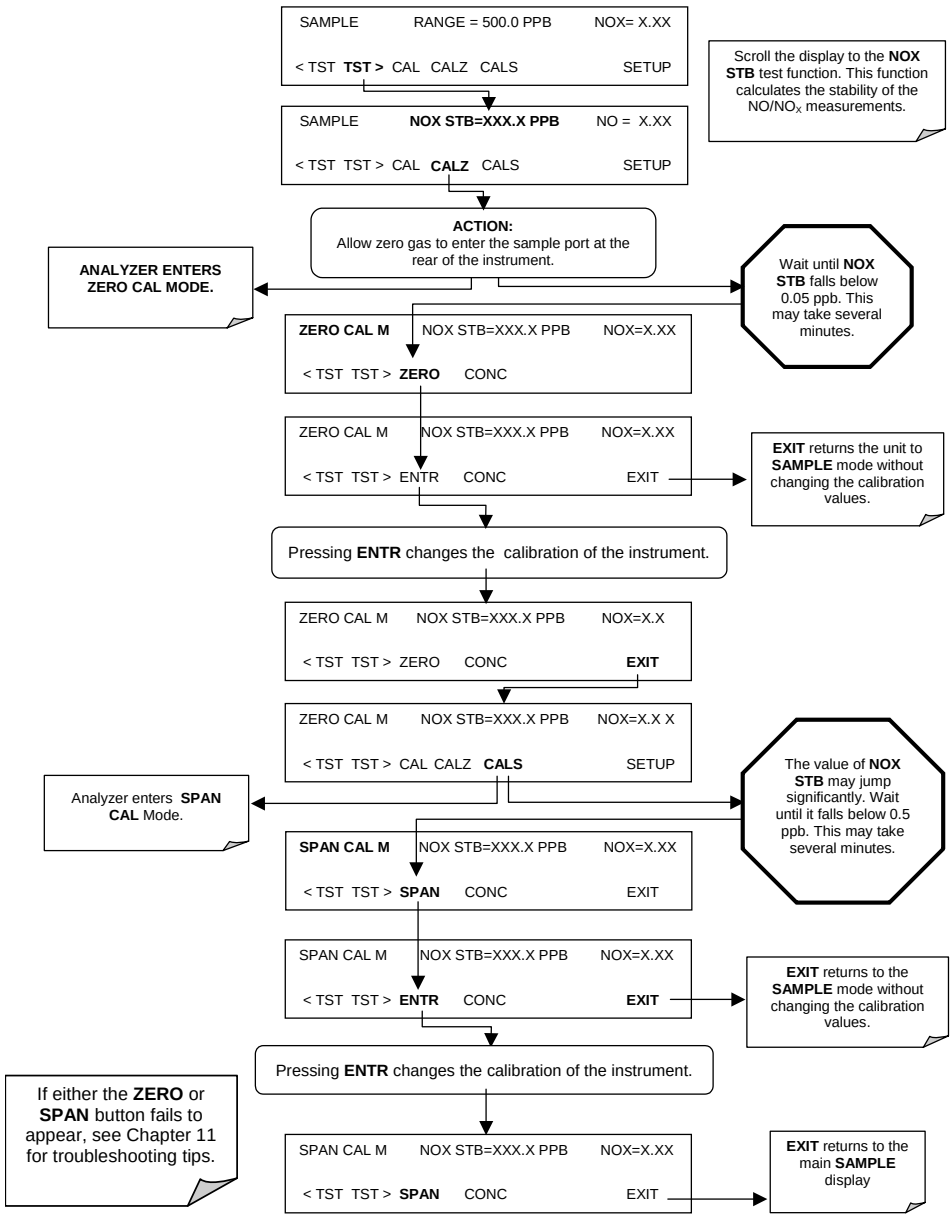


7.4. Calibration with Zero/Span Valves

To perform a manual calibration or calibration check of the analyzer with a zero/span valve option installed and functioning, use the following method. The basic differences between calibrating an M9110E with the zero/span valve option instead of the basic calibration method (Section 7.2) are that zero air and span gas are now supplied through dedicated gas inlets rather than through the sample inlet and that the zero and span operations are initiated directly and independently with dedicated keys **CALZ and CALS**.

Connect the sources of zero air and span gas to the respective ports on the rear panel (Figure 3-2) to follow the setup in Figure 7-4. Set the expected NO and NO_X values according to the procedure described in Section 7.2.

Perform the calibration or calibration check according to the following flow chart:



7.5. Calibration with IZS Option

When using the IZS option to calibrate the M9110E, the analyzer's **CAL_ON_NO2** feature must be turned on. This feature enables a continuous zero gas flow across the IZS

permeation tube and through the NO_2 converter (Figure 3-11). It also programs the analyzer to use the NO output from the NO_2 converter to calibrate the span value of both NO and NO_X.

NOTE
The IZS with NO_2 permeation tube has a limited accuracy of about ±5%. Whereas this may be sufficient for informal calibration checks, this method of calibration is not approved by the US EPA as a calibration source.

This feature should only be enabled when a span calibration or calibration check is performed. While **CAL-ON-NO2** is enabled, the NO_2 concentration will always be reported as zero. This is because the gas is continuously routed through the NO_2 converter and the analyzer's firmware simulates calibration with NO gas. Since the instrument sees the same concentration of NO during both NO and NO_X cycles, it reports an NO_2 concentration of zero.

Table 7-1: IZS Option Valve States with CAL_ON_NO_2 Turned ON

Valve	Condition	Valve Port Connections
Sample/Cal	Open to zero/span valve	1 → 2
Zero/Span	Open to SPAN GAS inlet	1 → 2
NO/NOx Valve	Open to NO2 converter	1 → 2
AutoZero Valve	Cycles normally	N/A

Performing a manual calibration of the analyzer with an IZS option installed is similar to the method described in Section 7.4, except that both zero air and span gas are supplied to the analyzer from ambient air through the zero gas inlet.

1. Connect the sources of zero air and span gas as shown in Figure 7-3.

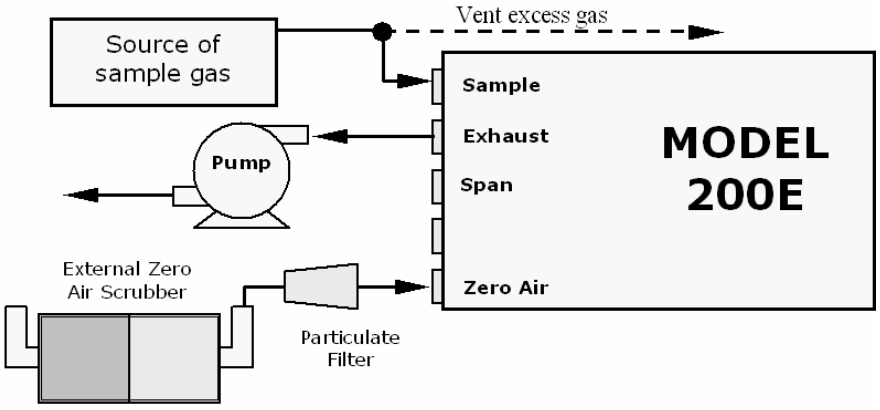
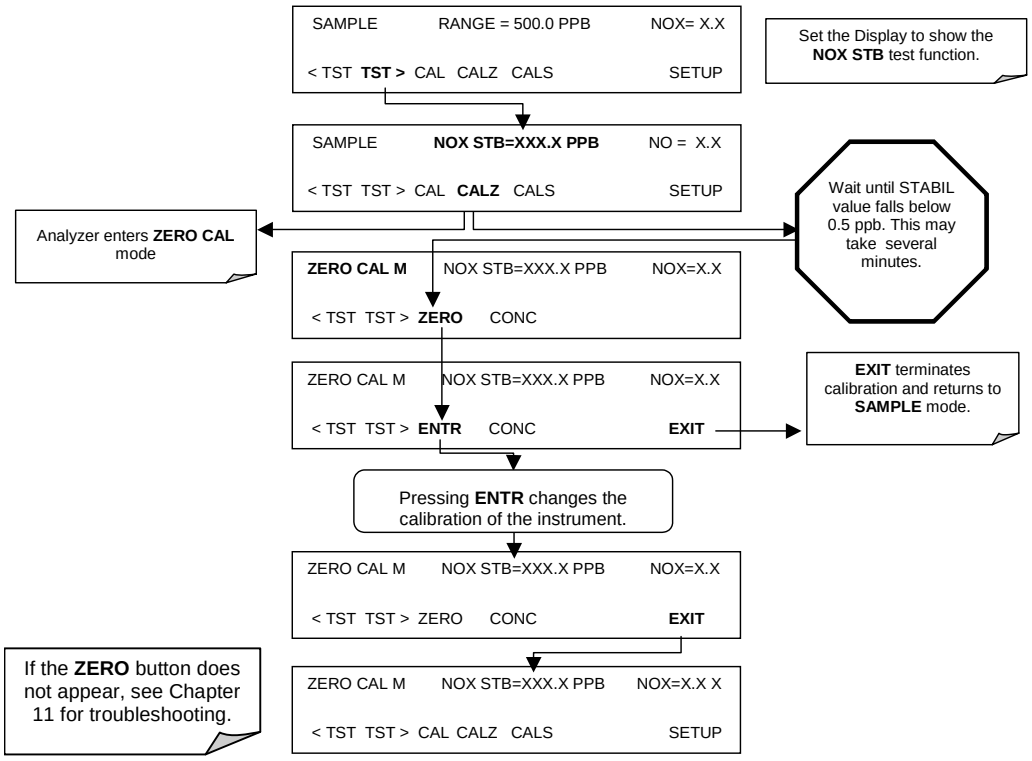


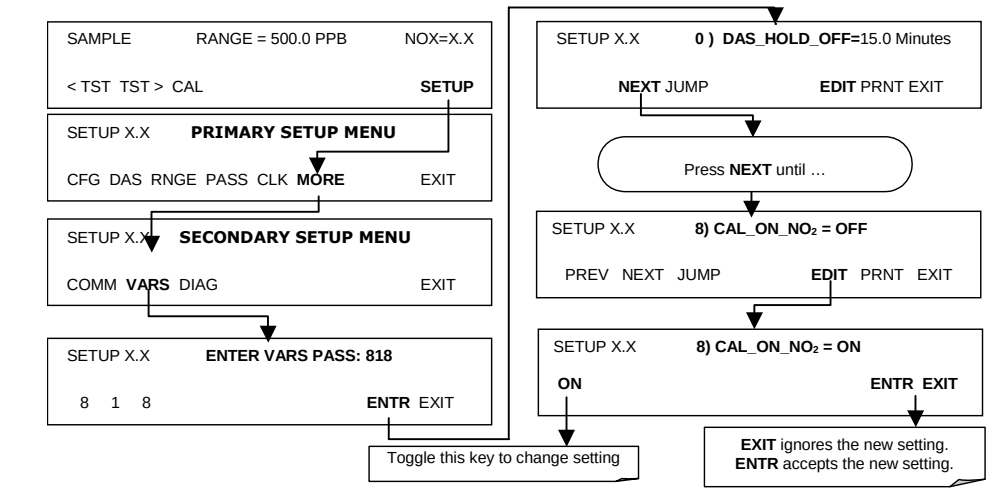
Figure 7-3: Pneumatic Connections for Manual Calibration Checks with IZS

Set the expected NO and NO_X values according to Section 7.2.

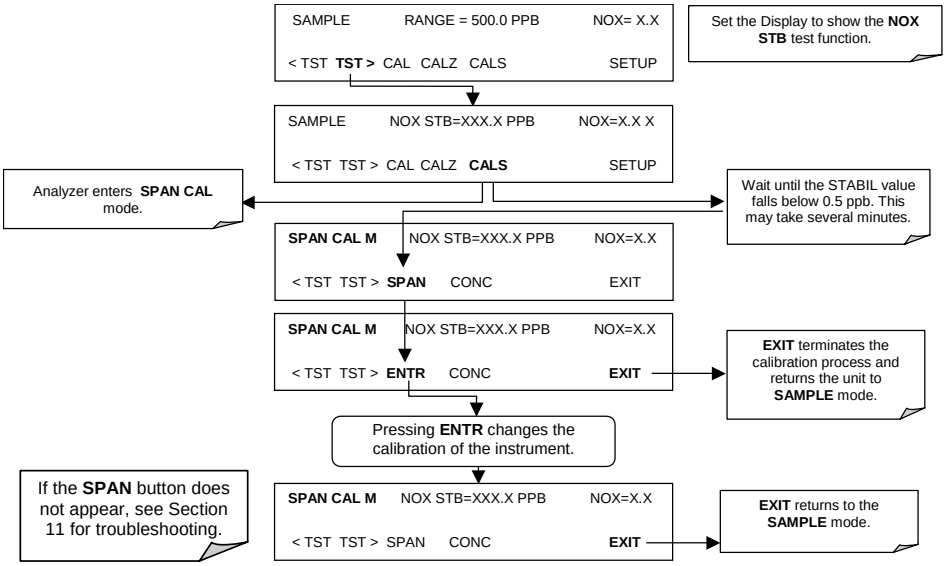
Perform the zero point calibration:



Turn ON the CAL_ON_NO_2 feature:



Perform the span calibration procedure:



Turn off the **CAL_ON_NO2** feature (step four above).

7.6. Calibration Checks with IZS or Zero/Span Valves

To perform a manual calibration check with zero/span valve or IZS option installed:

- Connect the sources of Zero Air and Span Gas as shown below.

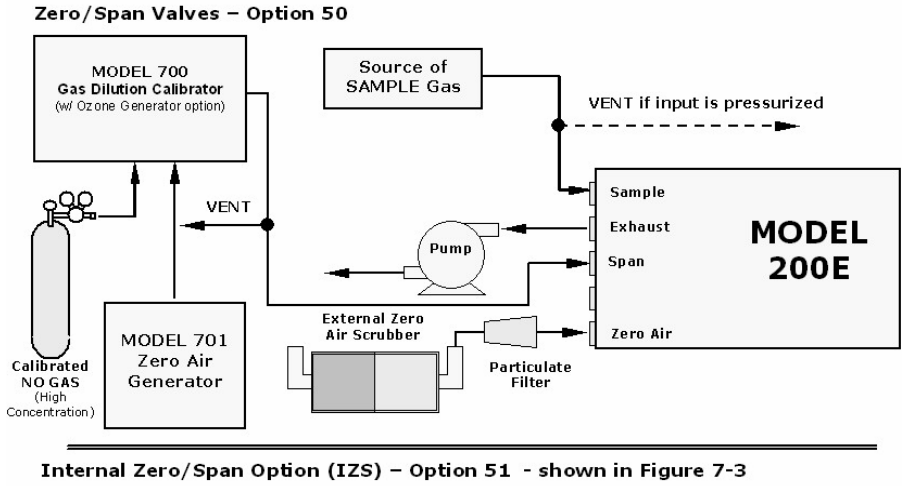


Figure 7-4: Setup for Manual Calibration Check with Z/S Valve or IZS Option

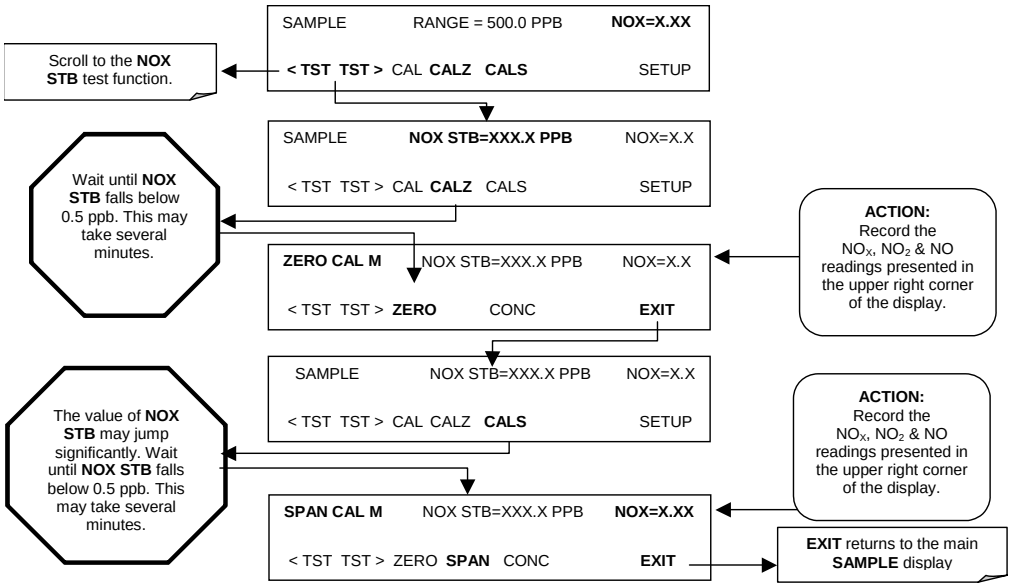
- Perform the zero/span check. Zero and span checks using the zero/span valve or IZS option are similar to that described in Section 7.3, except:

On units with an IZS option installed, zero air is supplied to the analyzer through the zero gas inlet and the same gas stream is used to create span gas internally using the permeation device.

On units with a zero/span valve option installed, zero air and span gas are supplied to the analyzer through the zero gas and span gas inlets from two different sources.

The zero and calibration operations are initiated directly and independently with dedicated keys **CALZ and CALS**.

Note that there is no option to use a dedicated span gas port if the IZS option is installed. Span gas from a gas tank would need to be supplied through the Sample port or through one of the auxiliary ports available on the rear panel (with modified internal plumbing), although the user could modify the plumbing to have the span gas go through the IZS oven (without the permeation tube installed).

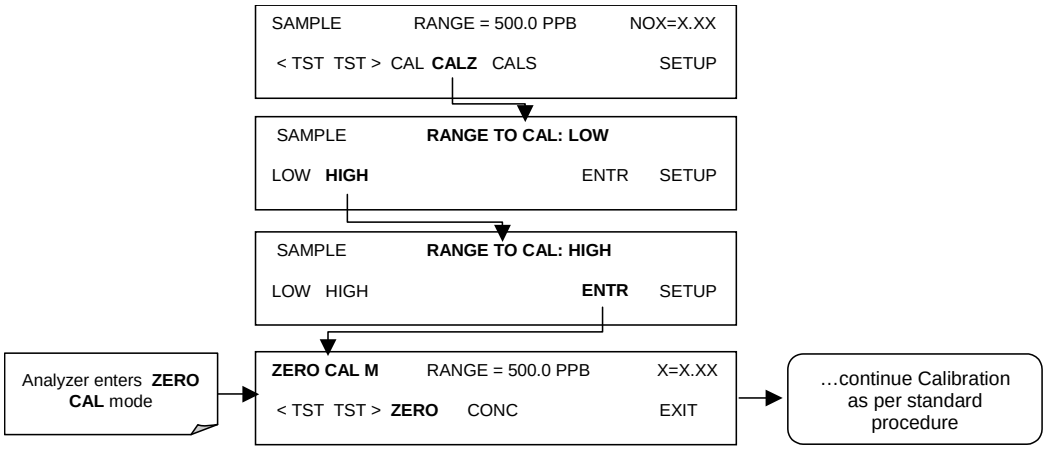


7.7. Calibration With Independent or AUTO Ranges

Additional considerations apply when calibrating a Model 9110E with reporting ranges set to **AUTO** (automatic) or **IND** (independent) mode (Sections 6.5.4 and 6.5.5).

7.7.1. Calibration in AUTO Range Mode

If the analyzer is operated in **AUTO** range mode, the high and low ranges must be independently calibrated. After pressing the **CAL**, **CALZ** or **CALS** keys, the user is prompted for the range to be calibrated as seen in the zero calibration example below.



Once this selection is made, the calibration/check procedure continues as described in Sections 7.2 through 7.6. The other range may be calibrated by starting over from the main **SAMPLE** display.

7.7.2. Independent Range Mode

Independent range mode is described in Section 6.5.4. When selecting span gas concentrations for the NO/NO_X or NO_2 dynamic calibrations, use concentrations around 80% of the highest reporting range for all gases. This will produce the most accurate calibration.

The span calibration routine is only required to be performed once, unlike AUTO range mode, which requires separate **HIGH** and **LOW** range calibrations. If the calibration data are obtained from the RS-232 port or from the front panel display, no special changes are necessary as the **IND** range mode only affects the scaling of the analog outputs.

7.7.3. Calibration With Remote Contact Closures

Contact closures for controlling calibration and calibration checks are located on the rear panel **CONTROL IN** connector. Instructions for setup and use of these contacts can be found in Section 6.8.2.

When the appropriate contacts are closed for at least 5 seconds, the instrument switches into zero, low span or high span mode and internal zero/span valves (if installed) will be automatically switched to the appropriate configuration. The remote calibration contact closures may be activated in any order. It is recommended that contact closures remain closed for at least 10 minutes to establish a reliable reading; the instrument will stay in the selected mode for as long as the contacts remain closed.

If contact closures are used in conjunction with the analyzer's AutoCal (Section 7.8) feature and the AutoCal attribute **CALIBRATE** is enabled, the M9110E will not re-calibrate the analyzer until the contact is opened. At this point, the new calibration values will be recorded before the instrument returns to SAMPLE mode. If the AutoCal attribute **CALIBRATE** is disabled, the instrument will return to SAMPLE mode, leaving the instrument's internal calibration variables unchanged.

7.8. Automatic Calibration (AutoCal)

The AutoCal feature allows unattended, periodic operation of the zero/span valve options by using the analyzer's internal time of day clock. The AutoCal feature is only available on the front panel menu (**ACAL**) if either the zero/span valve or the IZS option is installed.

AutoCal operates by executing user-defined sequences to initiate the various calibration modes of the analyzer and to open and close valves appropriately. It is possible to program and run up to three separate sequences (**SEQ1**, **SEQ2** and **SEQ3**). Each sequence can operate in one of three modes or be disabled (Table 7-2).

Table 7-2: AutoCal Modes

Mode	Action
Disabled	Disables the sequence
Zero	Causes the sequence to perform a zero calibration or check
Zero-Span	Causes the sequence to perform a zero calibration or check followed by a span concentration calibration or check
Span	Causes the sequence to perform a span concentration calibration or check

Each mode has seven parameters that control operational details of the sequence (Table 7-3).

Table 7-3: AutoCal Attribute Setup Parameters

Parameter	Action
Timer Enabled	Turns on the sequence timer
Starting Date	Sequence will operate on **Starting Date**
Starting Time	Sequence will operate at **Starting Time**
Delta Days	Number of days between each sequence trigger. If set to 7, for example, the AutoCal feature will be enabled once every week on the same day.
Delta Time	Incremental delay on each delta day that the sequence starts. If set to 0, the sequence will start at the same time each day. **Delta Time** is added to **Delta Days** for the total time between cycles. This parameter prevents the analyzer from being calibrated at the same daytime of each calibration day and prevents a lack of data for one particular daytime on the days of calibration.
Duration	Duration of the each sequence step in minutes. This parameter needs to be set such that there is enough time for the concentration signal to stabilize. The STABIL parameter shows if the analyzer response is stable at the end of the calibration. This parameter is logged with calibration values in the iDAS.
Calibrate	Enable to do a true, dynamic zero or span calibration; disable to do a calibration *check* only. This setting must be OFF for analyzers used in US EPA applications and with IZS option installed.
RANGE TO CAL	LOW calibrates the low range, HIGH calibrates the high range. Applies only to auto and remote range modes; this property is not available in single and independent range modes.

NOTE
The CALIBRATE attribute (formerly called "dynamic calibration") must always be set to OFF for analyzers used in US EPA controlled applications that have IZS option installed.

Calibration of instruments used in US EPA related applications should only be performed using external sources of zero air and span gas with an accuracy traceable to EPA or NIST standards and supplied through the analyzer's sample port (Section 7.2).

The following example sets sequence #2 to carry out a zero-span calibration every other day starting at 14:00 on 01 January, 2003, lasting 30 minutes (15 for zero and 15 for span). This sequence will start 30 minutes later each day.

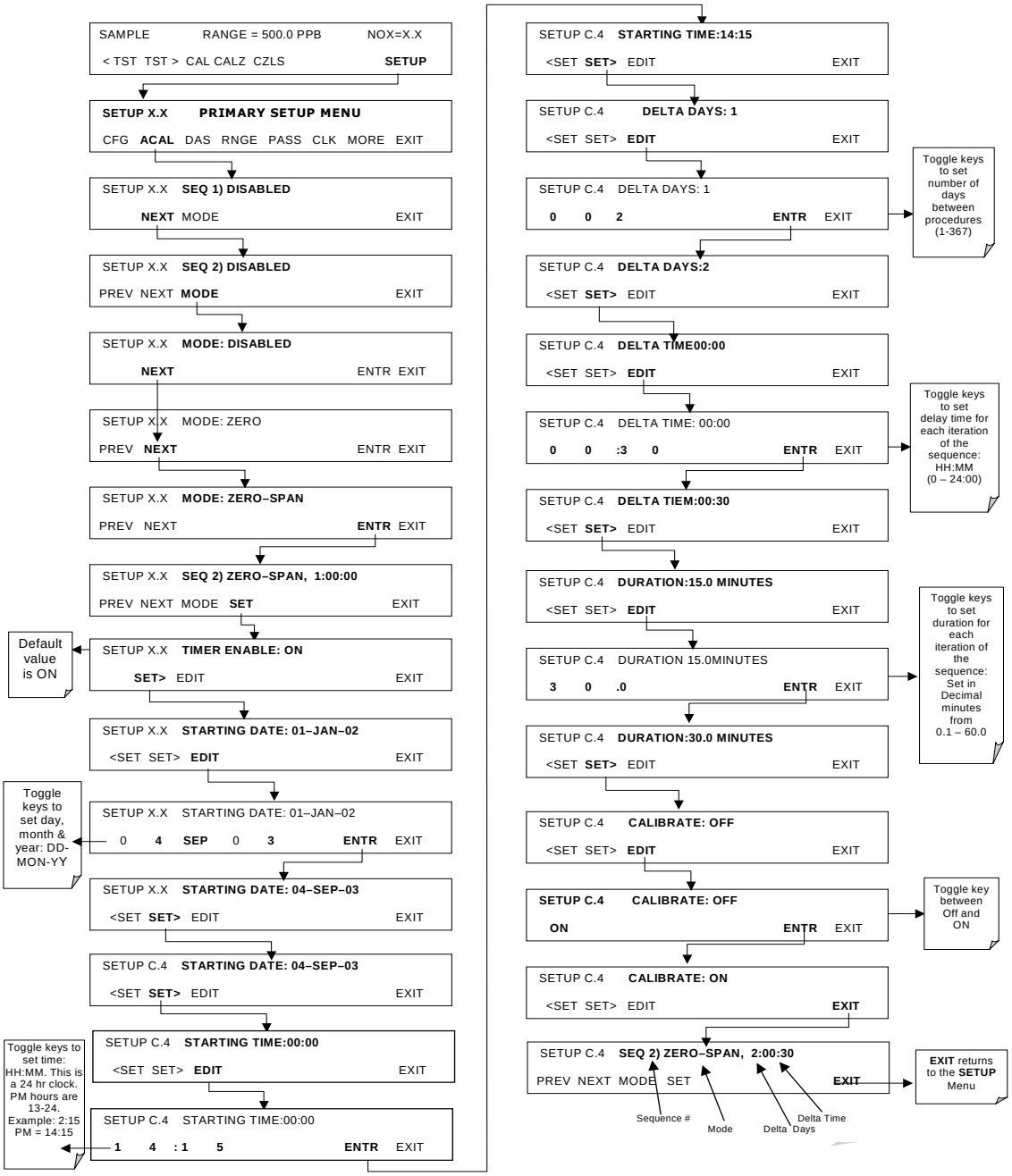
Table 7-4: Example Auto-Cal Sequence

Mode and Attribute	Value	Comment
Sequence	2	Define sequence #2
Mode	ZERO-SPAN	Select zero and span mode
Timer Enable	ON	Enable the timer
Starting Date	01-JAN-03	Start on or after 01 January 2003
Starting Time	14:00	First sequence starts at 14:00 (24-hour clock format)
Delta Days	2	Repeat this sequence every 2 days
Delta Time	00:30	Repeat sequence 30 minutes later each time (every 2 days and 30 minutes)
Duration	15.0	Each sequence step will last 15 minutes (total of 30 minutes when using zero-span mode)
Calibrate	ON	The instrument will recalculate the slope and offset values for the NO and NOX channel at the end of the AutoCal sequence.

Please note the following suggestions for programming the AutoCal feature.

- The programmed **Starting Time** must be 5 minutes later than the real time clock (Section 6.4.3).
- Avoid setting two or more sequences at the same time of the day. Any new sequence which is initiated from a timer, the COM ports, or the contact closures will override any sequence in progress. Note that two sequences with different daily increments may eventually overlap.
- If at any time an illegal entry is selected, (for example: Delta Days > 366) the ENTR key will disappear from the display.
- With **CALIBRATE** turned on, the state of the internal setup variables **DYN_SPAN** and **DYN_ZERO** is set to **ON** and the instrument will reset the slope and offset values for the NO and NO_X response each time the AutoCal program runs. This continuous re-adjustment of calibration parameters can often mask subtle fault conditions in the analyzer. It is recommended that, if **CALIBRATE** is enabled, the analyzer's test functions, slope and offset values be checked frequently to assure high quality and accurate data from the instrument.

To program the sample sequence shown above, follow this flow chart:



7.9. Calibration Quality Analysis

After completing one of the calibration procedures described above, it is important to evaluate the analyzer's calibration **SLOPE** and **OFFSET** parameters. These values describe the linear response curve of the analyzer, separately for NO and NO_X. The values for these

terms, both individually and relative to each other, indicate the quality of the calibration. To perform this quality evaluation, you will need to record the values of the following test functions (Section 6.2.1 or Appendix A-3), all of which are automatically stored in the iDAS channel **CALDAT** for data analysis, documentation and archival.

- **NO OFFS**
- **NO SLOPE**
- **NOX OFFS**
- **NOX SLOPE**

Make sure that these parameters are within the limits listed in Table 7-5 and frequently compare them to those values on the *Final Test and Checkout Sheet* that came attached to your manual, which should not be significantly different. If they are, refer to the trouble-shooting Chapter 11.

Table 7-5: Calibration Data Quality Evaluation

Function	Minimum Value	Optimum Value	Maximum Value
NOX SLOPE	-0.700	1.000	1.300
NO SLOPE	-0.700	1.000	1.300
NOX OFFS	-20.0 mV	0.0 mV	150.0 mV
NO OFFS	-20.0 mV	0.0 mV	150.0 mV

The default iDAS configuration records all calibration values in channel CALDAT as well as all calibration check (zero and span) values in its internal memory. Up to 200 data points are stored for up 4 years of data (on weekly calibration checks) and a lifetime history of monthly calibrations. Review these data to see if the zero and span responses change over time. These channels also store the STABIL figure (standard deviation of NO_X concentration) to evaluate if the analyzer response has properly leveled off during the calibration procedure. Finally, the CALDAT channel also stores the converter efficiency for review and documentation.

USER NOTES:

8. EPA PROTOCOL CALIBRATION

To ensure high quality, accurate measurements at all times, the M9110E analyzer must be calibrated prior to use. A quality assurance program centered on this aspect and including attention to the built-in warning features of the analyzer, periodic inspection, regular zero/span checks, regular evaluation of test parameters for predictive diagnostics and data analysis and routine maintenance of the instrument are paramount to achieving this goal.

The US EPA strongly recommends to obtain a copy of the *Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Part I* (abbreviated *Q.A. Handbook Volume II*). A new revision of this handbook is in progress[8]. A draft version of Section 2.3 can be downloaded online[8] and should be consulted as the latest reference about NO_2 measurements.

Special attention should be paid to Section 2.3 of the handbook[8] which covers the measurement of NO_2. Specific regulations regarding the use and operation of ambient NO_x analyzers can be found in Reference 1 at the end of this chapter.

If the M9110E is used for EPA compliance monitoring, it must be calibrated in accordance with the instructions in this section.

8.1. Calibration of Equipment

In general, calibration is the process of adjusting the gain and offset of the M9110E against a standard with certified, traceable concentration. The reliability of data derived from the analyzer depends primarily upon its state of calibration. In this section the term *dynamic calibration* is used to express a multipoint calibration against known standards. It involves introducing gas samples of known concentration into the instrument in order to adjust the instrument to a predetermined sensitivity and to produce a calibration relationship. This relationship is derived from the instrumental response to successive samples of different, known concentrations. As a minimum, three reference points and a zero point are recommended to define this relationship. The true values of the calibration gas must be traceable to NIST-SRM (Section 2.0.7, Q.A. Handbook).

All monitoring systems are subject to some drift and variation in internal parameters and cannot be expected to maintain accurate calibration over long periods of time. Therefore, it is necessary to dynamically check the calibration relationship on a predetermined schedule. Zero and span checks must be used to document that the data remain within control limits. These checks are also used in data reduction and validation. The internal data acquisition system of the M9110E allows to store all calibration checks (as well as full calibrations) over long periods of time for documentation. Table 8-1 summarizes the initial quality assurance activities for calibrating equipment. Table 8-2 is a matrix for the actual, dynamic calibration procedure.

Calibrations should be carried out at the field monitoring site. The analyzer should be in operation for at least several hours (preferably overnight) before calibration so that it is fully warmed up and its operation has stabilized. During the calibration, the M9110E should be in the CAL mode, and therefore sample the test atmosphere through all components used during normal ambient sampling and through as much of the ambient air inlet system as is practicable. If the instrument will be used on more than one range, it should be calibrated separately on each applicable range, see Section 6.6. Calibration documentation should be maintained with each analyzer and also in a central backup file.

Table 8-1: Activity Matrix for EPA Calibration Equipment and Supplies

Equipment/ Supplies	Acceptance Limits	Frequency And Method Of Measurement	Action If Requirements Are Not Met
Recorder	Compatible with output signal of analyzer; min chart width of 150 mm (6 in) is recommended	Check upon receipt	Return equipment to supplier
Sample line and manifold	Constructed of PTFE, glass or stainless steel	Check upon receipt	Return equipment to supplier
Calibration equipment	Meets guidelines and Section 2.3.2 of Q. A. Handbook	See Section 2.3.9 of Q. A. Handbook	Return equipment/ supplies to supplier or take corrective action
Working standard NO cylinder gas	Traceable to NIST-SRM. Meets limits in traceability protocol for accuracy and stability. Section 2.0.7 of Q. A. Handbook	Analyzed against NIST-SRM; see protocol in Section 2.0.7, Q.A. Handbook	Obtain new working standard and check for traceability
Recording forms	Develop standard forms	N/A	Revise forms as appropriate
Audit equipment	Cannot be the same as used for calibration	System must be checked out against known standards	Locate problem and correct or return to supplier

Table 8-2: Activity Matrix for Calibration Procedure

Equipment/ Supplies	Acceptance Limits	Frequency And Method Of Measurement	Action If Requirements Are Not Met
Calibration gases	Sec. 2.0.7, Q.A. Handbook	Assayed against an NIST-SRM quarterly, Sec. 2.0.7 (Q.A. Handbook)	Working gas standard is unstable, and/or measurement method is out of control; take corrective action such as obtaining new calibration gas
Dilution gas	Zero air, free of contaminants; TAD[2] and Sec. 2.0.7, Subsec. 7.1, Q.A. Handbook	See TAD[2]	Return to supplier or take appropriate action with generation system
Multi-point calibration (GPT)	t_R < 2 minutes P_R > 2.75 ppm/min Use calibration procedure in Q.A Handbook; also CFR[1] Converter efficiency > 96%	Method: Section 7.2 of this manual) CFR Title 40[1], Appendix F	Adjust flow conditions and/or reaction cell volume to meet suggested limits Repeat the calibration Replace or service the converter

8.2. Gas Phase Titration (GPT)

8.2.1. GPT Principle of Operation

Gas phase titration (GPT) is recommended for calibration of the M9110E. Those using a NO_2 permeation tube should refer to the CFR[1].

The principle of GPT is based on the rapid gas phase reaction between NO and O_3 which produces stoichiometric quantities of NO_2 as shown by the following equation:

$$NO + O_3 \longrightarrow NO_2 + O_2 + h\nu$$

Given that the O_3 concentration is known for this reaction, the resultant concentration of NO_2 can be determined. Ozone is added to excess NO in a dynamic calibration system as shown in Figure 8-1, and the NO channel of the chemiluminescence analyzer detects the changes in NO concentration. After the addition of O_3, the observed decrease in NO concentration on the calibrated NO channel is equivalent to the concentration of NO_2 produced. The amount of generated NO_2 may be varied by adding varying amounts of O_3 from a stable O_3 generator. All zero air used in this procedure should conform to the requirements stated in Section 8.1 of this manual.

Dynamic calibration systems based on this principle are commercially available, or may be assembled by the user. A recommended calibration system is described in the Federal Register[1] CFR[1].

8.2.2. GPT Calibrator Check Procedure

It has been empirically determined that the NO-O_3 reaction is complete (<1% residual O_3) if the NO concentration in the reaction cell (ppm) multiplied by the residence time (min.) of the reactants in the chamber is >2.75 ppm min. The theory behind the development of this equation is in the Federal Register[1]. The following procedures and equations should be used to determine whether an existing GPT calibration system will meet required conditions for a specific calibration.

For calibrators that have known pre-set flow rates, use equations 8-5 and 8-6 of steps 7 and 8 (below) to verify the required conditions. If the calibrator does not meet specifications, follow the complete procedure to determine what flow modifications must be made.

Select an NO standard gas that has a nominal concentration in the range of 50 to 100 ppm. Determine the exact concentration $[NO]_{STD}$ by referencing against an NIST-SRM, as discussed in the Q.A. Handbook.

Determine the volume (cm^3) of the calibrator reaction cell (V_{RC}). If the actual volume is not known, estimate the volume by measuring the approximate dimensions of the chamber and using an appropriate formula.

Determine the required minimum total flow output (F_T) using Equation 8-1:

F_T = analyzer flow demand (cm^3/min) x 110/100 **Eq 8-1**

If more than one analyzer is to be calibrated at the same time, multiply F_T by the number of analyzers.

Calculate the NO concentration $[NO]_{OUT}$ needed to approximate 90% of the URL of the NO_2 analyzer to be calibrated, using Equation 8-2:

$$[NO]_{OUT} = \text{URL of analyzer (ppm)} \times 90/100 \qquad \textbf{Eq 8-2}$$

Calculate the NO flow (F_{NO}) required to generate the NO concentration $[NO]_{OUT}$, using Equation 8-3:

$$F_{NO} = \frac{[NO]_{OUT} \, x \, F_T}{[NO]_{STD}} \qquad \textbf{Eq 8-}3$$

Calculate the required flow through the ozone generator (F_O), using Equation 8-4:

$$F_o = \sqrt{\frac{[NO]_{STD} \, X \, F_{NO} \, X \, V_{RC}}{2.75 \; ppm - min}} - F_{NO} \qquad \textbf{Eq 8-4}$$

Verify that the residence time (t_R) in the reaction cell is <2 min, using Equation 8-5:

$$t_R = \frac{V_{RC}}{F_O + F_{NO}} \leq 2 \, min \qquad \textbf{Eq 8-5}$$

Verify that the dynamic parameter specification (P_R) of the calibrator's reaction cell is >2.75 ppm-min using Equation 8-6:

$$P_R = [NO]_{STD} \times \frac{F_{NO}}{F_O + F_{NO}} \times \frac{V_{RC}}{F_O + F_{NO}} \geq 2.75 \qquad \textbf{Eq 8-6}$$

NOTE
If t_r is >2 minutes or if P_R is <2.75 ppm min, changes in flow conditions (F_T, F_O, F_{NO}) or in the reaction cell volume (V_{RC}), or both will have to be made, and t_r and P_R will have to be recalculated.

After equations 8-5 and 8-6 are satisfied, calculate the diluent air flow (F_D) using Equation 8-7:

$$F_D = F_T - F_O - F_{NO} \qquad \textbf{Eq 8-7}$$

8.2.3. Example GPT Calculation

Following is an example calculation that can be used to determine whether an existing GPT calibrator will meet the required conditions for a specific calibration. For this example, it is

assumed that only the volume of the reaction cell, V_{RC}, and the concentration of the NO standard, $[NO]_{STD}$, are known. All flow settings (F_{NO}, F_O, F_T, and F_D) will be calculated. In many uses, these flow settings are known and need only to be substituted in Equations 8-5 and 8-6 to verify the required conditions. Before doing any calculations, the URL and flow demand of the analyzer being calibrated must be known. Operating parameters are determined from the operations manual:

- Upper range limit = 0.5 ppm, and
- Flow demand = 500 cm^3/min.
- Volume of calibrator reaction cell is determined by physical measurement: V_{RC} = 180 cm^3
- The concentration of the NO standard gas to be used is determined by reference against an NIST-SRM (Section 2.0.7, Q.A. Handbook): $[NO]_{STD}$ = 50.5 ppm

Determine the minimum total flow (F_T) required at the output manifold using Equation 8-1:

$$F_T = 500\ cm^3/min\ (110/100) = 550\ cm^3/min$$

Because low flows are difficult to control and measure, it is often advantageous to set a higher total flow than needed. In this example, we will set F_T to 2750 cm^3/min.

Determine the highest NO concentration, $[NO]_{OUT}$, required at the output manifold, using Equation 8-2:

$$[NO]_{OUT} = 0.5\ ppm\ (90/100) = 0.45\ ppm$$

Calculate the NO flow (F_{NO}) required to generate the NO concentration $[NO]_{OUT}$, using Equation 8-3:

$$F_{NO} = \frac{0.45\,ppm \times 2750\,cm^3/min}{50.5\,ppm} = 24.5\,cm^3/min$$

Calculate the required flow rate through ozone generator (F_O) using Equation 8-4:

$$F_O = \sqrt{\frac{50.5\ ppm\ x\ 24.5\,cm^3/min\ x\ 180\,cm^3}{2.75\ ppm - min}} - 24.5\,cm^3/min$$

$$= \sqrt{80984\,cm^6/min^2} - 24.5\,cm^3/min = 260\ cm^3/min$$

Verify that the residence time (t_R) in the reaction cell is <2 min using Equation 8-5:

$$t_R = \frac{180\,cm^3}{260\,cm^3/min + 24.5\,cm^3/min} = 0.63\,min$$

Verify the dynamic parameter specification (P_R) of the calibrator reaction cell using Equation 8-6:

$$P_R = 50.5\,ppm \times \frac{24\,cm^3/min}{260\,cm^3/min + 24.5\,cm^3/min} \times \frac{180\,cm^3}{260\,cm^3/min + 24.5\,cm^3/min} = 2.75\,ppm - min$$

Calculate the diluent air flow (F_D) required at the mixing chamber, using Equation 8-7:

$$F_D = 2750\ cm^3/min - 260\ cm^3/min - 24.5\ cm^3/min = 2465.5\ cm^3/min$$

8.3. Multipoint Calibration Procedure

The procedure for calibration of chemiluminescence NO_x analyzers by GPT is specified in the Federal Register.[1] This section applies the general procedure to the specific case of the M9110E.

Calibration must be performed with a calibrator that meets all conditions specified in the Q.A. Handbook. Flow settings used in the GPT calibration for NO_2 must be determined as illustrated in Section 3.6, this manual.

The user should be sure that all flow meters are calibrated under the conditions of use against a reliable standard. All volumetric flow rates should be corrected to 25° C (78°F) and 760 mm (29.92 in.) Hg. Calibrations of flow meters are discussed in the QA Handbook, Vol. II, Part 1, Appendix 12[6].

Gas Phase Titration (GPT) requires the use of the NO channel of the analyzer to determine the amount of NO_2 generated by titration. Therefore it is necessary to calibrate and determine the linearity of the NO channel before proceeding with the NO_2 calibration. It is also necessary to calibrate the NO_x channel. This can be done simultaneously with the NO calibration. During the calibration the M9110E should be operating in its normal sampling mode, and the test atmosphere should pass through all filters, scrubbers, conditioners, and other components used during normal ambient sampling and as much of the ambient air inlet system as is practicable. All operational adjustments to the M9110E should be completed prior to the calibration. The following software features must be set into the desired state before calibration.

- Automatic converter efficiency compensation. See Section 7.1.7 of this manual.
- Independent reporting range selection. See Section 6.5.4 of this manual.
- Automatic temperature/pressure compensation. See Section 6.5.
- Alternate units, make sure ppb units are selected for EPA monitoring. See Section 6.5.6.
- Auto ranging reporting range option. See Section 6.5.5.

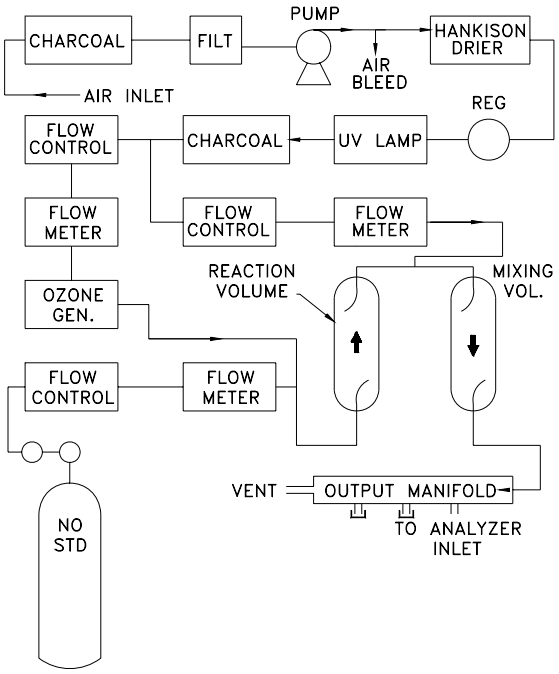


Figure 8-1: GPT Calibration System

Converter efficiency should be set prior to calibration since its value is used in the computation of the NO_X and NO_2 concentration outputs.

The analyzer should be calibrated on the same range used for monitoring.

If auto ranging or independent range options are selected the highest of the ranges will result in the most accurate calibration, and should be used.

Make sure the GPT calibration system can supply the range of concentrations at a sufficient flow over the whole range of concentrations that will be encountered during calibration.

8.3.1. Zero Calibration

The zero point calibration procedure is identical to that described in Sections 7.2, 7.4 or 7.5 of this manual.

8.3.2. Span Calibration

Adjust the NO concentration to approximately 80% of the URL of the NO channel. The expected NO and NO_X span concentrations can be determined by measuring the cylinder and diluent flows and computing the resulting concentrations. If there is any NO_2 impurity in the NO standard gas it should be taken into account when the NO_X concentration is entered during the NO/NO_X channel calibration. This is done by ADDING the impurity concentration to the NO concentration to get the NO_X concentration for calibration. Calculate the exact NO and NO_X concentrations as follows:

$$[NO]_{OUT} = \frac{F_{NO} \, x \, [NO]_{STD}}{F_T} \qquad \textbf{Eq 8-8}$$

Enter the respective concentrations using the procedure in Section 7.2. The expected span concentrations need not be re-entered each time a calibration is performed unless they are changed.

- Enter the expected NO_X and NO span gas concentrations:
- Sample the generated concentration until the NO and the NO_X responses have stabilized.
- Span the instrument by the following the same method as Sections 7.2, 7.4 or 7.5:

The analog voltage output should measure 80% of the voltage range selected. (e.g. 4.00 VDC if 0-5V output is selected.) The readings on the front panel display should be equal to the expected NO and NO_X concentrations entered in the procedure given in Sections 7.2, 7.4 or 7.5 above. See the Troubleshooting Chapter 11 if there are problems. Also see the Calibration Quality Check procedure Section 7.9.

After the zero and the 80% URL points have been set, generate five approximately evenly spaced calibration points between zero and 80% URL without further adjustment to the instrument. Allow the instrument to sample these intermediate concentrations for about 10 minutes each and record the instrument NO and NO_X responses.

Plot the analyzer NO and NO_X responses versus the corresponding calculated concentrations to obtain the calibration relationships. Determine the straight line of best fit (y = mx + b) determined by the method of least squares.

After the best-fit line has been drawn for the NO and the NO_X calibrations, determine whether the analyzer response is linear. To be considered linear, no calibration point should differ from the best-fit line by more than 2% of full scale.

8.3.3. GPT NO_2 Calibration

The M9110E computes the NO_2 concentration by subtracting the NO from the NO_X concentration. Unlike analog instruments, this difference is calculated by the M9110E's internal computer software. It is extremely unlikely that the NO_2 concentration will be in error. Therefore this procedure is a confirmation that the NO_2 subtraction algorithm in the computer is operating correctly.

NOTE
Do not make any adjustments to the instrument during this procedure.

Generate an NO concentration near 90% of the URL. Dilution air and O_3 generator air flows should be the same as used in the calculation of specified conditions of the dynamic parameter according to Section 8.2. Sample this NO concentration until the NO and NO_X responses stabilize. Record the NO and NO_x concentrations.

Second, turn on and adjust the O_3 generator in the calibrator to produce sufficient O_3 to decrease the NO concentration to about 10% of full scale. This will be equivalent to 80% of the URL of the NO_2 channel. After the analyzer responses stabilize, record the resultant NO, NO_X, and NO_2 concentrations.

NO_2 CONVERTER EFFICIENCY

if the NO_X reading should drop to less than 96% of its starting value during this step, it indicates the NO_2 converter is in need of troubleshooting or replacement. See Chapter 11 for further details.

While maintaining all other conditions, adjust the ozone generator to obtain several other concentrations of NO_2 evenly spaced between the 80% URL point and the zero point. Record the NO, NO_X, and NO_2 concentrations for each additional point.

Calculate the resulting NO_2 concentrations as follows:

$$[NO_2]_{OUT} = [NO]_{ORIG} - [NO]_{REM} + \frac{F_{NO} * [NO_2]_{IMP}}{F_T} \qquad \textbf{Eq 8-9}$$

Where $[NO]_{ORIG}$ is the NO concentration before the GPT ozone is turned on, and $[NO]_{REM}$ is the NO remaining after GPT.

Plot the NO_2 concentration output by the instrument on the y-axis against the generated NO_2 $[NO_2]_{OUT}$ on the x-axis. The plot should be a straight line within the ± 2% linearity criteria given for the NO_x and NO channels. If the plot is not linear the most likely cause is that the converter needs replacing. See Section 7.1.7 on NO_2 converter efficiency.

8.4. Calibration Frequency

To ensure accurate measurements of the NO, NO_X, and NO_2 concentrations, calibrate the analyzer at the time of installation, and re-calibrate it:

- No later than three months after the most recent calibration or performance audit which indicated analyzer calibration to be acceptable.
- An interruption of more than a few days in analyzer operation.
- Any repairs which might affect its calibration.
- Physical relocation of the analyzer.
- Any other indication (including excessive zero or span drift) of possible significant inaccuracy of the analyzer.

Following any of the activities listed above, the zero and span should be checked to determine if a calibration is necessary. If the analyzer zero and span drifts exceed the calibration limits in Section 12 of the Q.A. Handbook[6], a calibration should be performed.

8.5. Other Quality Assurance Procedures

Precision is determined by a one-point check at least once every two weeks. Accuracy is determined by a three-point audit once each quarter.

Essential to quality assurance are scheduled checks for verifying the operational status of the monitoring system. The operator should visit the site at least once each week. Every two weeks a Level 1 zero and span check must be made on the analyzer. Level 2 zero and span checks should be conducted at a frequency desired by the user. Definitions of these terms are given in Table 8-3.

Table 8-3: Definition of Level 1 and Level 2 Zero and Span Checks

LEVEL 1 ZERO AND SPAN CALIBRATION	LEVEL 2 ZERO AND SPAN CHECK
A Level 1 zero and span calibration is a simplified, two-point analyzer calibration used when analyzer linearity does not need to be checked or verified. (Sometimes when no adjustments are made to the analyzer, the Level 1 calibration may be called a zero/span check, in which case it must not be confused with a Level 2 zero/span check.) Since most analyzers have a reliably linear or near-linear output response with concentration, they can be adequately calibrated with only two concentration standards (two-point concentration). Furthermore, one of the standards may be zero concentration, which is relatively easily obtained and need not be certified. Hence, only one certified concentration standard is needed for the two-point (Level 1) zero and span calibration. Although lacking the advantages of the multipoint calibration, the two-point zero and span calibration--because of its simplicity--can be (and should be) carried out much more frequently. Also, two-point calibrations are easily automated. Frequency checks or updating of the calibration relationship with a two-point zero and span calibration improves the quality of the monitoring data by helping to keep the calibration relationship more closely matched to any changes (drifts) in the analyzer response.	A Level 2 zero and span check is an "unofficial" check of an analyzer's response. It may include dynamic checks made with uncertified test concentrations, artificial stimulation of the analyzer's detector, electronic or other types of checks of a portion of the analyzer, etc. Level 2 zero and span checks are not to be used as a basis for analyzer zero or span adjustments, calibration updates, or adjustment of ambient data. They are intended as quick, convenient checks to be used between zero and span calibrations to check for possible analyzer malfunction or calibration drift. Whenever a Level 2 zero or span check indicates a possible calibration problem, a Level 1 zero and span (or multipoint) calibration should be carried out before any corrective action is taken. If a Level 2 zero and span check is to be used in the quality control program, a "reference response" for the check should be obtained immediately following a zero and span (or multipoint) calibration while the analyzer's calibration is accurately known. Subsequent Level 2 check responses should then be compared to the most recent reference response to determine if a change in response has occurred. For automatic Level 2 zero and span checks, the first scheduled check following the calibration should be used for the reference response. It should be kept in mind that any Level 2 check that involves only part of the analyzer's system cannot provide information about the portions of the system not checked and therefore cannot be used as a verification of the overall analyzer calibration.

In addition, an independent precision check between 0.08 and 0.10 ppm must be carried out at least once every two weeks. Table 8-4 summarizes the quality assurance activities for routine operations. A discussion of each activity appears in the following sections.

To provide for documentation and accountability of activities, a checklist should be compiled and then filled out by the field operator as each activity is completed.

For information on shelter and sample inlet system, an in-depth study is in Field Operations Guide for Automatic Air Monitoring Equipment, Publication No. APTD-0736, PB 202-249 and PB 204-650, U.S. Environmental Protection Agency, Office of Air Programs, October 1972.

8.6. Summary of Quality Assurance Checks

The following items should be checked on a regularly scheduled basis to assure high quality data from the M9110E. See Table 8-4 for a summary of activities; also the QA Handbook should be checked for specific procedures.

Table 8-4: Activity Matrix for Data Quality

Characteristic	Acceptance Limits	Frequency and Method of Measurement	Action if Requirements are not Met
Shelter temperature	Mean temperature between 22°C and 28°C (72° and 82° F), daily fluctuations not greater than ± 2°C	Check thermograph chart weekly for variations greater than ± 2°C (4°F)	Mark strip chart for the affected time period Repair or adjust temperature control
Sample introduction system	No moisture, foreign material, leaks, obstructions; sample line connected to manifold	Weekly visual inspection	Clean, repair, or replace as needed
Recorder	Adequate ink & paper Legible ink traces Correct chart speed and range Correct time	Weekly visual inspection	Replenish ink and paper supply Adjust time to agree with clock; note on chart
Analyzer operational settings	TEST measurements at nominal values M9110E in SAMPLE mode	Weekly visual inspection	Adjust or repair as needed
Analyzer operational check	Zero and span within tolerance limits as described in Section 12 of the Q.A. Handbook[6]	Level 1 zero/span every 2 weeks; Level 2 between Level 1 checks at frequency desired by user	Find source of error and repair After corrective action, re-calibrate analyzer
Precision check	Assess precision as described in Sections 15&18 of the Q.A. Handbook[6]	Every 2 weeks, Subsec. 3.4.3 (Ibid.)	Calc, report precision, Section 12 of the Q.A. Handbook[6]

8.7. Short Calibration Checks

A system of Level 1 and Level 2 zero/span checks (Table 8-3) is recommended. These checks must be conducted in accordance with the specific guidance given in Section 12 of the Q.A. Handbook[6]. Level 1 zero and span checks must be conducted every two weeks. Level 2 checks should be conducted in between the Level 1 checks at a frequency desired by the user. Span concentrations for both levels should be between 70 and 90% of the measurement range.

Zero and span data are to be used to:

- Provide data to allow analyzer adjustment for zero and span drift;
- Provide a decision point on when to calibrate the analyzer;
- Provide a decision point on invalidation of monitoring data.

These items are described in detail in Sections 15&18 of the Q.A. Handbook[6]. Refer to Chapter 11 of this manual if the instrument is not within the allowed margins. We recommend to use APICOM and the iDAS for analysis and documentation of zero/span check data.

8.7.1. Zero/Span Check Procedures

The Zero and span calibration can be checked in a variety of different ways. They include:

- Manual zero/span checks can be done from the front panel keyboard. The procedure is in Section 7.3 or 7.6 of this manual.

- Automatic zero/span checks can be performed every night. See Section 7.8 of this manual for setup and operation procedures.
- Zero/Span checks through remote contact closure can be initiated through remote contact closures on the rear panel. See Section 7.7.3 of this manual.
- Zero/span checks can also be controlled through the RS-232 port. See Section 6.9 of this manual for more details on setting up and using the analyzer's RS-232 port.

8.7.2. Precision Check

A periodic check is used to assess the data for precision. A one-point precision check must be carried out at least once every 2 weeks on each analyzer at an NO_2 concentration between 0.08 and 0.10 ppm. The analyzer must be operated in its normal sampling mode, and the precision test gas must pass through all filters, scrubbers, conditioners, and other components used during normal ambient sampling. The standards from which precision check test concentrations are obtained must be traceable to NIST-SRM. Those standards used for calibration or auditing may be used.

8.7.3. Precision Check Procedure

Connect the analyzer to a precision gas that has an NO_2 concentration between 0.08 and 0.10 ppm. An NO_2 precision gas may be generated by either GPT or a NO_2 permeation tube. If a precision check is made in conjunction with a zero/span check, it must be made prior to any zero or span adjustments.

- Allow the analyzer to sample the precision gas until a stable trace is obtained.
- Record this value. NO and NO_X precision checks should also be made if those data are being reported. Information from the check procedure is used to assess the precision of the monitoring data; see in Section 12 of the Q.A. Handbook[6] for procedures for calculating and reporting precision.

8.8. Certification of Working Standards

The NO content of the NO working standard must be periodically assayed against NIST-traceable NO or NO_2 standards. Any NO_2 impurity in the cylinder must also be assayed. Certification of the NO working standard should be made on a quarterly basis or more frequently, as required. Procedures are outlined below for certification against NO traceable standard which is the simplest and most straightforward procedure.

To assure data of desired quality, two considerations are essential:

- The measurement process must be in statistical control at the time of the measurement and;
- Any systematic errors, when combined with the random variation in the measurement process, must result in a suitably small uncertainty.

Evidence of good quality data includes documentation of the quality control checks and the independent audits of the measurement process by recording data on specific forms or on a quality control chart and by using materials, instruments, and measurement procedures that can be traced to appropriate standards of reference.

To establish traceability, data must be obtained routinely by repeated measurements of standard reference samples (primary, secondary, and/or working standards). More specifically, working calibration standards must be traceable to standards of higher accuracy.

8.8.1. Certification Procedures of Working Standards

This procedure requires the use of calibrated NO gas traceable to an NIST-SRM and the gas phase titration calibration procedure (Section 8.2) to calibrate the NO, NO_X, and NO_2 responses of the analyzer. Also the efficiency of the analyzer's NO_2 converter must be determined (Section 7.1.7).

Generate several NO concentrations by diluting the NO working standard. Use the nominal NO cylinder concentration, $[NO]_{NOM}$, to calculate the diluted concentrations. Plot the analyzer NO response (in ppm) versus the nominal diluted NO concentration and determine the slope, S_{NOM}. Calculate the NO concentration of the working standard $[NO]_{STD}$ from:

$$[NO]_{STD} = [NO]_{NOM} \times S_{NOM}$$

A more detailed procedure is presented in Reference 1.

8.8.1.1. Other Methods of Establishing Traceability

Methods of establishing traceability are:

- Using a NO working standard traced to NIST NO_2 standard
- Using a NO_2 working standard traced to NIST NO_2 standard
- Using a NO_2 working standard traced to NIST NO standard

NOTE
If the NO_2 impurity in the NO cylinder, $[NO_2]_{imp}$ is greater than the 1 ppm value allowed in the calibration procedure, check that the NO delivery system is not the source of contamination before discarding the NO standard.
For further information on calibration by GPT and NO_2 permeation devices, refer to part 50 of Chapter 1, Title 40 CFR, Appendix F Reference 13 of that Appendix.

8.9. References

1. Environmental Protection Agency, Title 40, Code of Federal Regulations, Part 50, Appendix F, Measurement Principle and Calibration Procedure for the Measurement of Nitrogen Dioxide in the Atmosphere (Gas Phase Chemiluminescence), Federal Register, 41 (232), 52688-52692, December 1976 (as amended at 48 FR 2529, Jan 20, 1983).

2. Ellis, Elizabeth C. Technical Assistance Document for the Chemiluminescence Measurement of Nitrogen Dioxide, U.S. Environmental Protection Agency, Research Triangle Park, NC. 83 pages, December 1975. Available online at http://www.epa.gov/ttn/amtic/files/ambient/criteria/reldocs/4-75-003.pdf.

3. Environmental Protection Agency, Title 40, Code of Federal Regulations, Part 58, Appendix A, Measurement Principle and Calibration Procedure for the Measurement of Nitrogen Dioxide in the Atmosphere (Gas Phase Chemiluminescence), Federal

Register, 41 (232), 52688-52692, December 1976 (as amended at 48 FR 2529, Jan 20, 1983).

4. Mavrodineanu, R., and Gills, T. E., Standard Reference Materials: Summary of Gas Cylinder and Permeation Tube Standard Reference Materials Issued by the National Bureau of Standards, Document SP260-108, May 1987.
   And: Taylor, J. K., Standard Reference Materials: Handbook for SRM Users, Document number SP260-100, February 1993. Available online at: http://patapsco.nist.gov/srmcatalog/sp_publications/publications.htm

5. Quality Assurance Handbook for Air Pollution Measurement Systems - Volume I, "A Field Guide to Environmental Quality Assurance," EPA-600/R-94/038a, April 1994. Available online at: http://www.epa.gov/ttn/amtic/qabook.html.

6. Quality Assurance Handbook for Air Pollution Measurement Systems - Volume II, Ambient Air Specific Methods. EPA-600/4-77/027a, December 1986. US EPA Order Number: 454R98004, available at the National Technical Information Service (NTIS), 5285 Port Royal Rd Springfield, VA 22151. Portions are also available at: http://www.epa.gov/ttn/amtic/qabook.html.

7. Environmental Protection Agency, Title 40, Code of Federal Regulations, Part 58, Appendix B, Measurement Principle and Calibration Procedure for the Measurement of Nitrogen Dioxide in the Atmosphere (Gas Phase Chemiluminescence), Federal Register, 41 (232), 52688-52692, December 1976 (as amended at 48 FR 2529, Jan 20, 1983).

8. Quality Assurance Guidance Document. Reference Method for the Determination of Nitrogen Dioxide in the Atmosphere (Chemiluminescence). Draft document, 58 pages, February 2002. Office of Air Quality Planning and Standards, Research Triangle Park NC 27711, draft document available at http://www.epa.gov/ttn/amtic/qabook.html. Guidelines about the measurement of NO_2 in this document replace those in the old QA Handbook and should be consulted as the latest reference.

9. INSTRUMENT MAINTENANCE

Predictive diagnostic functions including data acquisition, failure warnings and alarms built into the analyzer allow the user to determine when repairs are necessary without performing unnecessary, preventative maintenance procedures. There is, however, a minimal number of simple procedures that, when performed regularly, will ensure that the analyzer continues to operate accurately and reliably over its lifetime. Repair and troubleshooting procedures are covered in Chapter 11 of this manual.

NOTE
A span and zero calibration check must be performed following some of the maintenance procedures listed below. Refer to Chapter 7.

CAUTION
Risk of electrical shock. Disconnect power before performing any operations that require entry into the interior of the analyzer.

NOTE
The operations outlined in this chapter must be performed by qualified maintenance personnel only.

9.1. Maintenance Schedule

Table 9-1 is the recommended maintenance schedule for the M9110E. Please note that in certain environments with high levels of dust, humidity or pollutant levels some maintenance procedures may need to be performed more often than shown.

Table 9-1: M9110E Preventive Maintenance Schedule

Item	Action	Frequency	Cal Check ?	Manual Section	Date Performed								
TEST functions	Review and evaluate	Weekly	No	Table A-3									
Particulate filter	Change particle filter	Weekly	No	9.3.1									
Zero/span check	Evaluate offset and slope	Weekly	Yes	7.3, 7.6									
Zero/span calibration	Zero and span calibration	Every 3 months	Yes	7.2, 7.4, 7.5									

Table 9-1: M9110E Preventive Maintenance Schedule (continued)

Item	Action	Frequency	Cal Check ?	Manual Section	Date Performed							
NO_2 converter	Check conversion efficiency	Every 3 months	Yes on change, else no	9.3.8								
External zero air scrubber (optional)	Exchange chemical	Every 3 months	No	9.3.7								
External dryer (optional)	Replace chemical	When indicator color changes	No									
Ozone filter	Change chemical	Annually	Yes	9.3.3								
Reaction cell window	Clean	Annually or as necessary	Yes	9.3.9								
DFU filter (air inlet filter of Perma Pure dryer, pump dust filter and IZS filter)	Change particle filter	Annually	No	9.3.2 9.3.7								
Pneumatic sub-system	Check for leaks in gas flow paths	Annually or after repairs involving pneumatics	Yes on leaks, else no	11.5.1, 11.5.2								
Reaction cell and O_3 O-rings and sintered filters	Replace	Annually	Yes on Rcell or PMT O-rings.	9.3.10								
PMT Sensor Hardware Calibration	Low-level hardware calibration	On PMT/ preamp changes or if slope is outside of 1.0±0.3	Yes	7.9								
Pump	Rebuild head	when RCEL pressure exceeds 10 in-Hg-A (at sea level)	Yes	9.3.4								
NO_2 converter	Replace converter	Every 3 years or if conversion efficiency drops below 96%	Yes (if CE factor is used)	9.3.8								

Items shown in bold face are required to maintain full warranty, all other items are strongly recommended.

9.2. Predictive Diagnostics

The analyzer's test functions can be used to predict failures by looking at trends in their values. Initially it may be useful to compare the state of these test functions to the values measured on your instrument at the factory and recorded on the *M9110E Final Test and Validation Data Form* (TAI part number 04490, attached to the manual). Table 9-2 can be used as a basis for taking action as these values change with time. The internal data acquisition system (iDAS) is a convenient way to record and track these changes. APICOM control software can be used to download and review these data even from remote locations (Section 6.11.5 describes APICOM).

Table 9-2: Predictive Uses for Test Functions

Function	Expected	Actual	Interpretation & Action
RCEL pressure	Constant to within ± 0.5	Fluctuating	Developing leak in pneumatic system. Check for leaks
		Slowly increasing	Pump performance is degrading. Replace pump head when pressure is above 10 in-Hg-A
SAMPLE pressure	Constant within atmospheric changes	Fluctuating	Developing leak in pneumatic system. Check for leaks
		Slowly increasing	Flow path is clogging up. Replace orifice filters
		Slowly decreasing	Developing leak in pneumatic system to vacuum (developing valve failure). Check for leaks
Ozone Flow	Constant to within ± 15	Slowly decreasing	Flow path is clogging up. Replace orifice filters
AZERO	Constant within ±20 of check-out value	Significantly increasing	Developing AZERO valve failure. Replace valve
			PMT cooler failure. Check cooler, circuit, and power supplies
			Developing light leak. Leak check.
			O_3 air filter cartridge is exhausted. Change chemical
NO2 CONC	Constant for constant concentrations	Slowly decreasing signal for same concentration	Converter efficiency may be degrading. Replace converter.
NO2 CONC (IZS)	Constant response from day to day	Decreasing over time	Change in instrument response. Low level (hardware) calibrate the sensor
			Degradation of IZS permeation tube. Change permeation tube
NO2 CONC (IZS)	Constant response from day to day	Heavily fluctuating from day to day	Ambient changes in moisture are affecting the performance. Add a dryer to the zero air inlet.
NO CONC	Constant for constant concentration	Decreasing over time	Drift of instrument response; clean RCEL window, change O_3 air filter chemical.

9.3. Maintenance Procedures

The following procedures need to be performed regularly as part of the standard maintenance of the Model 9110E.

9.3.1. Changing the Sample Particulate Filter

The particulate filter should be inspected often for signs of plugging or excess dirt. It should be replaced according to the service interval in Table 9-1 even without obvious signs of dirt. Filters with 1 and 5 µm pore size can clog up while retaining a clean look. We recommend to handle the filter and the wetted surfaces of the filter housing with gloves and tweezers. We recommend not to touch any part of the housing, filter element, PTFE retaining ring, glass cover and the O-ring with bare hands as this may cause the pores to clog quicker and surfaces to become dirty due to possible oils from your hands.

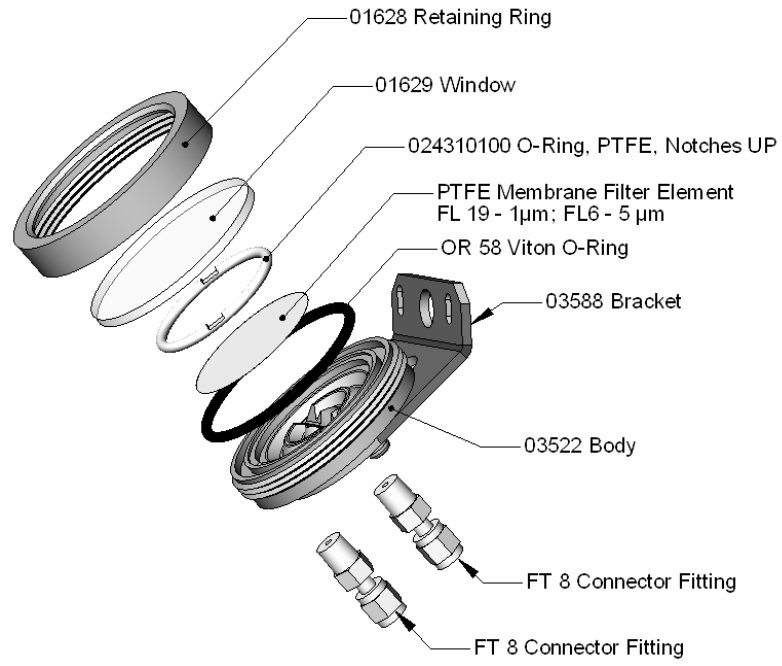


Figure 9-1: Sample Particulate Filter Assembly

- To change the filter according to the service interval in Table 9-1, follow this procedure:
- Turn OFF the pump to prevent drawing debris into the sample line.
- Remove the CE Mark locking screw in the center of the front panel and open the hinged front panel and unscrew the knurled retaining ring of the filter assembly.
- Carefully remove the retaining ring, glass window, PTFE O-ring and filter element. We recommend to clean the glass and O-rings at least once monthly, weekly in very polluted areas.
- Install a new filter element, carefully centering it in the bottom of the holder.
- Re-install the PTFE O-ring with the notches facing up (important!), the glass cover, then screw on the hold-down ring and hand-tighten the assembly. Inspect the (visible) seal between the edge of the glass window and the O-ring to assure proper gas tightness.

- To fulfill CE Mark safety requirements, the front panel locking screw must be installed at all times during operation of the analyzer.
- Re-start the analyzer.

9.3.2. Changing the O_3 Dryer Particulate Filter

The air for the O_3 generator passes through a Perma Pure© dryer, which is equipped with a small particulate filter at its inlet. This filter prevents dust from entering the Perma Pure© dryer and degrading the dryer's performance over time. To change the filter according to the service interval in Table 9-1:

- Before starting the procedure, check and write down the average RCEL pressure and the OZONE flow values.
- Turn off the analyzer, unplug the power cord and remove the cover.
- Unscrew the nut around the port of the filter using 5/8" and 9/16" wrenches and by holding the actual fitting body steady with a 7/16" wrench.

CAUTION
Risk of significant leak. Make sure to use proper wrenches and to not turn the fitting against the Perma Pure© dryer. This may loosen the inner tubing and cause large leaks.

- Take off the old filter element and replace it with a suitable equivalent (TAPI part# FL-3).

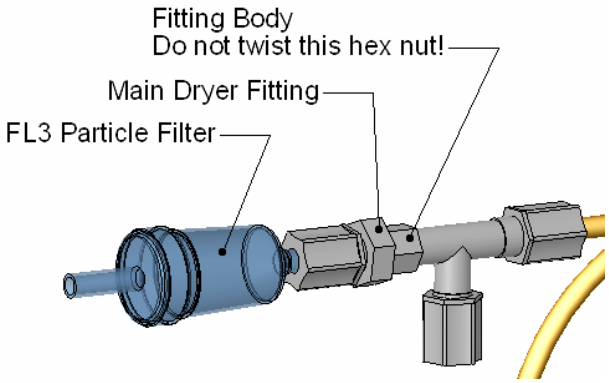


Figure 9-2: Particle Filter on O_3 Supply Air Dryer

- Holding the fitting steady with a 5/8" wrench, tighten the nut with your hands. If necessary use a second wrench but do not over-tighten the nut.
- Replace the cover, plug in the power cord and restart the analyzer.
- Check the O_3 flow rate, it should be around 80 cm^3/min ± 15. Check the RCEL pressure, it should be the same value as before.

9.3.3. Changing the Ozone Filter Chemical

The O_3 filter is located between the O_3 generator and the reaction cell and cleans the O_3 stream from solid and liquid contaminants that are created inside the O_3 generator. The content of the filter cartridge needs periodical exchange according to Table 9-1, a rebuild kit is available from the factory. Appendix B of this manual lists the part numbers of the ozone filter rebuild kit. Some older models 9110E contain a Teflon cartridge, which is shown in the inset. Use a special tool FT267 for the red fittings of those cartridges, otherwise follow these instructions:

- To change the filter chemical, follow these steps:
- Turn of power to the analyzer and pump. Remove the analyzer cover and locate the O_3 filter in the front of the analyzer next to the O_3 generator.
- Use a 7/16" wrench to remove both pieces of 1/8" tubing from the filter.

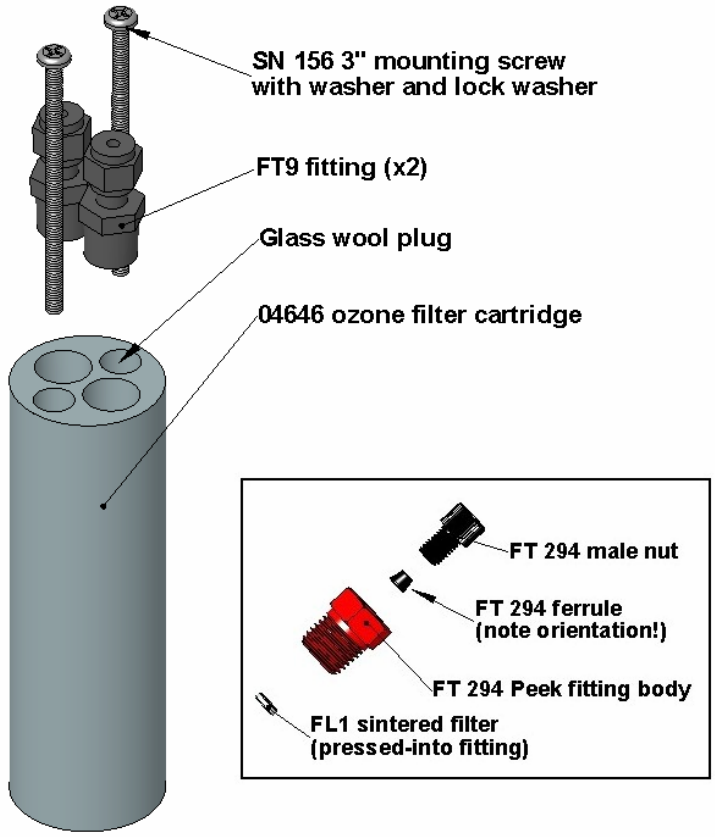


Figure 9-3: 04419 Ozone Filter Unit

- Remove the two 3" mounting screws with a Phillips screw driver and take out the filter cartridge.
- Using a 9/16" wrench, remove both fittings from the cartridge.

- Pour the contents of the cartridge onto a sheet of white paper. Notice any discoloration of the contents, which is usually white and slightly transparent. Note how much of the chemical is discolored (usually with yellow tint), this may give you an indication of the lifetime of the chemical in your application. The maintenance cycle of this item is dependent on ambient moisture, sub-micron particle load and other factors and may differ from that shown in Table 9-1.
- Discard the used chemical without touching it. It may contain nitric acid, which is a corrosive and highly irritating substance. Immediately wash you hands after contact.
- Using a small powder funnel, fill the cartridge with about 10 g new chemical (TAPI part # CH43) so that it is level on both legs of the cartridge. Slight vibration is required to settle the chemical into the cartridge and achieve tightest packing, which increases performance and lifetime of the filter. Make sure that the level of the chemical does not protrude farther than the first two threads of the NPT fitting.

NOTE
Use only genuine, pre-conditioned Teledyne-API refill kits for this procedure. Do not leave this material uncovered for more than a few seconds, as it will absorb contaminants from ambient air!

- Seal the chemical with one plug of glass wool on each side. Ensure that the plug is large enough and compressed into the cartridge so that the chemical is securely held in place.
- Screw the NPT fittings back into the cartridge using a layer of new Teflon tape.
- Screw the cartridge back onto the chassis, orientation is not important.
- Evaluate the ferrules on the tubing. If the ferrules are too old, we recommend to replace them with new ferrules.
- Reconnect the tubing using 7/16” and 9/16” wrenches. Do not over-tighten the fittings.
- If the service interval for this item has been exceeded, it may also be necessary to clean the reaction cell as described in Section 9.3.9.
- Leak check the system using the pressurized approach described in Section 11.5.2. You can use soap leak detector liquid to evaluate if the cartridge is not tight. If necessary, tighten the fittings some more but do not over-tighten.
- Restart the analyzer and pump and continue operation.
- If the chemical used for replacement has not been conditioned properly or was stored over long periods of time or was exposed to ambient air, you may see a significant increase of the AutoZero value, slowly diminishing over time. Until diminished, this may cause large negative offsets on calibration and a changing calibration over time. It may take 2-3 weeks to clean the material properly, hence, we recommend to use genuine Teledyne-API refill kits to ensure minimum downtimes.
- Re-calibrate the analyzer after one hour (Chapter 7). If AutoZero is high, you may have to wait day until calibration.

9.3.4. Rebuilding the External Sample Pump

The sample pump head periodically wears out and must be replaced when the RCEL pressure exceeds 10 in-Hg-A (at sea level, adjust this value accordingly for elevated

locations). A pump rebuild kit is available from the factory. Appendix B of this manual lists the part numbers of the pump rebuild kit. Instructions and diagrams are included in the kit.

A flow and leak check after rebuilding the sample pump is recommended. A span check and re-calibration after this procedure is necessary as the response of the analyzer changes with the RCEL pressure.

9.3.5. Changing the Pump and IZS Dust Filters

The exhaust air from the analyzer passes a small particle filter (*DFU* filter, part # FL3) before entering the pump. When this particle filter becomes visibly dirty or the pressure drop between SAMP and RCEL pressure increases significantly, it needs replacement in order to prevent a large pressure drop with degraded analyzer performance.

- Power down the analyzer and pump.
- For internally mounted filters, skip the next two steps.
- For externally mounted filters on the pump housing, remove the analyzer exhaust tube from the dust filter. Remove the particle filter from the pump. To do so, push the white plastic ring into the fitting and pull the filter out of the fitting. If necessary, use needle-nose pliers to pry the filter out of the fittings.
- Push a new filter into the pump fitting and make sure that the arrow on the filter points towards the pump. Push the exhaust tubing onto the filter. Skip the next two steps.
- For internally mounted filters at the inside rear panel, remove the chassis and locate the filter between the vacuum manifold and the exhaust port fitting.
- Disconnect the clear tubing from the filter body and change the filter with the arrow pointing against the gas flow. To remove the hose clamps, slide the two clamp ends in opposite directions with a needle-nose pliers until the clamp comes apart. Reconnect the tubing by using the same or new clamps and pushing tightening them until a good seal is achieved.
- Restart the pump and clear any error warnings from the front panel display.
- After about 5 minutes, check the RCEL pressure reading and ensure that it is similar to its value before changing the filter but less than 10 in-Hg-A.

A similar procedure applies to the same *DFU* particle filter that is used in the optional IZS zero air scrubber assembly (Figure 9-4). To change this filter, simply disconnect the tube and fitting from one end and remove the filter from the scrubber cartridge. Insert a new filter and attach the tubing. Make sure that the embedded small arrow points in flow direction.

9.3.6. Changing the IZS Permeation Tube

The optional IZS permeation tube that is filled with liquid NO_2 will be exhausted at some point. The lifetime depends on the frequency of usage. To change this tube, purchase a replacement and then

- Turn off the analyzer, unplug the power cord and remove the cover.
- Locate the IZS oven in the rear left of the analyzer.
- Remove the top layer of insulation if necessary.

- Unscrew the black aluminum cover of the IZS oven (3 screws) using a medium Phillips-head screw driver. Leave the fittings and tubing connected to the cover.
- Remove the old permeation tube if necessary and replace it with the new tube. Make sure that the tube is placed into the larger of two holes and that the open permeation end of the tube (plastic) is facing up.
- Re-attach the cover with three screws and make sure that the sealing O-ring is properly in place and that the three screws are tightened evenly.
- Replace the analyzer cover, plug the power cord back in and turn on the analyzer.
- Carry out an IZS span check to see if the new permeation device works properly. The permeation rate may need several days to stabilize.

WARNING
Do not leave instrument turned off for more than 8 hours without removing the permeation tube. Do not ship the instrument without removing the permeation tube. The tube continues to emit NO_2, even at room temperature and will contaminate the entire instrument.

9.3.7. Changing the External Zero Air Scrubber

The external zero air scrubber contains two chemicals, pink Purafil© (Part # CH 9) and black, charcoal (Part # CH 1). The Purafil© converts NO in the ambient air to NO_2 and the following charcoal absorbs any NO_2. The chemicals need to be replaced periodically according to Table 9-1 or as needed. This procedure can be carried out while the instrument is running. Make sure that the analyzer is not in ZERO calibration mode.

- Locate the scrubber on the outside rear panel. Figure 3-7 shows the location, Figure 9-4 the exploded assembly.
- Remove the old scrubber by disconnecting the 1/4” plastic tubing from the particle filter using 9/16” and 1/2" wrenches.
- Remove the particle filter from the cartridge using 9/16” wrenches.
- Unscrew the top of the scrubber canister and discard the Purafil© and charcoal contents. Make sure to abide to local laws about discarding these chemicals. The rebuild kit (listed in Appendix B) comes with a Material and Safety Data Sheet, which contains more information on these chemicals.
- Refill the scrubber with charcoal at the bottom and the Purafil© chemical at the top and use three, white retainer pads to separate the chemicals as shown in Figure 9-4.
- Replace the screw-top cap and tighten the cap - hand-tight only.
- If necessary, replace the DFU filter with a new unit and discard the old. The bottom retainer pad should catch most of the dust, the filter should not be visibly dirty (on the inside)
- Replace the scrubber assembly into its clips on the rear panel.
- Reconnect the plastic tubing to the fitting of the particle filter.
- Adjust the scrubber cartridge such that it does not protrude above or below the analyzer in case the instrument is mounted in a rack. If necessary, squeeze the clips for a tighter grip on the cartridge.

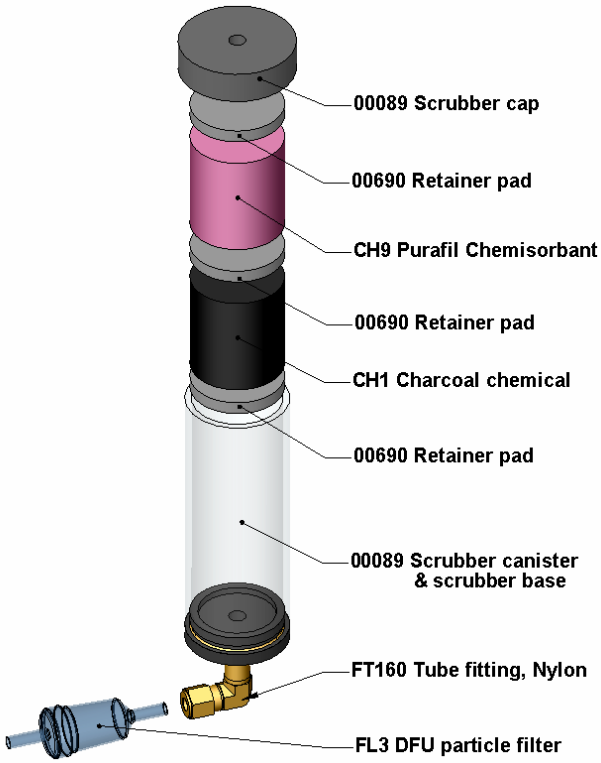


Figure 9-4: Zero Air Scrubber Assembly

9.3.8. Changing the NO_2 converter

The NO_2 converter is located in the center of the instrument, see Figure 3-2 for location, and Figure 9-5 for the assembly. The converter is designed for replacement of the cartridge only, the heater with built-in thermocouple can be reused.

- Turn off the analyzer power, remove the cover and allow the converter to cool.
- Remove the top lid of the converter as well as the top layers of the insulation until the converter cartridge can be seen.

CAUTION
The converter operates at 315º C. Severe burns can result if the assembly is not allowed to cool. Do not handle the assembly until it is at room temperature. This may take several hours.

- Remove the tube fittings from the converter.
- Disconnect the power and the thermocouple of the converter. Unscrew the grounding clamp of the power leads with a Phillips-head screw driver.

- Remove the converter assembly (cartridge and band heater) from the can. Make a note of the orientation of the tubes relative to the heater cartridge.
- Unscrew the band heater and loosen it, take out the old converter cartridge.

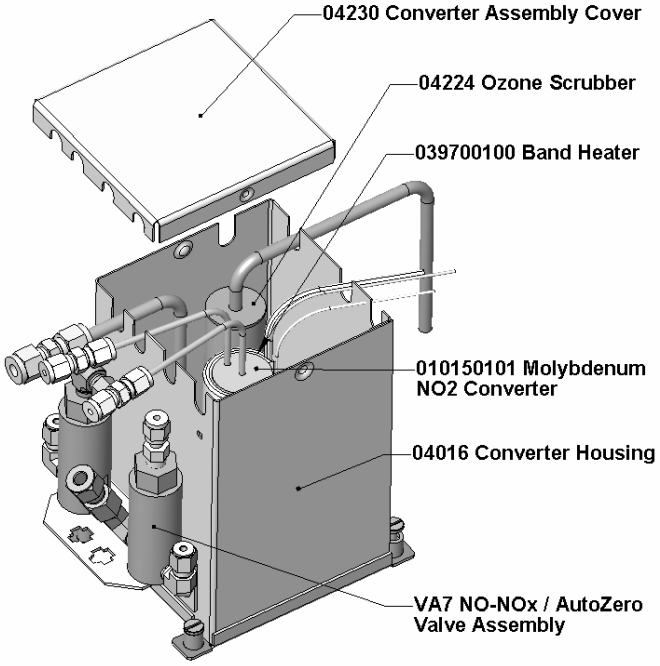


Figure 9-5: NO_2 Converter Assembly

- Wrap the band heater around the new replacement cartridge and tighten the screws using a high-temperature anti-seize agent such as copper paste. Make sure to use proper alignment of the heater with respect to the converter tubes.
- Replace the converter assembly, route the cables through the holes in the can and reconnect them properly. Reconnect the grounding clamp around the heater leads for safe operation.
- Re-attach the tube fittings to the converter and replace the insulation and cover.
- Replace the instrument cover and power up the analyzer.
- Allow the converter to burn-in for 24 hours, then re-calibrate the instrument.

9.3.9. Cleaning the Reaction Cell

The reaction cell should be cleaned whenever troubleshooting suggests. A dirty reaction cell will cause excessive noise, drifting zero or span values, low response or a combination of all. To clean the reaction cell, it is necessary to remove it from the sensor housing. refer to Section 11.6.6. for an overview of the entire sensor assembly. Use the following guide to clean the reaction cell:

- Turn off the instrument power and vacuum pump. Refer to the Figure 9-6for the following procedure.

- Disconnect the black 1/4" exhaust tube and the 1/8” sample and ozone air tubes from the reaction cell. Disconnect the heater/thermistor cable.
- Remove four screws holding the reaction cell to the PMT housing and lift the cell and manifold out as shown in the inset of Figure 9-6.

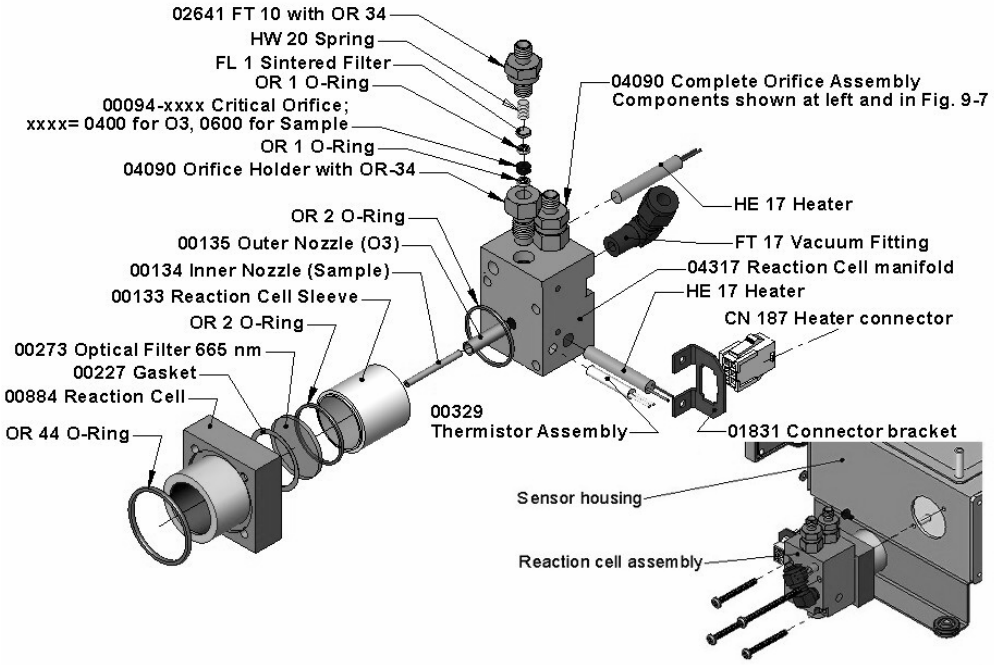


Figure 9-6: Reaction Cell Assembly

- The reaction cell will separate into two halves, the stainless steel manifold assembly and the black plastic reaction cell with window, stainless steel cylinder and O-rings.
- The reaction cell (both plastic part and stainless steel cylinder) and optical glass filter should be cleaned with methanol and a clean tissue and dried thereafter.
- Usually it is not necessary to clean the sample and ozone flow orifices since they are protected by sintered filters. If tests show that cleaning is necessary, refer to Section 9.3.10 on how to clean the critical flow orifice.
- Do not remove the sample and ozone nozzles. They are Teflon threaded and require a special tool for reassembly. If necessary, the manifold with nozzles attached can be cleaned in an ultrasonic bath.
- Reassemble in proper order and re-attach the reaction cell to the sensor housing. Reconnect pneumatics and heater connections, then re-attach the pneumatic sensor assembly and the cleaning procedure is complete.
- After cleaning the reaction cell, it is also recommended to exchange the ozone supply air filter chemical as described in Section 9.3.3.
- After cleaning, the analyzer span response may drop 10 - 15% in the first 10 days as the reaction cell window conditions. This is normal and does not require another cleaning.

9.3.10. Cleaning or Changing Critical Flow Orifices

There are several critical flow orifices installed in the M9110E, Figure 9-6 shows one of the two most important orifice assemblies, located on the reaction cell. Refer to Section 10.2.9 for a detailed description on functionality and locations. Despite the fact that these flow restrictors are protected by sintered stainless steel filters, they can, on occasion, clog up, particularly if the instrument is operated without sample filter or in an environment with very fine, sub-micron particle-size dust.

The M9110E introduces an orifice holder that makes changing the orifice very easy. In fact, it is recommended to keep spare orifice holder assemblies at hand to minimize downtime and swap orifices in a matter of a few minutes. Appendix B lists several complete spare part kits for this purpose. To clean or replace a critical flow orifice, do the following:

- Turn off power to the instrument and vacuum pump. Remove the analyzer cover and locate the reaction cell (Figure 9-6, Figure 11-7 and Figure 3-7).
- Unscrew the 1/8” sample and ozone air tubes from the reaction cell
- For orifices on the reaction cell (Figure 9-6): Unscrew the orifice holder with a 9/16” wrench. This part holds all components of the critical flow assembly as shown in Figure 9-7. Appendix B contains a list of spare part numbers.
- For orifices in the vacuum manifold: the assembly is similar to the one shown in Figure 9-7, but without the orifice holder, part number 04090, and bottom O-ring OR34 and with an NPT fitting in place of the FT 10 fitting. After taking off the connecting tube, unscrew the NPT fitting.
- Take out the components of the assembly: a spring, a sintered filter, two O-rings and the orifice. For the vacuum manifold only, you may need to use a scribe or pressure from the vacuum port to get the parts out of the manifold.
- Discard the two O-rings and the sintered filter and clean the critical flow orifice in a ultrasonic cleaner for about 30 minutes using methanol. Let the part dry.
- Re-assemble the parts as shown in Figure 9-7 and re-connect them to the reaction cell manifold or the vacuum manifold.
- Reconnect all tubing, power up the analyzer and pump and - after a warm-up period of 30 minutes, carry out a leak test as described in Section 11.5.1.

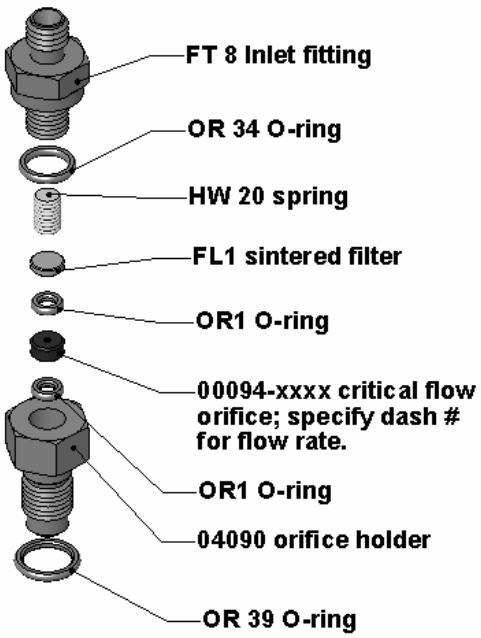


Figure 9-7: Critical Flow Orifice Assembly

9.3.11. Checking for Light Leaks

When re-assembled or operated improperly, the M9110E can develop small leaks around the PMT, which let stray light from the analyzer surrounding into the PMT housing. To find such light leaks, follow the below procedures. CAUTION: this procedure can only be carried out with the analyzer running and its cover removed. This procedure should only be carried out by qualified personnel.

- Scroll the TEST functions to PMT.
- Supply zero gas to the analyzer.
- With the instrument still running, carefully remove the analyzer cover. Take extra care not to touch any of the inside wiring with the metal cover or your body. Do not drop screws or tools into a running analyzer!
- Shine a powerful flashlight or portable incandescent light at the inlet and outlet fitting and at all of the joints of the reaction cell as well as around the PMT housing. The PMT value should not respond to the light, the PMT signal should remain steady within its usually noise.
- If there is a PMT response to the external light, symmetrically tighten the reaction cell mounting screws or replace the 1/4" vacuum tubing with new, black PTFE tubing (this tubing will fade with time and become transparent). Often, light leaks are also caused by O-rings being left out of the assembly.
- Carefully replace the analyzer cover. If tubing was changed, carry out a leak check (Section 11.5.2).

10. THEORY OF OPERATION

The M9110E Nitrogen Oxides Analyzer is a microprocessor controlled instrument that determines the concentration of nitric oxide (NO), total nitrogen oxides (NO_X, the sum of NO and NO_2) and nitrogen dioxide (NO_2) in a sample gas drawn through the instrument. It requires that sample and calibration gases are supplied at ambient atmospheric pressure in order to establish a constant gas flow through the reaction cell where the sample gas is exposed to ozone (O_3), initiating a chemical reaction that gives off light (chemiluminescence). The instrument measures the amount of chemiluminescence to determine the amount of NO in the sample gas. A catalytic-reactive converter converts any NO_2 in the sample gas to NO, which is then – including the NO in the sample gas – is then reported as NO_X. NO_2 is calculated as the difference between NO_X and NO.

Calibration of the instrument is performed in software and usually does not require physical adjustments to the instrument. During calibration, the microprocessor measures the sensor output signal when gases with known amounts of NO or NO_2 are supplied and stores these results in memory. The microprocessor uses these calibration values along with the signal from the sample gas and data of the current temperature and pressure of the gas to calculate a final NO_X concentration.

The concentration values and the original information from which it was calculated are stored in the unit's internal data acquisition system (iDAS Section 6.10.2) and are reported to the user through a vacuum fluorescence display or several output ports.

10.1. Measurement Principle

10.1.1. Chemiluminescence

The principle of the M9110E's measurement method is the detection of chemiluminescence, which occurs when nitrogen oxide (NO) reacts with ozone (O_3). This reaction is a two-step process. In the first step, one molecule of NO and one molecule of O_3 collide and chemically react to produce one molecule of oxygen (O_2) and one molecule of nitrogen dioxide (NO_2). Some of the NO_2 retains a certain amount of excess energy from the collision and, hence, remains in an excited state, which means that one of the electrons of the NO_2 molecule resides in a higher energy state than is normal (denoted by an asterisk in Equation 10-1).

$$NO + O_3 \rightarrow NO_2^* + O_2 \qquad \textbf{Eq 10-1}$$

Thermodynamics requires that systems seek the lowest stable energy state, hence, the NO_2 molecule quickly returns to its ground state in a subsequent step, releasing the excess energy in form of a quantum of light ($h\nu$) with wavelengths between 600 and 3000 nm, with a peak at about 1200 nm (Equation 10-2, Figure 10-1).

$$NO_2^* \rightarrow NO_2 + h\nu \qquad \textbf{Eq 10-2}$$

All things being constant, the relationship between the amount of NO present in the reaction cell and the amount of light emitted from the reaction is very linear. More NO produces more light, which can be measured with a light-sensitive sensor in the near-infrared spectrum (Figure 10-1). In order to maximize the yield of reaction (1), the M9110E supplies the reaction cell with a large, constant excess of ozone (about 3000-5000 ppm) from the internal ozone generator.

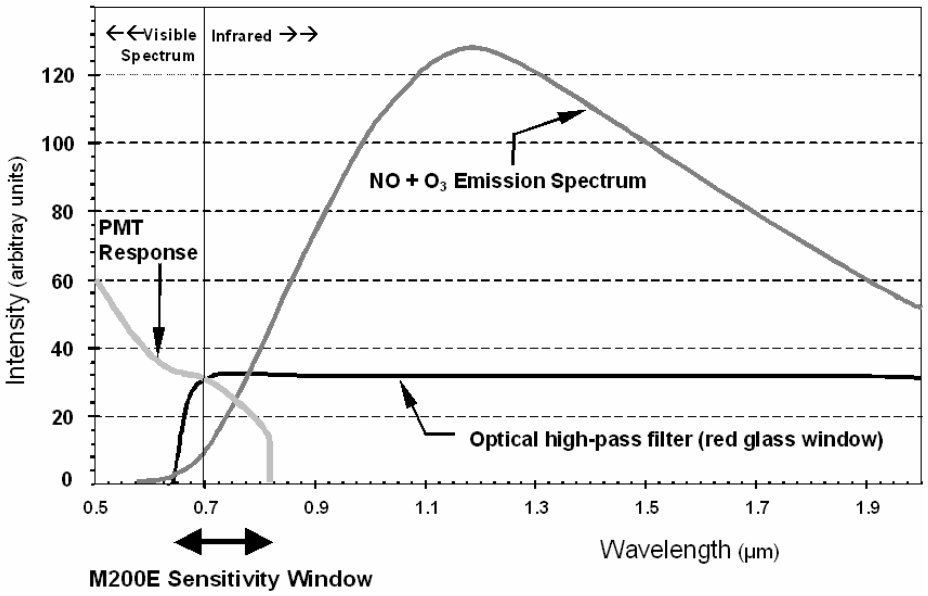


Figure 10-1: M9110E Sensitivity Spectrum

However, only about 20% of the NO_2 that is formed through reaction 10-1 is in the excited state. In addition, the excited NO_2 can collide with another collision partner *M* in the reaction cell (mostly other molecules but also cell walls) and transfer its excess energy to its collision partner without emitting any light at all (Equation 10-3). In fact, by far the largest portion of the NO_2* returns to the ground state this way, leaving only a few percent yield of usable chemiluminescence.

$$NO_2^* + M \rightarrow NO_2 + M \qquad \textbf{Eq 10-3})$$

In order to enhance the light yield of the reaction, the reaction cell is maintained at reduced pressure. The probability of a collision between the NO_2* molecule and a collision partner *M* increases proportionally with the reaction cell pressure. This non-radiating collision with the NO_2* molecules is usually referred to as *quenching*, an unwanted process further described in Section 10.1.5.2.

10.1.2. NO_X and NO_2 Determination

The only gas that is truly measured in the M9110E is NO. Any NO_2 contained in the gas is not detected in the above process since NO_2 does not react with O_3 to undergo chemiluminescence.

In order to measure the concentration of NO or NO_X (which is defined here as the sum of NO and NO_2 in the sample gas), the M9110E periodically switches the sample gas stream through a converter cartridge filled with molybdenum (Mo, "moly") chips (Figure 10-6) heated to a temperature of 315° C. The heated molybdenum reacts with NO_2 in the sample gas and produces a vriety of molybdenum oxides and NO according to Equation 10-4.

$$xNO_2 + yMo \rightarrow xNO + M_yO_z \quad (at\ 315°C) \qquad \textbf{Eq 10-4}$$

Once the NO_2 in the sample gas has been converted to NO, it is routed to the reaction cell where it undergoes the chemiluminescence reaction described in Equations 10-1 and 10-2.

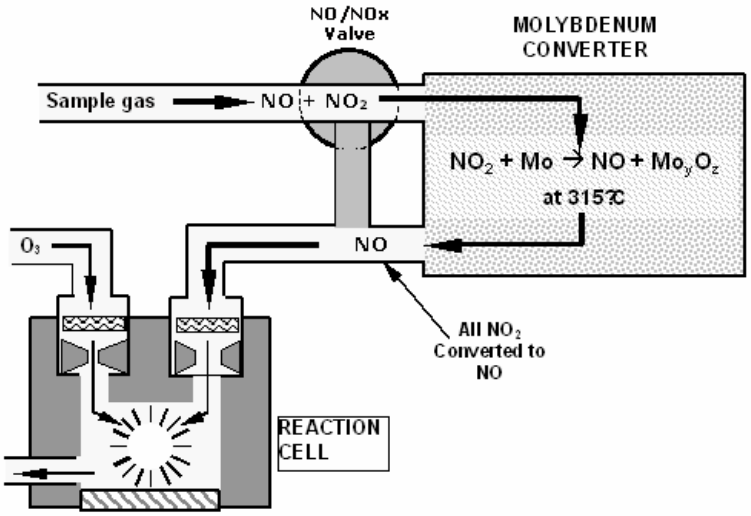


Figure 10-2: NO_2 Conversion Principle

By converting the NO_2 in the sample gas into NO, the analyzer can measure the total NO_X ($NO+NO_2$) content of the sample gas. By switching the NO_2 converter in and out of the sample gas stream every 6 - 10 seconds, the M9110E analyzer is able to quasi-continuously measure both the NO and the total NO_X content.

The NO_2 concentration, finally, is not measured but calculated by simply subtracting the known NO content of the sample gas from the known NO_X content.

10.1.3. Chemiluminescence Detection

10.1.3.1. The Photo Multiplier Tube

The M9110E uses a photo-multiplier tube (PMT) to detect the amount of light created by the NO and O_3 reaction in the reaction cell.

A PMT is typically a vacuum tube containing a variety of specially designed electrodes. Photons enter the PMT and strike a negatively charged photo cathode causing it to emit electrons. These electrons are accelerated by an applied high voltage and multiply through a sequence of such acceleration steps (dynodes) until a useable current signal is generated. This current increases or decreases with the amount of detected light (Section 10.3.2.2 for more details), is converted to a voltage and amplified by the preamplifier board and then reported to the motherboard's analog inputs.

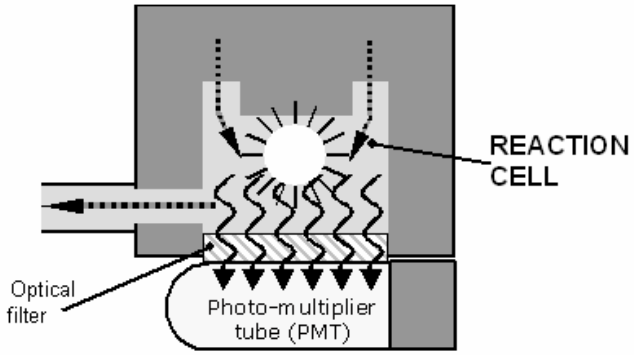


Figure 10-3: Reaction Cell with PMT Tube

10.1.3.2. Optical Filter

Another critical component in the method by which your M9110E detects chemiluminescence is the optical filter that lies between the reaction cell and the PMT (Figure 10-2). This filter is a high pass filter that is only transparent to wavelengths of light above 645 nm. In conjunction with the response characteristics of the PMT, this filter creates a very narrow window of wavelengths of light to which the M9110E will respond (Figure 10-1).

The narrow band of sensitivity allows the M9110E to ignore extraneous light and radiation that might interfere with the M9110E's measurement. For instance, some oxides of sulfur can also undergo chemiluminescence when in contact with O_3 but emit light at shorter wavelengths (usually around 260 nm to 480 nm).

10.1.4. Auto Zero

Inherent in the operation of any PMT is a certain amount of noise. This is due to a variety of factors such as black body infrared radiation given off by the metal components of the reaction cell, unit to unit variations in the PMT units and even the constant universal background radiation that surrounds us at all times. In order to reduce this amount of noise and offset, the PMT is kept at a constant 7° C (45° F) by a thermo-electric cooler (TEC).

While this intrinsic noise and offset is significantly reduced by cooling the PMT, it is not eradicated. To determine how much noise remains, the M9110E diverts the sample gas flow directly to the vacuum manifold without passing the reaction cell once every minute for about 5 seconds (Figure 10-4). During this time, only O_3 is present in the reaction cell, effectively turning off the chemiluminescence reaction. Once the chamber is completely dark, the M9110E records the output of the PMT and keeps a running average of these **AZERO** values. This average offset value is subtracted from the raw PMT readings while the instrument is measuring NO and NO_X to arrive at a auto-zero corrected reading.

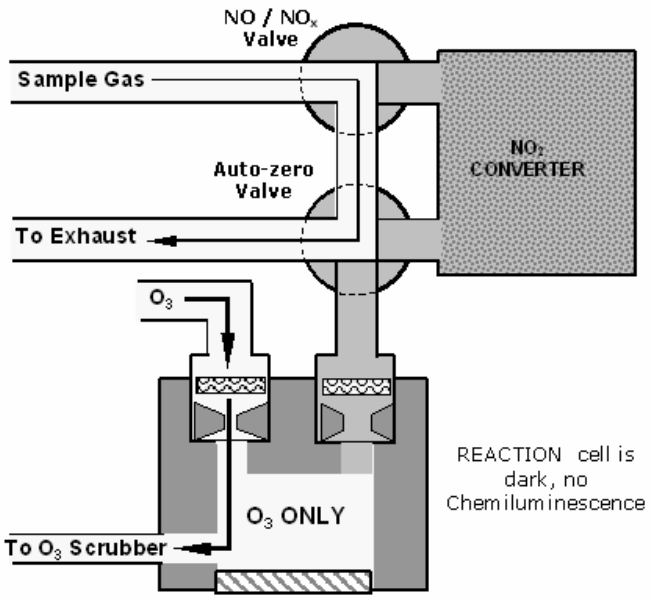


Figure 10-4: Reaction Cell During the AutoZero Cycle.

10.1.5. Measurement Interferences

It should be noted that the chemiluminescence method is subject to interferences from a number of sources. The M9110E has been successfully tested for its ability to reject interference from most of these sources. Table 10-1 lists the most important gases, which may interfere with the detection of NO in the M9110E.

10.1.5.1. Direct Interference

Some gases can directly alter the amount of light detected by the PMT due to chemiluminescence in the reaction cell. This can either be a gas that undergoes chemiluminescence by reacting with O_3 in the reaction cell or a gas that reacts with other compounds and produces excess NO upstream of the reaction cell.

10.1.5.2. Third Body Quenching

As shown in Equation 10-3, other molecules in the reaction cell can collide with the excited NO_2^*, preventing the chemiluminescence of Equation 10-2, a process known as quenching. CO_2 and H_2O are the most common quenching interferences, but N_2 and O_2 also contribute to this interference type.

Quenching is an unwanted phenomenon and the extent to which it occurs depends on the properties of the collision partner. larger, more polarized molecules such as H_2O and CO_2 quench NO chemiluminescence more effectively than smaller, less polar and electronically "harder" molecules such as N_2 and O_2.

The influence of water vapor on the M9110E measurement can be eliminated with an optional, internal sample gas dryer. The concentrations of N_2 and O_2 are virtually constant

in ambient air measurements, hence provide a constant amount of quenching and the interference of varying CO_2 amounts is negligible at low concentrations.

Table 10-1: List of Interferents

Gas	Interference Type	Rejection Method
CO_2	Dilution: Viscosity of CO_2 molecules causes them to collect in aperture of Critical Flow Orifice altering flow rate of NO.	If high concentrations of CO_2 are suspected, special calibration methods must be performed to account for the affects of the CO_2. Contact TAI Customer Service department for details.
	3^{rd} Body Quenching: CO_2 molecules collide with NO_2* molecules absorbing excess energy kinetically and preventing emission of photons.	
SO_X	Some SO_X variants can also initiate a chemiluminescence reaction upon exposure to O_3 producing excess light.	Wavelengths of light produced by chemiluminescence of SO_X are screened out by the Optical Filter.
	Chemically reacts with NH_3, O_2 and H_2O in O_3 generator to create $(NH_3)_2SO_4$ (ammonium sulfate) and NH_3NO_2 (ammonium nitrate) which form opaque white deposits on optical filter window. Also forms highly corrosive HNO_3 (Nitric Acid)	Most of the ammonium sulfate and ammonium nitrate produced is removed from the sample gas by an air purifier located between the O_3 Generator and the reaction cell.
	3^{rd} Body quenching: SO_X molecules collide with NO_2* molecules absorbing excess energy kinetically and preventing emission of photons.	If high concentrations of SO_X are suspected, special calibration methods must be performed to account for the affects of the SO_2. Contact TAI Customer Service department for details.
H_20	3^{rd} Body quenching: H_2O molecules collide with NO_2* molecules absorbing excess energy kinetically and preventing emission of light.	Analyzer's operating in high humidity areas must have some drying applied to the sample gas (Section 5.8 for more details).
	Water also reacts with NH_3 and SO_X in the O_3 generator to create $(NH_3)_2SO_4$ (ammonium sulfate) and NH_3NO_2 (ammonium nitrate) which form opaque white deposits on the optical filter window. This also forms highly corrosive HNO_3 (nitric acid)	Water is effectively removed from the O_3 gas stream by the Perma Pure® Dryer (Section 10.2.6 for more details). We offer several Perma Pure dryers for the sample stream, see Section 5.9.
NH_3	Direct Interference: NH_3 is converted to H_2O and NO by the NO_2 converter. Excess NO reacts with O_3 in the reaction cell creating a chemiluminescence artifact.	If a high concentration of NH_3 is suspected, steps must be taken to remove the NH_3 from the sample gas prior to its entry into the NO_2 converter, see Section 5.9.
	NH_3 also reacts with H_2O, O_2 and SO_X in the O_3 generator to create $(NH_3)_2SO_4$ (ammonium sulfate) and NH_3NO_2 (ammonium nitrate) which form opaque white deposits on optical filter window. Also forms highly corrosive HNO_3 (nitric acid).	The Perma Pure® dryer built into the M9110E is sufficient for removing typical ambient concentration levels of NH_3.

In cases with excessively high CO_2 concentrations (larger than 0.5%), the effect can be calibrated out by using calibration gases with a CO_2 content equal to the measured air. Only very high and highly variable CO_2 concentrations will then be cause of measurable interference. For those applications, we recommend to use other analyzer models. Please consult sales or our website.

10.1.5.3. Light Leaks

The M9110E sensitivity curve includes a small portion of the visible light spectrum (Figure 10-3), hence, it is important to make sure than the reaction cell is completely sealed with respect to light. To ensure this, all pneumatic tubing leading into the reaction cell is either opaque (vacuum exit tubing) in order to prevent light from entering the cell or light penetration is prevented by stainless steel filters and orifices (gas entries).

10.2. Pneumatic Operation

CAUTION
It is important that the sample airflow system is leak-tight and not pressurized over ambient pressure. Regular leak checks should be performed on the analyzer as described in the maintenance schedule, Table 9-1. Procedures for correctly performing leak checks can be found in Section 11.5.

10.2.1. Pump and Exhaust Manifold

NOTE
Relative Pressure versus absolute pressure. In this manual vacuum readings are given in inches of mercury absolute pressure (in-Hg-A), i.e. indicate an absolute pressure referenced against zero (a perfect vacuum).

The gas flow for the M9110E is created by an external pump (Figure 10-5) that is pneumatically connected through a 6.4 mm / 0.25" tube to the analyzer's exhaust port located on the rear panel (Figure 3-2). This pump creates a vacuum of approximately 5 in-Hg-A at one standard liter/minute, which is provided to various pneumatic components by a vacuum manifold located just in front of the rear panel (Figure 3-2 and **Error! Reference source not found.**). Gas flow is created by keeping the analyzer's sample gas inlet near ambient pressure, usually by means of a small vent installed in the sample line at the inlet, in effect pulling the gas through the instrument's pneumatic systems.

There are several advantages to this external pump / pull-through configuration.

- By using an external pump, it is possible to remove a significant source of acoustic noise and vibration from the immediate vicinity of the sensor. The PMT can act as a "microphone", amplifying noise and vibration within the chassis. This is one of the main reasons, why the M9110E has an external pump.
- Pumping heats and compresses the sample air, complicating the measurement process if the pump is upstream.
- Most importantly, however, certain physical parts of the pump itself are made of materials that might chemically react with the sample gas. Placing the pump downstream of the reaction cell avoids these problems.

See Section 3.1 for information on connecting and operating the external pump.

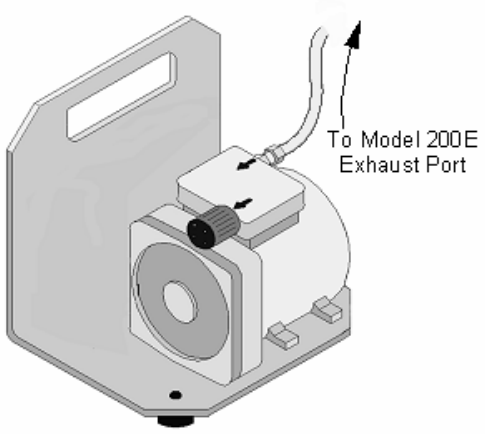


Figure 10-5: External Pump Pack

Finally, the M9110E requires a steady, high underpressure, which cannot be achieved reliably over extended periods of time with small vacuum pumps. The external pump used for the M9110E has a very long lifetime and duty cycle and provides a very good vacuum for its entire lifetime. However, the pump is too large to fit into the chassis of the analyzer.

10.2.2. Sample Gas Flow

The sample gas is the most critical flow path in the analyzer, as the medium has to be routed through a variety of valves and tubes for the measurement of zero offset and concentrations of both NO and NO_X (and possibly the drying of the gas if the optional sample dryer is installed). At any point before and in the reaction cell, the integrity of the sample gas cannot be compromised.

Sample gas flow in the M9110E analyzer is not a directly measured value, but is rather calculated from the sample pressure using the flow principle across a critical orifice. In general, the differential pressure ratio between sample pressure and reaction cell pressure needs to exceed 2:1 to allow critical flow. The actual flow rate is then only dependent on the size of the orifice and the upstream pressure. Refer to Section 10.2.9 for a detailed description of critical flow.

The M9110E uses a 0.010" (10 mil) diameter orifice to achieve a flow rate of about 450-500 cm^3/min. With nominal pressures of 28 and 4 in-Hg-A for the sample and reaction cell pressures, respectively. The necessary ratio of sample to reaction cell pressure of 2:1 is largely exceeded and accommodates a wide range of possible variability in atmospheric pressure and pump degradation. Once the pump degrades and vacuum pressure exceeds 14 in-Hg-A, the ratio between sample and vacuum pressures is less than 2:1 and, hence, a critical flow rate can no longer be calculated. At this point, the instrument will display an invalid sample flow rate measurement (**XXXX**).

Table 10-2: M9110E Valve Cycle Phases

Phase	NO/ NO_x Valve Status	Autozero Valve Status	Time Index	Activity	Figure
NO Measure	Open to AutoZero valve	Open to reaction cell	0 - 2 s	Wait period (NO dwell time). Ensures reaction cell has been flushed of previous gas.	Figure 10-2
			2 - 4 s	Analyzer measures chemiluminescence in reaction cell.	
NO_X Measure	Open to NO_2 converter	Open to reaction cell	4 – 6 s	Wait period (NO_X dwell time). Ensures reaction cell has been flushed of previous gas.	Figure 10-2
			6 – 8 s	Analyzer measures NO + O_3 chemiluminescence in reaction cell.	
Cycle repeats every ~8 seconds					
AutoZero	Open to AutoZero valve	Open to vacuum manifold	0 – 4 s	Wait period (AZERO dwell time). Ensures reaction cell has been flushed of sample gas and chemiluminescence reaction is stopped.	Figure 10-4
			4 - 6 s	Analyzer measures background noise without sample gas	
Cycle repeats every minute					

The M9110E uses a 0.010" (10 mil) diameter orifice to achieve a flow rate of about 450-500 cm³/min. With nominal pressures of 28 and 4 in-Hg-A for the sample and reaction cell pressures, respectively. The necessary ratio of sample to reaction cell pressure of 2:1 is largely exceeded and accommodates a wide range of possible variability in atmospheric pressure and pump degradation. Once the pump degrades and vacuum pressure exceeds 14 in-Hg-A, the ratio between sample and vacuum pressures is less than 2:1 and, hence, a critical flow rate can no longer be calculated. At this point, the instrument will display an invalid sample flow rate measurement (**XXXX**).

For the routing of the sample gas flow, the analyzer uses a variety of valves. The NO/NO_X valve directs the sample gas either directly to the reaction cell or through the unit's NO_2 converter, alternating every ~4 s. The AutoZero valve directs the sample gas stream to completely bypass the reaction cell for dark noise measurement once every minute, which is then subtracted as a measurement offset from the raw concentration signal. The valve cycle phases are summarized in Table 10-2.

10.2.3. Sample Particulate Filter

To remove particles in the sample gas, the analyzer is equipped with a PTFE membrane filter of 47 mm diameter (also referred to as the sample filter) with a 1 µm pore size. The filter is accessible through the front panel, which folds down (after removal of the CE Mark safety screw), and should be changed according to the maintenance schedule in Table 9-1.

10.2.4. Ozone Gas Air Flow

The excess ozone needed for reaction with NO in the reaction cell is generated inside the analyzer because of the instability and toxicity of ozone. Besides the ozone generator itself, this requires a dry air supply and filtering of the gas before it is introduced into the reaction cell. Due to its toxicity and aggressive chemical behavior, O_3 must also be removed from the gas stream before it can be vented through the exhaust outlet.

In contrast to the sample flow, the ozone flow is measured with a mass flow sensor, which is mounted on the pneumatic sensor board (Figure 11-5), just behind the PMT sensor assembly. This mass flow sensor has a full scale range of 0-1000 cm^3/min and can be calibrated through software to its span point (Section 6.7.8). As the flow value displayed on the front panel is an actual measurement (and not a calculated value), the flow variability may be higher than that of the sample flow, which is based on a calculation from (more stable) differential pressures. On the other hand, the drift, i.e. long-term change, in the ozone flow rate may be higher and usually indicates a flow problem. As with all other test parameters, we recommend to monitor the ozone flow over time for predictive diagnostics and maintenance evaluation.

CAUTION
Ozone (O_3) is a toxic gas. Obtain a Material and Safety Data Sheet (MSDS) for this gas. Read and rigorously follow the safety guidelines described there. Always make sure that the plumbing of the O_3 generation and supply system is maintained and leak-free.

10.2.5. O_3 Generator

The M9110E uses a corona discharge (CD) tube for creating its O_3. Corona discharge generation is capable of producing high concentrations of ozone efficiently and with low excess heat. Although there are many cell designs, the fundamental principle remains the same (Figure 10-6).

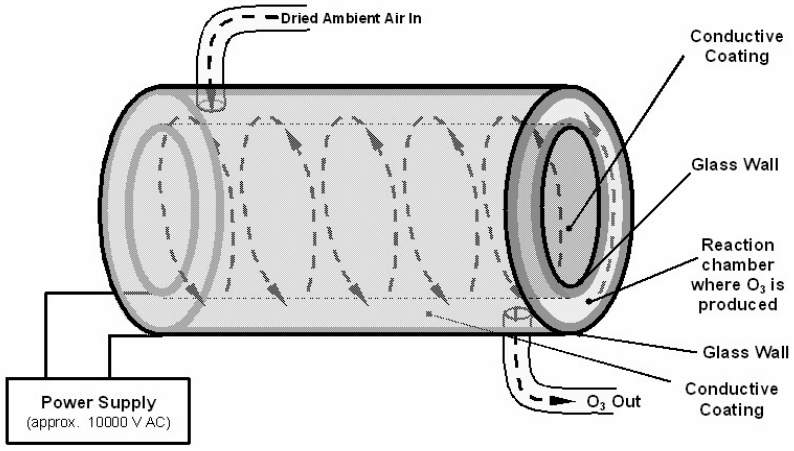


Figure 10-6: Ozone Generator Principle

The M9110E utilizes a dual-dielectric design. This method utilizes a glass tube with hollow walls. The outermost and innermost surfaces are coated with electrically conductive material. The air flows through the glass tube, between the two conductive coatings, in effect creating a capacitor with the air and glass acting as the dielectric. The layers of glass also separate the conductive surfaces from the air stream to prevent reaction with the O_3. As the capacitor charges and discharges, electrons are created and accelerated across the air gap and collide with the O_2 molecules in the air stream splitting them into elemental oxygen. Some of these oxygen atoms recombine with O_2 to O_3.

The quantity of ozone produced is dependent on factors such as the voltage and frequency of the alternating current applied to the CD cells. When enough high-energy electrons are produced to ionize the O_2 molecules, a light emitting, gaseous plasma is formed, which is commonly referred to as a corona, hence the name corona discharge generator.

10.2.6. Perma Pure® Dryer

The air supplied to the O_3 generation system needs to be as dry as possible. Normal room air contains a certain amount of water vapor, which greatly diminishes the yield of ozone produced by the ozone generator. Also, water can react with other chemicals inside the O_3 Generator to produce chemicals that damage the optical filter located in the reaction cell (Table 10-4) such as ammonium sulfate or highly corrosive nitric acid.

To accomplish this task the M9110E uses a Perma Pure® single tube permeation dryer. The dryer consists of a single tube of Nafion® , a co-polymer similar to Teflon® that absorbs water very well but not other chemicals. The Nafion® tube is mounted within an outer, flexible plastic tube. As gas flows through the inner Nafion® tube, water vapor is absorbed into the membrane walls. The absorbed water is transported through the membrane wall and evaporates into the dry, purge gas flowing through the outer tube, countercurrent to the gas in the inner tube (Figure 10-7).

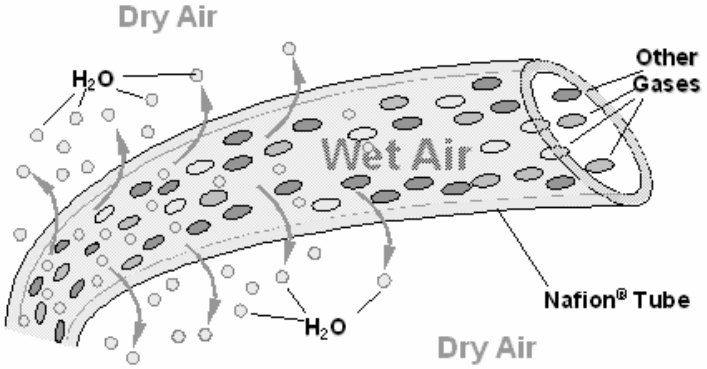


Figure 10-7: Semi-Permeable Membrane Drying Process

This process is called per-evaporation and is driven by the humidity gradient between the inner and outer tubes as well as the flow rates and pressure difference between inner and outer tubing. Unlike micro-porous membrane permeation, which transfers water through a relatively slow diffusion process, per-evaporation is a simple kinetic reaction. Therefore, the drying process occurs quickly, typically within milliseconds. The first step in this process is a chemical reaction between the molecules of the Nafion® material and water, other chemical components of the gases to be dried are usually unaffected. The chemical reaction is based

on hydrogen bonds between the water molecule and the Nafion material. Other small polar gases that are capable of hydrogen bonds can be absorbed this way, too, such as ammonia (NH_3) and some low molecular amines. The gases of interest, NO and NO_2, do not get absorbed and pass the dryer unaltered.

To provide a dry purge gas for the outer side of the Nafion tube, the M9110E returns some of the dried air from the inner tube to the outer tube (Figure 10-8). When the analyzer is first started, the humidity gradient between the inner and outer tubes is not very large and the dryer's efficiency is low at first but improves as this cycle reduces the moisture in the sample gas and settles at a minimum humidity.

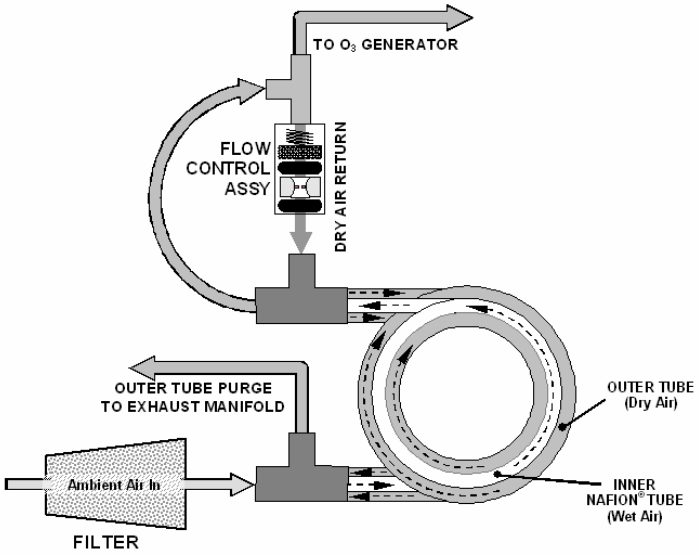


Figure 10-8: M9110E Perma Pure® Dryer

Just like on startup, if the instrument is turned on after having been off for more than 30 minutes, it takes a certain amount of time for the humidity gradient to become large enough for the Perma Pure® Dryer to adequately dry the air. In this case, called a cold start, the O_3 Generator is not turned on for 30 minutes. When rebooting the instrument within less than 30 minutes of power-down, the generator is turned on immediately.

The Perma Pure® Dryer used in the M9110E is capable of adequately drying ambient air to a dew point of ≤ -5°C (~4000 ppm residual H_2O) at a flow rate of 1 standard liter per minute (slpm) or down to ≤ -15°C (~1600 ppm residual H_2O) at 0.5 slpm. The Perma Pure® Dryer is also capable of removing ammonia from the sample gas up to concentrations of approximately 1 ppm.

10.2.7. Ozone Supply Air Filter

The M9110E uses ambient air as the supply gas for the O_3 generator and may produce a variety of byproducts. Small amounts of water, ammonia and various sulfur oxides can combine to create ammonium sulfate, ammonium nitrate, nitric acid and other compounds. Whereas sulfates and nitrates can create powdery residues inside the reaction cell causing sensitivity drift, nitric acid is a very aggressive compound, which can deteriorate the analyzer's components. In order to remove these chemical byproducts from the O_3 gas

stream, the output of the O_3 generator flows through a special filter between the generator and the reaction cell.

Any NO_X that may be produced in the generator (from reaction of O_2 or O_3 and N_2 in the air) and may cause an artifact in the measurement, is calibrated out through the Auto-zero functionality, which checks the background signal of the O_3 stream only once per minute.

10.2.8. Ozone Scrubber

Even though ozone is unstable and typically reacts to form O_2, the break-down is not quite fast enough to ensure that it is completely removed from the exhaust gas stream of the M9110E by the time the gas exits the analyzer. Due to the high toxicity and reactivity of O_3, a special catalytic ozone scrubber is used to remove all of the O_3 exiting the reaction cell. Besides its efficient destruction of O_3, this catalyst does not produce any toxic or hazardous gases as it only converts ozone to oxygen and it also does not pose an explosion hazard like charcoal scrubbers.

The O_3 scrubber is located inside the NO_2 converter housing next to the NO_2 converter in order to utilize residual heat given of by the converter heater. Even though the catalyst is 100% efficient at scrubbing ozone at room temperature, heating it significantly reduces the necessary residence time (the amount of time the gas must be in contact with the catalyst) for 100% efficiency and full efficiency can be maintained at higher gas flow rates. As this is a true catalytic converter, there are no maintenance requirements as would be required for charcoal-based scrubbers.

A certain amount of fine, black dust may exit the catalyst, particularly if the analyzer is subjected to sudden pressure drops (for example, when disconnecting the running pump without letting the analyzer properly and slowly equilibrate to ambient pressure). To avoid the dust from entering the reaction cell or the pump, the scrubber is equipped with sintered stainless steel filters of 20 µm pore size on either end and on some models, an additional dust filter may be attached to the exhaust port.

10.2.9. Flow Rate Control - Critical Flow Orifices

In order to maintain constant flow rates for both the O_3 supply air and the sample gas, the M9110E uses a variety of critical-orifice flow control assemblies (Figure 9-7) located at these places in the pneumatic system of the instrument:

- Reaction cell, sample inlet (Figure 9-6)
- Reaction cell, ozone inlet (Figure 9-6)
- Vacuum manifold, AutoZero exit (Figure 10-10)
- Vacuum manifold, IZS exit (if installed (Figure 10-10)
- Permapure ozone air dryer, purge flow control (Figure 10-8)
- Permapure sample or combo dryer (if installed), purge flow control (Figure 10-8)

The most important component of each flow control assembly is the critical flow orifice. Critical flow orifices are a simple means to regulate stable gas flow rates. They operate without moving parts by taking advantage of the laws of fluid dynamics. By restricting the flow of gas through the orifice, a pressure differential is created. This pressure differential, created by the analyzer's external pump, draws the gas through the orifice.

As the pressure on the downstream side of the orifice (the pump side) continues to drop, the speed of the gas flowing through the orifice continues to rise. Once the ratio of upstream pressure to downstream pressure is greater than 2:1, the velocity of the gas through the orifice reaches the speed of sound and remains constant, regardless of any further pressure difference. As long as that ratio stays at least 2:1, the gas flow rate is unaffected by fluctuations, surges, or changes in downstream pressure because such variations only travel at the speed of sound themselves and are therefore cancelled out at the downstream exit of the critical flow orifice.

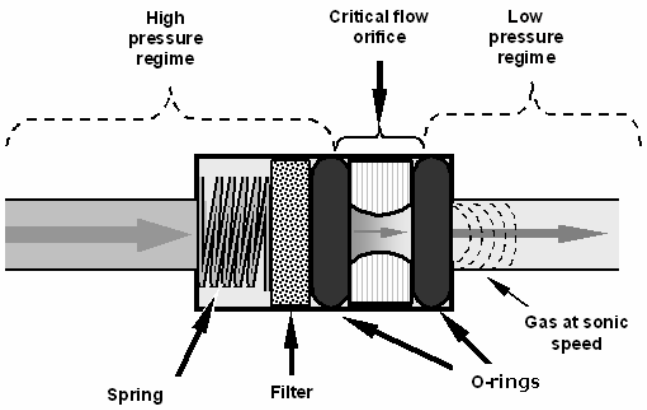


Figure 10-9: Flow Control Assembly & Critical Flow Orifice

The actual flow rate of gas through the orifice depends entirely on the size and shape of the aperture in the orifice and the upstream pressure. The larger the hole or the higher the upstream pressure, the more gas molecules pass through the orifice. The flow rate of the gas is also unaffected by small degradations in pump efficiency due to age as long as the 2:1 pressure difference is maintained.

Table 10-3: M9110E Gas Flow Rates

Location	Purpose	Orifice Diameter	Flowrate (nominal)
Sample gas inlet of reaction cell	Controls rate of flow of sample gas into the reaction cell.	0.010" (0.25 mm)	500 cm³/min
O_3 supply inlet of reaction cell.	Controls rate of flow of ozone gas into the reaction cell.	0.004" (0.10 mm)	80 cm³/min
Dry air return of Perma Pure® dryer	Controls flow rate of dry air return / purge air of the dryer.	0.004" (0.10 mm)	80 cm³/min
Vacuum manifold , auto-zero port.	Controls rate of sample gas flow when bypassing the reaction cell during the auto-zero cycle.	0.010" (0.25 mm)	500 cm³/min
Vacuum manifold, IZS exhaust port	Controls rate of flow of zero purge gas through the IZS option (when installed and enabled) when inactive.	0.004" (0.10 mm)	80 cm³/min

Note that the diameter of the critical orifice may change with temperature because of expansion of the orifice material (ruby) and, hence, the most critical flow orifices in the M9110E are maintained at a constant temperature inside the reaction cell. These are the

sample and O_3 flows. Table 10-3 shows the flow rates for each of the critical flow orifices of the M9110E. See Appendix B for spare part numbers of these orifices.

In addition to controlling the gas flows, the two critical flow orifices at the inlets of the reaction cell also maintain an underpressure inside the reaction cell, effectively reducing the number of molecules in the chamber and therefore increasing the chemiluminescence yield as the likelihood of third body quenching is reduced (Section 10.1.5.1). The M9110E sensitivity reaches a peak at about 2 in-Hg-A, below which the sensitivity drops due to a low number of molecules and decreased yield in the chemiluminescence reaction.

The other components of the flow control assemblies are:

- A sintered stainless steel filter, which prevents particulates from entering the reaction cell and potentially plug the orifice. Note that very fine sub-micron particles may still accumulate on that filter and slowly clog up either the filter or the orifice over time. See Chapter 11 on trouble-shooting sample flow for more information.
- Two O-rings are located before and after the critical flow orifice to seal the gap between the walls of the assembly housing and the critical orifice and force all gas through the orifice opening.
- A spring applies mechanical force to form the seal between the o-rings, the critical flow orifice and the assembly housing and to prevent the components to float up and turn on sudden pressure drops.

10.2.10. Pneumatic Sensors

NOTE
The M9110E displays all pressures in inches of mercury absolute (in-Hg-A), i.e. absolute pressure referenced against zero (a perfect vacuum).

The M9110E uses three pneumatic sensors to verify gas streams. These sensors are located on a printed circuit assembly, called the pneumatic pressure/flow sensor board, located just behind the sensor assembly.

10.2.10.1. Vacuum Manifold

The vacuum manifold is the central exit port for all analyzer pneumatics. All gas streams of the analyzer exit through this assembly and connect to the instrument's pump. Figure 10-10 shows the standard configuration. Configurations will vary depending on the optional equipment that is installed. An IZS option, for example, will add another FT8 connector and orifice assembly to the manifold, an optional sample dryer may add a Tee-fitting so that two ¼" tubes can be connected to the same port shown in the Figure.

At this time, the vacuum manifold does not yet support the orifice holder shown in Figure 9-7. To exchange the critical orifice installed in the vacuum manifold, the user needs to either blow the orifice out with reversed pressure or remove the entire manifold for this task. However, orifices installed in the vacuum manifold should not have to be cleaned under normal circumstances.

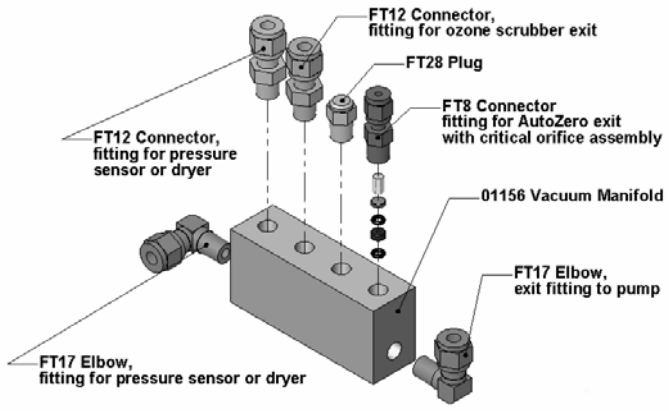


Figure 10-10: Vacuum Manifold, Standard Configuration

10.2.10.2. Sample Pressure Sensor

An absolute pressure transducer connected to the input of the NO/NO_X valve is used to measure the pressure of the sample gas before it enters the analyzer's reaction cell. This is the "upstream" pressure mentioned above, which is used to compute sample flow rate. In conjunction with the vacuum pressure sensor, it is also used to validate the critical flow condition (2:1 pressure ratio) through the sample gas critical flow orifice (Section 10.2.9). If the temperature/pressure compensation (TPC) feature is turned on (Section 10.4.3), the output of this sensor is also used to supply pressure data for that calculation.

The actual pressure value is viewable through the analyzer's front panel display as the test function **SAMP**. The flow rate of the sample gas is displayed as **SAMP FLW**..

10.2.10.3. Vacuum Pressure Sensor

An absolute pressure transducer connected to the exhaust manifold is used to measure the pressure downstream from and inside the instrument's reaction cell. The output of the sensor is used by the CPU to calculate the pressure differential between the gas upstream of the reaction cell and the gas downstream from it and is also used as the main diagnostic for proper pump operation. If the ratio between the upstream pressure and the downstream pressure falls below 2:1, a warning message (**SAMPLE FLOW WARN**) is displayed on the analyzer's front panel (Section 6.2.2) and the sample flow rate will display **XXXX** instead of an actual value. If this pressure exceeds 10 in-Hg-A, an **RCEL Pressure Warning** is issued, even though the analyzer will continue to calculate a sample flow up to ~14 in Hg.

Also, if the temperature/pressure compensation (TPC) feature is turned on (Section 10.4.3), the output of this sensor is used to supply pressure data for that calculation. This measurement is viewable through the analyzer's front panel as the test function **RCEL**.

10.2.10.4. O_3 Supply Air Flow Sensor

A mass flow meter connected between the Perma Pure® dryer and the O_3 generator measures the flow rate of O_3 supply air through the analyzer. This information is used to validate the O_3 gas flow rate. If the flow rate exceeds ±15% of the nominal flow rate (80

cm³/min), a warning message **OZONE FLOW WARNING** is displayed on the analyzer's front panel (Section 6.2.2) and the O_3 generator is turned off. As second warning, **OZONE GEN OFF**, is displayed. This flow measurement is viewable through instrument's front panel display as the test function **OZONE FL**.

10.2.11. Dilution Manifold

Certain applications require to measure NO_X in sample gases that do not contain any oxygen. However, the molybdenum NO_2 converter requires a minimum amount of oxygen to operate properly and to ensure constant conversion efficiency. For these special applications, the M9110E analyzer may be equipped with a dilution manifold (Figure 10-11) to provide the instrument with an internal sample stream that contains about 2.5% O_2. This manifold is mounted between converter housing and vacuum manifold on a small mounting bracket. The manifold is equipped with two orifice holders that control the flow of the O_2-free sample gas and the bleeds in a small amount of zero air before the combined sample stream goes to the NO/NO_X valve for measurement. The zero air is produced by an external zero air scrubber cartridge, mounted on the rear panel (Figure 3-3 and Figure 9-4).

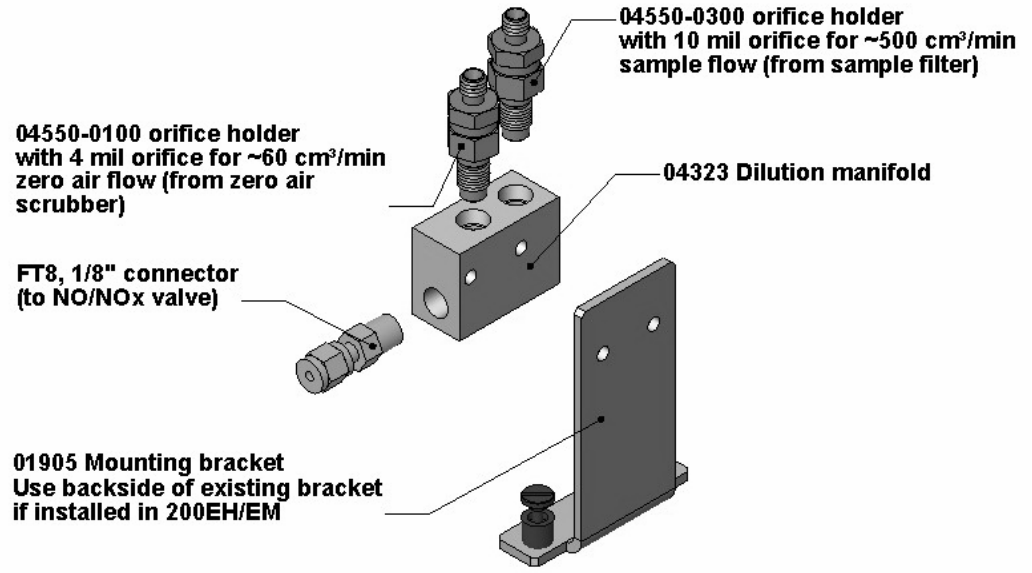


Figure 10-11: Dilution Manifold

Please inquire with Teledyne-API sales if the M9110E can be modified to fit your application.

10.3. Electronic Operation

Figure 10-12 shows a block diagram of the major electronic components of the M9110E.

The core of the analyzer is a microcomputer (CPU) that controls various internal processes, interprets data, calculates data, and reports results using specialized firmware developed by TAI. It communicates with the user, receives data from and issues commands to a variety

of peripheral devices through the motherboard, the main printed circuit assembly on the rear panel (Figure 3-2).

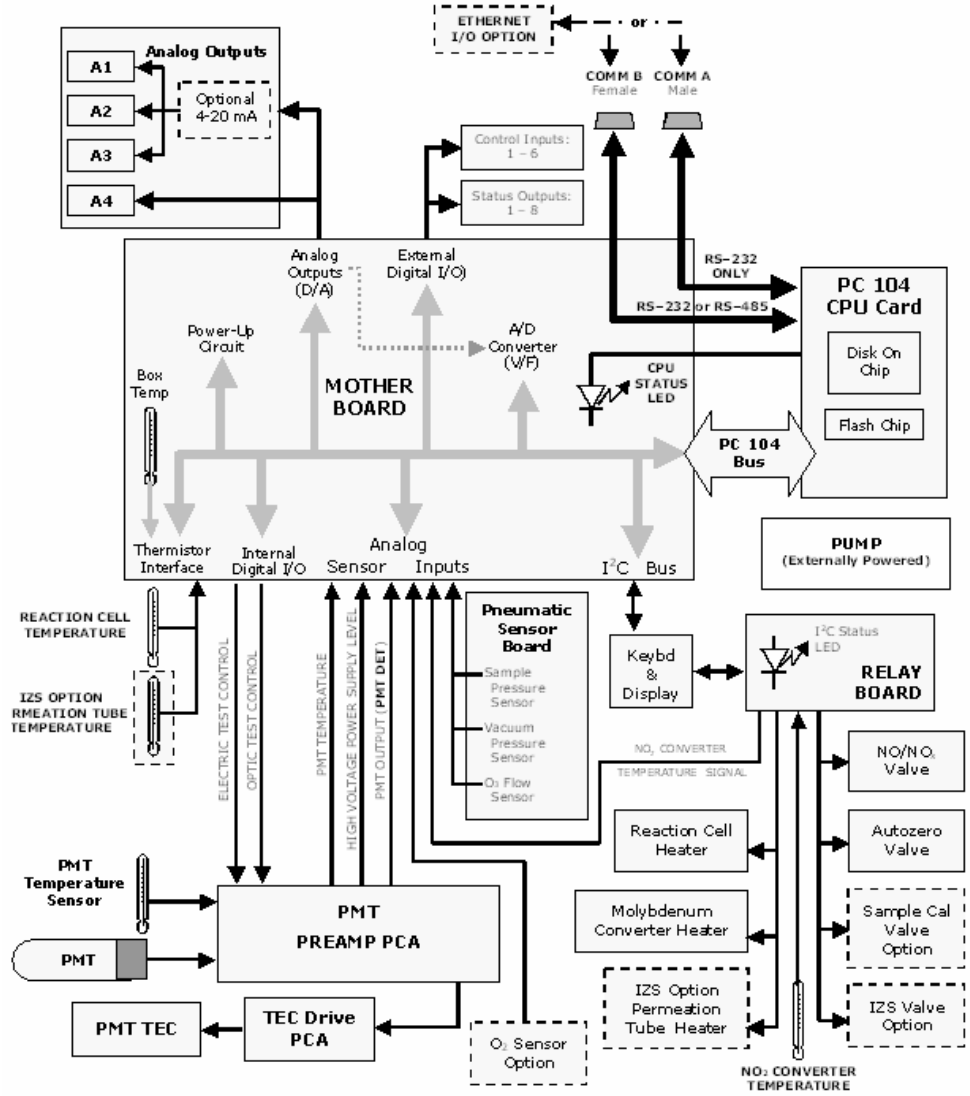


Figure 10-12: M9110E Electronic Block Diagram

10.3.1. CPU

The CPU is a low power (5 VDC, 0.8A max), high performance, 386-based microcomputer running a version of the DOS operating system. Its operation and assembly conform to the PC-104 specification, version 2.3 for embedded PC and PC/AT applications. It has 2 MB of DRAM memory on board and operates at 40 MHz clock rate over an internal, 32-bit data and address bus. Chip to chip data handling is performed by two 4-channel, direct memory

access (DMA) devices over data busses of either 8-bit or 16-bit bandwidth. The CPU supports both RS-232 and RS-485 serial protocols. Figure 10-13 shows the CPU board.

- The CPU communicates with the user and the outside world in a variety of ways:
- Through the analyzer's keyboard and vacuum fluorescence display over a clocked, digital, serial I/O bus using the I^2C protocol (read *I-square-C bus*)
- RS-232 and/or RS-485 serial ports (one of which can be connected to an Ethernet converter)
- Various analog voltage and current outputs
- Several digital I/O channels

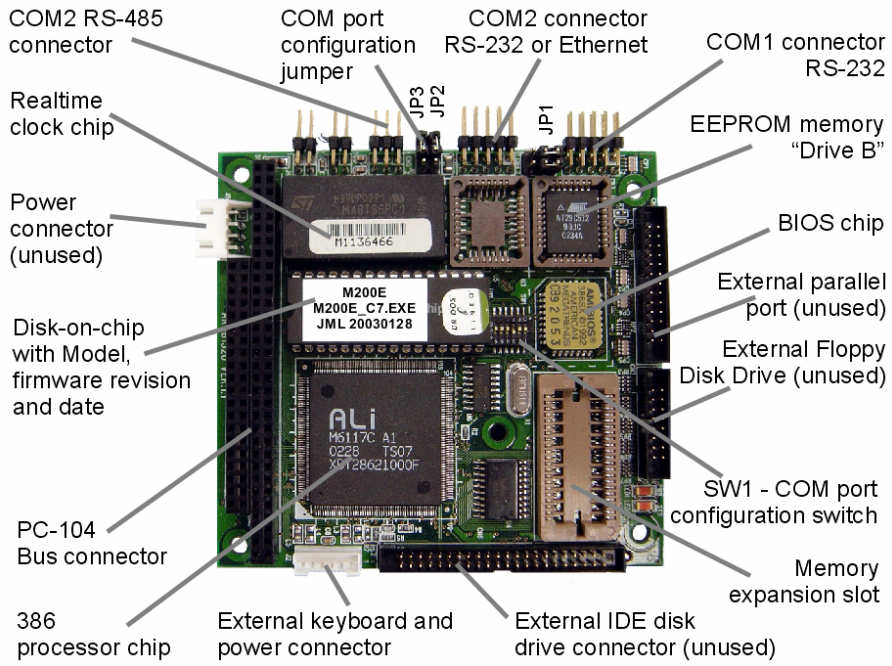


Figure 10-13: M9110E CPU Board Annotated

Finally, the CPU issues commands (also over the I2C bus) to a series of relays and switches located on a separate printed circuit assembly, the relay board (located in the right rear of the chassis on its own mounting bracket) to control the function of heaters and valves. The CPU includes two types of non-volatile data storage, one disk-on-chip and one or two flash chips.

10.3.1.1. Disk On Chip

Technically, the disk-on-chip is an EEPROM, but appears to the CPU as, behaves as, and performs the same functions in the system as an 8 mb disk drive, internally labeled as DOS drive C:\. It is used to store the computer's operating system files, the TAI firmware and peripheral files, and the operational data generated by the analyzer's internal data acquisition system (iDAS - Sections 10.4.5 and 6.11).

10.3.1.2. Flash Chip

The flash chip is another, smaller EEPROM with about 64 kb of space, internally labeled as DOS drive B:\. The M9110E CPU board can accommodate up to two EEPROM flash chips. The M9110E standard configuration is one chip with 64 kb of storage capacity, which is used to store the analyzer configuration as created during final checkout at the factory. Separating these data onto a less frequently accessed chip significantly decreases the chance of data corruption through drive failure.

In the unlikely event that the flash chip should fail, the analyzer will continue to operate with just the DOC. However, all configuration information will be lost, requiring the unit to be recalibrated.

10.3.2. Sensor Module, Reaction Cell & PMT

Electronically, the M9110E sensor assembly (Figure 10-14) consists of several subassemblies with different tasks: to detect the intensity of the light from the chemiluminescence reaction between NO and O_3 in the reaction cell, to produce a current signal proportional to the intensity of the chemiluminescence, to control the temperature of the PMT to ensure the accuracy and stability of the measurements and to drive the high voltage power supply that is needed for the PMT. The individual functions are described individually below, Section 11.6.6 shows the sensor assembly and its components.

10.3.2.1. Reaction Cell Heating Circuit

The stability of the chemiluminescence reaction between NO and O_3 can be affected by changes in the temperature and pressure of the O_3 and sample gases in the reaction cell. In order to reduce temperature effects, the reaction cell is maintained at a constant 50° C, just above the high end of the instrument's operation temperature range.

Two AC heaters, one embedded into the bottom of the reaction cell, the other embedded directly above the chamber's exhaust fitting, provide the heat source. These heaters operate off of the instrument's main AC power and are controlled by the CPU through a power relay on the relay board (Section 10.3.4). A thermistor, also embedded in the bottom of the reaction cell, reports the cell's temperature to the CPU through the thermistor interface circuitry of the motherboard (Section 10.3.5).

10.3.2.2. Photo Multiplier Tube (PMT)

The M9110E uses a photo multiplier tube (PMT) to detect the chemiluminescence created by the reaction of NO with O_3 in the reaction cell.

A typical PMT is a vacuum tube containing a variety of specially designed electrodes (Figure 10-14). Photons from the reaction are filtered by an optical high-pass filter, enter the PMT and strike a negatively charged photo cathode causing it to emit electrons. A high voltage potential across these focusing electrodes directs the electrons toward an array of high voltage dynodes. The dynodes in this electron multiplier array are designed so that each stage multiplies the number of emitted electrons by emitting multiple, new electrons. The greatly increased number of electrons emitted from one end of electron multiplier are collected by a positively charged anode at the other end, which creates a useable current signal. This current signal is amplified by the preamplifier board and then reported to the motherboard.

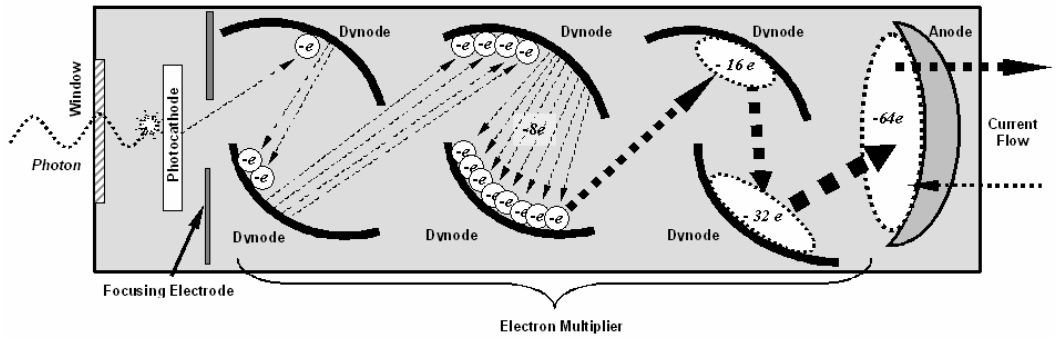


Figure 10-14: Schematic of Basic PMT Design and Functionality

A significant performance characteristic of the PMT is the voltage potential across the electron multiplier. The higher the voltage, the greater is the number of electrons emitted from each dynode of the electron multiplier, making the PMT more sensitive and responsive to small variations in light intensity but also increases random noise (dark noise). The gain voltage of the PMT used in the M9110E is usually set between 450 V and 800 V. This parameter is viewable through the front panel as test function **HVPS** (Section 6.2.1) and does not need to be changed unless the PMT or the HVPS itself is changed. For information on when and how to set this voltage, see Section 11.6.5.

The PMT is housed inside the sensor module assembly (Figure 11-7). This assembly also includes the high voltage power supply required to drive the PMT, an LED used by the instrument's optical test function (Section 6.7.5), a thermistor that measures the temperature of the PMT and various components of the PMT cooling system including the thermoelectric cooler (TEC).

10.3.2.3. PMT Cooling System

The performance of the analyzer's PMT is significantly affected by temperature. The warmer it is, the noisier its signal becomes and significant variations in PMT temperature will render the concentration signal useless, as it will directly reflect those variations.

The core part of the M9110E PMT cooling system is a thermoelectric cooler (TEC), which keeps the PMT temperature at a constant, low level (7±2°C) for optimum performance. Thermoelectric coolers are solid state (semi-conductor) heat pumps, which transfer heat from one side to the other when a DC current is passed through its circuits. Heat absorbed at the cold junction (the PMT cold-block) is pumped to the hot junction (the cooling fins) at a rate proportional to the current passing through the TEC circuit and the number of junctions. The TEC is just one of many components in the M9110E's PMT cooling system as shown in Figure 11-7.

10.3.2.4. TEC Control Board

The TEC control printed circuit assembly is located under the slanted shroud, next to the cooling fins and directly above the cooling fan. Using the amplified PMT temperature signal from the PMT preamplifier board, it sets the drive for the thermoelectric cooler. The warmer the PMT gets, the more current is passed through the TEC.

A red LED located on the top edge of this circuit board indicates that the control circuit is receiving power. Four test points are also located at the top of this assembly. For the definitions and acceptable signal levels of these test points see Chapter 11.

10.3.2.5. PMT Preamplifier

The PMT preamplifier board (Figure 10-15 and Figure 11-3) converts and amplifies the PMT current signal into a useable analog voltage **(PMTDET)** that can be used by the CPU to calculate the NO concentration of the gas in the reaction cell.

The output signal of the PMT is controlled by two different adjustments. First, the voltage across the electron multiplier array of the PMT is adjusted with a set of two hexadecimal switches. Adjusting this voltage directly affects the HVPS voltage and, hence, the signal from the PMT. Secondly, the gain of the amplified signal can further be adjusted through a potentiometer. These adjustments should only be performed when encountering problems that cannot be rectified with the software calibration. See Section 11.6.5 for this hardware calibration.

The PMT temperature control loop maintains the PMT temperature around 7° C and can be viewed as test function **PMT TEMP** on the front panel.

The electrical test (ETEST) circuit generates a constant, electronic signal that simulates the output of the PMT. By bypassing the detector's actual signal, it is possible to test most of the signal handling and conditioning circuitry on the PMT preamplifier board. See Section 6.7.6 for instructions on performing this test.

The optical test (OTEST) consists of an LED inside the PMT cold block that creates a light signal, which can be measured with the PMT. If zero air is supplied to the analyzer, the entire measurement capability of the sensor module can be tested including the PMT and the current to voltage conversion circuit on the PMT preamplifier board.

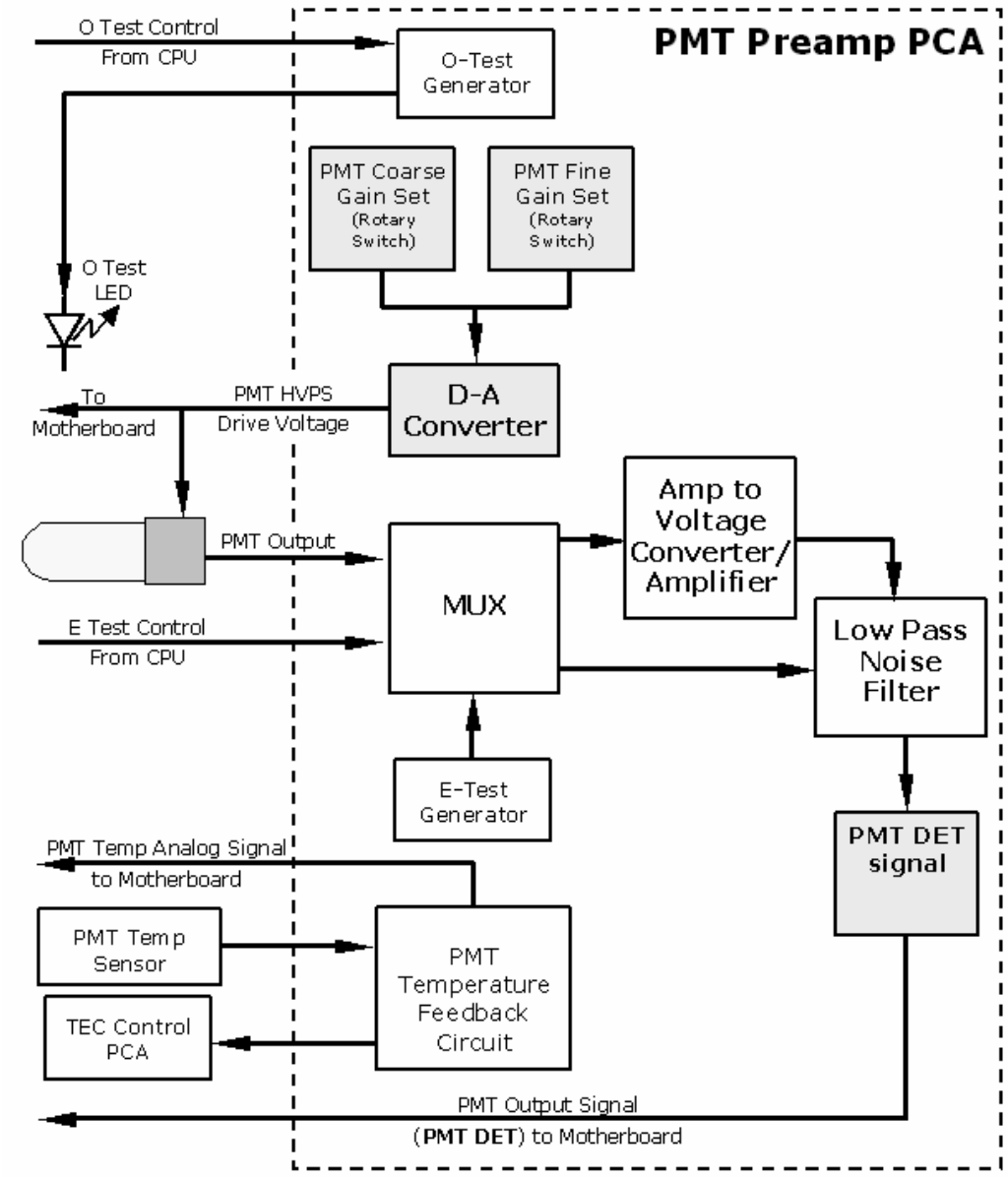


Figure 10-15: PMT Preamp Block Diagram

10.3.3. Pneumatic Sensor Board

The flow and pressure sensors of the M9110E are located on a printed circuit assembly just behind the PMT sensor. Refer to Section 11.5.15 for a figure and on how to test this assembly. The signals of this board are supplied to the motherboard for further signal

processing. All sensors are linearized in the firmware and can be span calibrated from the front panel.

10.3.4. Relay Board

The relay board is the central switching and power distribution unit of the analyzer. It contains power relays, valve drivers and status LEDs for all heated zones and valves, as well as thermocouple amplifiers, power distribution connectors and the two switching power supplies of the analyzer. The relay board communicates with the motherboard over the I^2C bus and can be used for detailed trouble-shooting of power problems and valve or heater functionality. See Figure 11-4 for an annotated view of the relay board.

10.3.4.1. Heater Control

The M9110E uses a variety of heaters for its individual components. All heaters are AC powered and can be configured for 100/120 VAC or 220/230VAC at 50-60 Hz. The M9110E has five power relays, only some of which are used for the following circuits.

The two reaction cell heaters are electronically connected in parallel for analyzers at 100/120 VAC line power and in series for units configured for 220/230 VAC. One configuration plug on the relay board determines the power configuration for the entire analyzer.

In order to operate efficiently, the NO_2 converter must be heated to 315°C. An AC band heater wrapped around the NO_2 converter cartridge contains two heater coils that can also be configured with the above configuration plug. A thermocouple imbedded in the heater measures the temperature and feeds a small voltage to the relay board's thermocouple amplifier, which, in turn, transmits the linearized analog voltage to the motherboard.

On units with IZS options installed, an additional set of AC heaters is attached to the IZS oven. Some special M9110E models may have other, non-standard heating zones installed, such as a bypass manifold.

10.3.4.2. Valve Control

The relay board also hosts two valve driver chips, each of which can drive up four valves. The main valve assembly in the M9110E is the NO/NO_X - Auto-zero solenoid valve component mounted right in front of the NO_2 converter housing. These two valves are actuated with 12 V supplied from the relay board and driven by the CPU through the I^2Z bus.

A second set of valves may be installed if the zero/span valve or the IZS option is enabled in the analyzer. Specialty manifold valves may be present in the analyzer.

10.3.4.3. Status LEDs

Sixteen LEDs are located on the analyzer's relay board to indicate the status of the analyzer's heating zones and valves as well as a general operating watchdog indicator. Section 11.1.4.3 shows the states of these LEDs and their respective functionality and location.

Special status circuitry monitors the communication between motherboard and relay board and drives the red LED labeled D1 (watchdog LED). Should this LED ever stay **ON** or **OFF**

for 30 seconds, the watchdog circuit will assume lost connection and automatically turn of all valves and heaters and may cause the analyzer to reboot or the I^2Z bus to hang up.

10.3.5. Motherboard

This is the largest electronic assembly in the analyzer and is mounted to the rear panel as the base for the CPU board and all I/O connectors. This printed circuit assembly provides a multitude of functions including A/D conversion, digital input/output, PC-104 to I^2C translation, temperature sensor signal processing and is a pass through for the RS-232 and RS-485 signals.

10.3.5.1. A to D Conversion

Analog signals, such as the voltages received from the analyzer's various sensors, are converted into digital signals that the CPU can understand and manipulate by the analog to digital converter (A/D).Under the control of the CPU, this functional block selects a particular signal input and then coverts the selected voltage into a digital word.

The A/D consists of a voltage-to-frequency (V-F) converter, a programmable logic device (PLD), three multiplexers, several amplifiers and some other associated devices. The V-F converter produces a frequency proportional to its input voltage. The PLD counts the output of the V-F during a specified time period, and sends the result of that count, in the form of a binary number, to the CPU.

The A/D can be configured for several different input modes and ranges but in the is used in uni-polar mode with a +5V full scale. The converter includes a 1% over and under-range. This allows signals from -0.05V to +5.05V to be fully converted.

For calibration purposes, two reference voltages are supplied to the A/D converter: Reference ground and +4.096 VDC. During calibration, the device measures these two voltages, outputs their digital equivalent to the CPU. The CPU uses these values to compute the converter's offset and slope and uses these factors for subsequent conversions. See Section 6.7.8 for instructions on performing this calibration.

10.3.5.2. Sensor Inputs

The key analog sensor signals are coupled to the A/D converter through the master multiplexer from two connectors on the motherboard. Terminating resistors (100 kΩ) on each of the inputs prevent cross-talk between the sensor signals.

- The PMT detector output from the PMT preamplifier is used in the computation of the NO, NO_X and NO_2 concentrations displayed on the front panel display and reported through the instrument's analog outputs and COM ports.
- The PMT high voltage is based on the drive voltage from the preamplifier board. It is digitized and sent to the CPU where it is used to calculate the voltage setting of the HVPS and stored in the instrument's memory as the test function **HVPS.**
- The PMT temperature is measured with a thermistor inside the PMT cold block. Its signal is amplified by the PMT temperature feedback circuit on the preamplifier board and is digitized and sent to the CPU where it is used to calculate the current temperature of the PMT. This measurement is stored in the iDAS and displayed as test function **PMT TEMP**.

- The NO_2 converter temperature is measured with a Type-K thermocouple attached to the NO_2 converter heater and its analog signal is amplified by the circuitry on the relay board. It is sent to the CPU and then digitized and is used to calculate the current temperature of the NO_2 converter. It is also stored in the iDAS and reported as test function **MOLY TEMP**.
- The sample gas pressure is measured upstream of the reaction cell, stored in the iDAS and reported as **SAMPLE**. The vacuum gas pressure is measured downstream of the reaction cell and is stored in the iDAS and reported as **RCEL**. For more information on these sensor's functions see Section 10.2.10.
- The O_3 gas flow is measured upstream of the ozone generator, stored in the iDAS and reported as test function **OZONE FL**. For more information on this sensor's function see Section 10.2.10.

10.3.5.3. Thermistor Interface

This circuit provides excitation, termination and signal selection for several negative-coefficient, thermistor temperature sensors located inside the analyzer. They are:

- The reaction cell temperature sensor is a thermistor embedded in the reaction cell manifold. This temperature is used by the CPU to control the reaction cell heating circuit and as a parameter in the temperature/pressure compensation algorithm. This measurement is stored in the analyzer's iDAS and reported as test function **RCEL TEMP**.
- BOX TEMPERATURE SENSOR: A thermistor is attached to the motherboard. It measures the analyzer's inside temperature. This information is stored by the CPU and can be viewed by the user for troubleshooting purposes through the front panel display. It is also used as part of the NO, NO_X and NO_2 calculations when the instrument's Temperature/Pressure Compensation feature is enabled. This measurement is stored in the analyzer. Memory as the test function **BOX TEMP** and is viewable as a test function (Section 6.2.1) through the analyzer's front panel.
- The IZS option's thermistor is attached to the IZS oven and reports the current temperature of the NO_2 permeation source to the CPU as part of a control loop that keeps the tube at a constant temperature. It is stored and reported as test function **IZS TEMP**.
- The thermistor inside the PMT cold block as well as the thermistor located on the preamplifier board are both converted to analog signals on the preamplifier board before being sent to the motherboard's A/D converter. They are not connected to the motherboard's thermistor circuitry. The cold block temperature is stored and reported as test function **PMT TEMP**, whereas the preamplifier board temperature is neither stored nor reported. It is used only as a reference internal to the preamplifier.

10.3.5.4. Analog Outputs

The analyzer comes equipped with four analog outputs. On the instrument's rear panel **ANALOG** connector, they are labeled **A1**, **A2**, **A3** and **A4**.

Outputs labeled **A1**, **A2** and **A3** carry the concentration signals of NO_X, NO and NO_2, respectively. A variety of scaling measurement and electronic factors apply to these signals. See Section 6.6 for information on setting the reporting range type and measurement range scaling factors for these output channels. See Sections 6.7 for instructions on setting the electronic scaling factors for these channels.

The output labeled **A4** can be set by the user (Section 6.7.2) to carry the signal of any of these **TEST** parameters: none **, PMT DETECTOR, OZONE FLOW, SAMPLE FLOW, SAMPLE PRESSURE, RCELL PRESSURE, RCELL TEMP, MANIFOLD TEMP, IZS TEMP, CONV TEMP, PMT TEMP, BOX TEMP, HVPS VOLTAGE.**

In its standard configuration, the analyzer comes with all four of these channels set up to report a DC voltage (default A4 signal is **NONE**). However, current loop drivers can be purchased for the first three of these outputs, A1 to A3 (Section 5.3. for this optional equipment, Section 6.7.3.5 for setup).

All of the analog outputs are connected back to the A/D converter through a loop-back circuit, which permits the voltage outputs to be calibrated by the CPU without the need for any additional tools or fixtures (Section 6.7.3).

10.3.5.5. External Digital I/O

The external digital I/O performs two functions.

The **STATUS** outputs carry logic-level (5V) signals through an optically isolated 8-pin connector on the rear panel of the analyzer. These outputs convey on/off information about certain analyzer conditions such as **CONC VALID**. They can be used to interface with certain types of programmable devices (Section 6.9.1).

The **CONTROL** inputs can be initiated by applying 5V DC power from an external source such as a PLC or data logger (Section 6.9.2). Zero and span calibrations can be initiated by contact closures on the rear panel.

10.3.5.6. I^2C Data Bus

I^2C is a two-wire, clocked, digital serial I/O bus that is used widely in commercial and consumer electronic systems. A transceiver on the motherboard converts data and control signals from the PC-104 bus to I^2C. The data are then fed to the keyboard/display interface and finally onto the relay board.

Interface circuits on the keyboard/display interface and relay board convert the I^2C data to parallel inputs and outputs. An additional interrupt line from the keyboard to the mother-board allows the CPU to recognize and service key strokes on the keyboard.

10.3.5.7. Power-up Circuit

This circuit monitors the +5V power supply during analyzer start-up and sets the analog outputs, external digital I/O ports, and I^2C circuitry to specific values until the CPU boots and the instrument software can establish control.

10.3.6. Power Supply/ Circuit Breaker

The analyzer operates in two main AC power ranges: 100-120 VAC and 220-240 VAC (both ± 10%) between 47 and 63 Hz. Note, however, that the analyzer's pump is specifically configured for one voltage and one frequency only. Individual analyzers are set up at the factory to accept one of these two voltage ranges. As illustrated in Figure 10-16, power enters the analyzer through a standard IEC 320 power receptacle located on the rear panel of the instrument. From there, it is routed through the ON/OFF switch located in the lower

right corner of the front panel and back to the relay board, which carries the switching power supplies.

AC line power is stepped down and converted to DC power by two switching power supplies, one for +12 VDC (5 A) for various valves and the TEC, and a second supply that provides +5 VDC (3 A) and ±15 VDC (1.5/0.5 A) for logic and analog circuitry as well as the ozone generator. All AC and DC Voltages are distributed through the relay board. A 5 ampere circuit breaker is built into the ON/OFF switch. In case of a wiring fault or incorrect supply power, the circuit breaker will automatically turn off the analyzer. Under normal operation, the M9110E draws about 1.5 A at 115 V and 2.0 A during start-up.

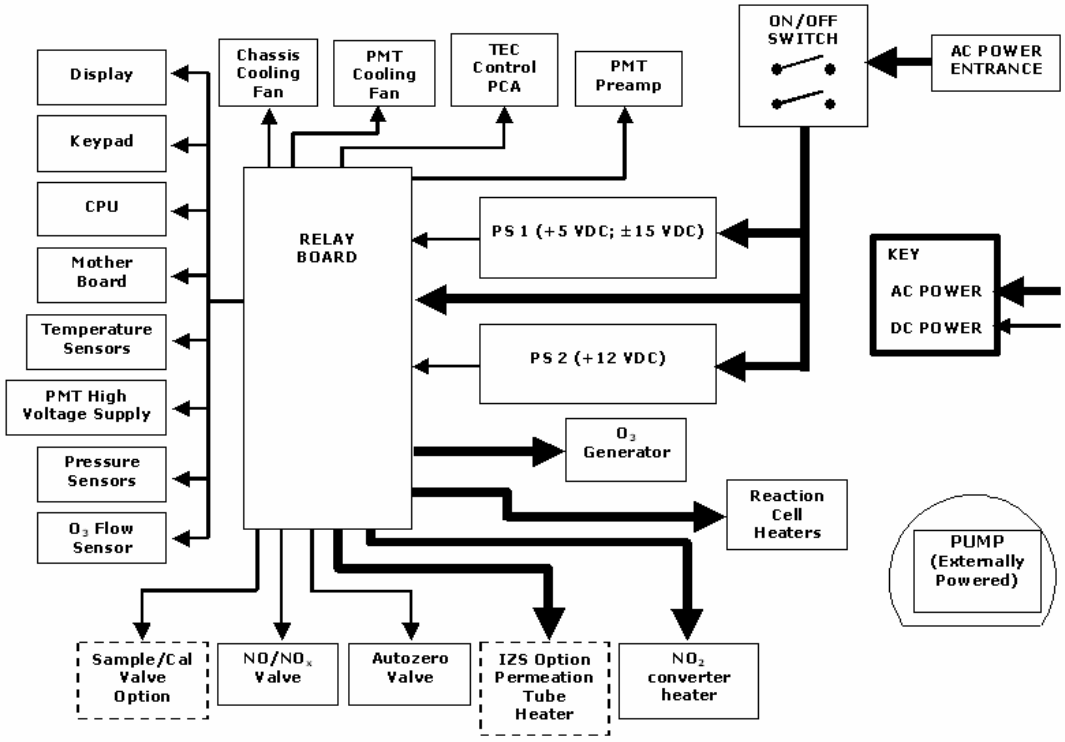


Figure 10-16: Power Distribution Block Diagram

CAUTION
Should the power circuit breaker trip correct the condition causing this situation before turning the analyzer back on.

10.3.7. Communications Interface

The analyzer has several ways to communicate with the outside world as shown in Figure 10-17. Users can enter data and receive information directly through the front panel keypad and display. Direct communication with the CPU is also available through the analyzer's RS-232 and RS-485 ports. The analyzer can also send and receive different kinds of information

through its external, digital I/O connectors and through the four analog outputs, all located on the rear panel.

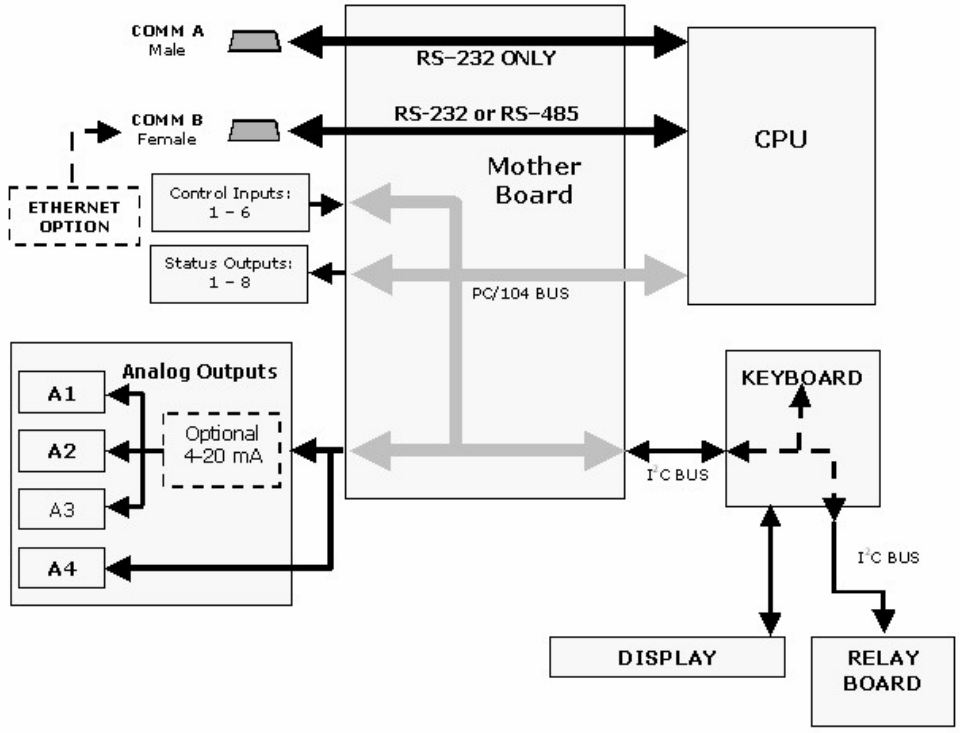


Figure 10-17: M9110E Electronic Interface Block Diagram

10.3.7.1. Front Panel

The front panel of the analyzer is hinged at the bottom and may be opened to gain access to various components mounted on the panel itself or located near the front of the instrument (such as the particulate filter). Two fasteners located in the upper right and left corners of the panel lock it in place, whereas a locking screw in the center top prevents users without tools from accessing the interior of the analyzer (Figure 3-2).

10.3.7.2. Display

The main display of the analyzer is an vacuum florescent display with two lines of 40 text characters each. Information is organized in the following manner:

Mode Field: The far left portion of the top line of text displays the name of the operation mode in which the analyzer is currently operating for more information on operation modes see Section 6.1.

Message Field: The center portion of the top line of text displays a variety of informational messages. Warning messages are displayed here as are responses by the analyzer to queries for operation data about the instrument. During interactive tasks, such as instru-

ment calibration or certain diagnostic procedures, the instrument's response messages are also displayed here.

Concentration Field: The far right portion of the top line of text displays the concentration of the sample gas currently being measured by the analyzer. The number reported here is the actual concentration of the sample gas reported in whatever units the user selects (Section 6.5.6). This number remains unaffected, regardless of how the ranges of the instrument's analog outputs are configured.

Key Definition Field: The bottom line of text displays is reserved for defining the test function of the row of keys just below the display. These definitions change depending on which part of the software menu tree is currently being displayed.

10.3.7.3. Keypad

The row of eight keys just below the vacuum florescent display are the main method by which the user interacts with the analyzer. These keys are context sensitive and are dynamically re-defined as the user moves around in the software menu structure.

10.3.7.4. Front Panel States LED's

There are three status LED's located in the upper right corner of the M9110E's front panel:

Table 10-4: Front Panel Status LED's

Name	Color	State	Definition
SAMPLE	Green	Off	Unit is not operating in sample mode, iDAS is disabled.
		On	Unit is operating in Sample Mode, Front Panel Display being updated, iDAS data being stored.
		Blinking	Unit is operating in sample mode, front panel display being updated, iDAS hold-off mode is ON, iDAS disabled
CAL	Yellow	Off	Auto Cal disabled
		On	Auto Cal enabled
		Blinking	Unit is in calibration mode
FAULT	Red	Off	No warning exists
		Blinking	Warning(s) exist

10.3.7.5. Display / Keyboard Interface Electronics

The display of the analyzer is a vacuum fluorescence display with two lines of 40 text characters each. Information is organized as shown in Figure 3-2. Figure 10-17 shows the electronic diagram of the display / keyboard circuitry.

Through the keyboard/display interface electronics, the M9110E Analyzer captures the status of the eight front panel keys, alerts the CPU when keys are depressed and manages communications between the keyboard, the CPU and the front panel display. Except for the keyboard interrupt status bit, all communication between the CPU and the keyboard/display is handle by the instrument's I^2C bus. The CPU controls the clock signal and determines when the various devices on the bus are allowed to talk or required to listen. Data packets are labeled with addresses that identify for which device the information is intended.

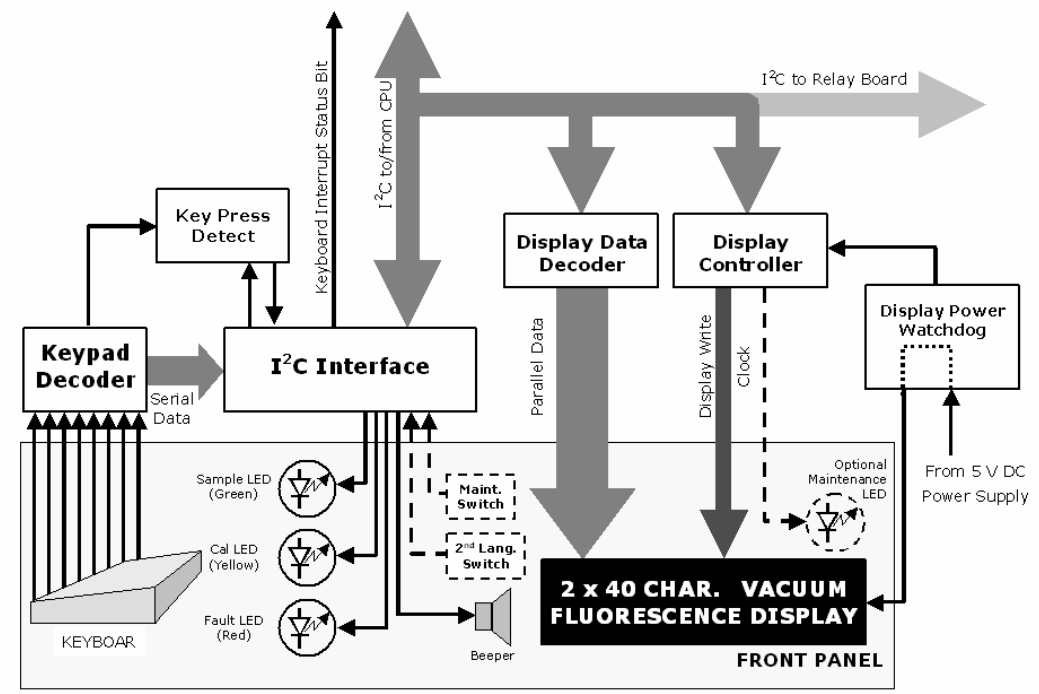


Figure 10-18: Keyboard and Display Interface Block Diagram

10.4. Software Operation

The M9110E NO_X analyzer's core module is a high performance, 386-based microcomputer running a version of DOS. On top of the DOS shell, special software developed by TAI interprets user commands from various interfaces, performs procedures and tasks, stores data in the CPU's memory devices and calculates the concentrations of NO_X in the sample gas. Figure 10-19 shows a block diagram of this software functionality.

10.4.1. Adaptive Filter

The M9110E NO_X analyzer software processes sample gas concentration data through a built-in adaptive filter. Unlike other analyzers that average the output signal over a fixed time period, the M9110E averages over a defined number of samples, with samples being about 8 seconds apart (reflecting the switching time of 4 s each for NO and NO_X). This technique is known as boxcar filtering. During operation, the software may automatically switch between two different filters lengths based on the conditions at hand.

During constant or nearly constant concentrations, the software, by default, computes an average of the last 42 samples, or approximately 5.6 minutes. This provides smooth and stable readings and averages out a considerable amount of random noise for an overall less noisy concentration reading.

If the filter detects rapid changes in concentration the filter reduces the averaging to only 6 samples or about 48 seconds to allow the analyzer to respond more quickly. Two conditions

must be simultaneously met to switch to the short filter. First, the instantaneous concentration must differ from the average in the long filter by at least 50 ppb. Second, the instantaneous concentration must differ from the average in the long filter by at least 10% of the average in the long filter.

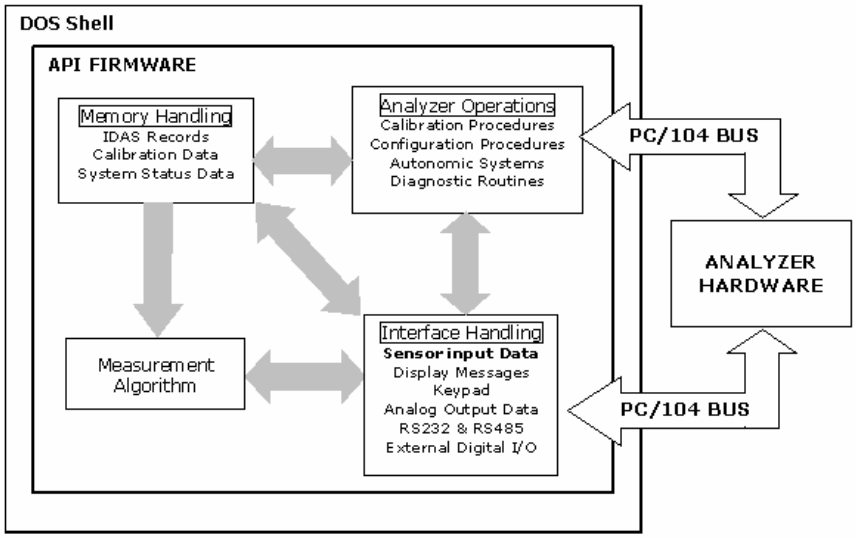


Figure 10-19: Schematic of Basic Software Operation

If necessary, these boxcar filter lengths can be changed between 1 (no averaging) and 1000 samples but with corresponding tradeoffs in rise time and signal-to-noise ratio. Signal noise increases accordingly when in adaptive filter mode, but remains within the official M9110E specifications defined by the EPA as long as the filter size remains at or above 3 samples.

In order to avoid frequent switching between the two filter sizes, the analyzer has a delay of 120 s before switching out of adaptive filter mode, even if the two threshold conditions are no longer met.

10.4.2. Calibration - Slope and Offset

Aside from the hardware calibration of the preamplifier board (Section 11.6.5) upon factory checkout, calibration of the analyzer is usually performed in software. During instrument calibration (Chapters 7 and 8) the user enters expected values for span gas concentration through the front panel keypad and supplies the instrument with sample gas of know NO and NO_X concentrations. The readings are then compared to the expected values and the software computes values for the new instrument slope and offset for both NO and NO_X response. These values are stored in memory for use in calculating the NO, NO_X and NO_2 concentration of the sample gas. By default, the iDAS stores 200 software calibration settings for documentation, review and data analysis.

Instrument slope and offset values recorded during the last calibration can be viewed on the front panel. **NO SLOPE**, **NOX SLOPE**, **NO OFFS** and **NOX OFFS** are four of the test parameters accessible through the **<TST TST>** buttons.

10.4.3. Temperature/Pressure Compensation (TPC)

The software features a compensation of some temperature and pressure changes critical in the measurement of NO and NO_X concentration. When the TPC feature is enabled (default setting), the analyzer divides the value of the PMT output signal (**PMTDET)** by a value called **TP_FACTOR**. **TP_FACTOR** is calculated according to the following equation.

$$TP_FACTOR = A\left[\frac{RCELL\,TEMP\,(K)}{323\,(K)}\right] \times B\left[\frac{7\,(in\,Hg)}{RCEL\,(in\,Hg)}\right] \times C\left[\frac{SAMP\,(in\,Hg}{29.92\,(in\,Hg)}\right] \times D\left[\frac{BOX\,TEMP\,(K)}{298\,(K)}\right] \quad \textbf{Eq 10-5}$$

Where A, B, C, D are gain functions. The four parameters used to compute TP_FACTOR are:

- **RCELL TEMP**: The temperature of the reaction cell, measured in K.
- **RCEL**: The pressure of the gas in the vacuum manifold, measured in in-Hg-A.
- **SAMP**: The pressure of the sample gas before it reaches the reaction cell, measured in in-Hg-A. This measurement is ~1 in-Hg-A lower than atmospheric pressure.
- **BOX TEMP**: The temperature inside the analyzer's case measured in K. This is typically about 5 K higher than room temperature.

The current value of all four of these measurements are viewable as **TEST FUNCTIONS** through the instrument's front panel display.

Note that, as **RCEL TEMP, BOX TEMP** and **SAMP** pressure increase, the value of **TP_FACTOR** increases and, hence, the PMTDET value decreases. Conversely, increases in the reaction cell pressure (**RCEL**) decrease **TP_FACTOR** and, hence increase the **PMTDET** value. These adjustments are meant to counter-act changes in the concentrations caused by these parameters.

Each of the terms in the above equation is attenuated by a gain function with a numerical value based on a preset gain parameter (shown below in *CAPITALIZED ITALICS)* normalized to the current value of the parameter being attenuated. The gain functions A, B, C and D are defined as:

$$A = 1 + [(\frac{rcell_temp(K)}{323(K)} - 1) \times RCTEMP_TPC_GAIN] \quad \textbf{Eq 10-6}$$

$$B = 1 + [(\frac{7("Hg)}{rcell_pressure("Hg)} - 1) \times RCPRESS_TPC_GAIN] \quad \textbf{Eq 10-7}$$

$$C = 1 + [(\frac{rcell_temp(K)}{323(K)} - 1) \times SPRESS_TPC_GAIN] \quad \textbf{Eq 10-8}$$

$$D = 1 + [(\frac{box_temp(K)}{298(K)} - 1) \times BXTEMP_TPC_GAIN] \quad \textbf{Eq 10-9}$$

The preset gain parameters are set at the factory and may vary from analyzer to analyzer. Section 6.5 describes the method for enabling/disabling the TPC feature.

10.4.4. NO_2 Converter Efficiency Compensation

Over time, the molybdenum in the NO_2 converter oxidizes and looses its original capacity of converting NO_2 into NO, eventually resulting in a decreased converter efficiency (CE). Even though we recommend to replace the converter if CE drops below 96%, the analyzer's firmware allows adjusting minor deviations of the CE from 1.000 and enables reporting the true concentrations of NO_2 and NO_X. Converter efficiency is stored in the instrument's memory as a decimal fraction that is multiplied with the NO_2 and NO_X measurements to calculate the final concentrations for each. Periodically, this efficiency factor must be measured and - if it has changed from previous measurements - entered into the analyzer's memory (Section 7.1.7). Note that EPA applications do not allow an analyzer to be operated if efficiency is below 96% or above 102%, even though the analyzer would allow to adjust for larger discrepancies.

10.4.5. Internal Data Acquisition System (iDAS)

The iDAS is designed to implement predictive diagnostics that stores trending data for users to anticipate when an instrument will require service. Large amounts of data can be stored in non-volatile memory and retrieved in plain text format for further processing with common data analysis programs. The iDAS has a consistent user interface among all TAI A- and E-series instruments. New data parameters and triggering events can be added to the instrument as needed. Section 6.9.10 describes the iDAS and its default configuration in detail, Chapter 9 shows the parameters that can be used for predictive diagnostics.

Depending on the sampling frequency and the number of data parameters, the iDAS can store several months of data, which are retained even when the instrument is powered off. However, if new firmware or a new iDAS configuration are uploaded to the analyzer, we recommend retrieving data before doing so to avoid data loss. The iDAS permits users to access the data through the instrument's front panel or the remote interface. The latter can automatically report stored data for further processing. APICOM, a user-friendly remote control program is the most convenient way to view, retrieve and store iDAS data (Section 6.11.5).

11. TROUBLESHOOTING & REPAIR

This section contains a variety of methods for identifying and solving performance problems with the analyzer.

NOTE
The operations outlined in this chapter must be performed by qualified maintenance personnel only.

CAUTION
Risk of electrical shock. Some operations need to be carried out with the analyzer open and running. Exercise caution to avoid electrical shocks and electrostatic or mechanical damage to the analyzer. Do not drop tools into the analyzer or leave those after your procedures. Do not shorten or touch electric connections with metallic tools while operating inside the analyzer. Use common sense when operating inside a running analyzer.

11.1. General Troubleshooting

The analyzer has been designed so that problems can be rapidly detected, evaluated and repaired. During operation, the analyzer continuously performs diagnostic tests and provides the ability to evaluate its key operating parameters without disturbing monitoring operations.

A systematic approach to troubleshooting will generally consist of the following five steps:

- Note any warning messages and take corrective action as necessary.
- Examine the values of all TEST functions and compare them to factory values. Note any major deviations from the factory values and take corrective action.
- Use the internal electronic status LED's to determine whether the electronic communication channels are operating properly. Verify that the DC power supplies are operating properly by checking the voltage test points on the relay board. Note that the analyzer's DC power wiring is color-coded and these colors match the color of the corresponding test points on the relay board.
- Suspect a leak first! Customer service data indicate that the majority of all problems are eventually traced to leaks in the pneumatic system of the analyzer (including the external pump), the source of zero air or span gases or the sample gas delivery system. Check for gas flow problems such as clogged or blocked internal/external gas lines, damaged seals, punctured gas lines, a damaged pump diaphragm, etc.
- Follow the procedures defined in Section 3.5.4. to confirm that the analyzer's vital functions are working (power supplies, CPU, relay board, keyboard, PMT cooler, etc.). See Figure 3-2, Figure 3-3, and Figure 3-4 for general layout of components and sub-assemblies in the analyzer. See the wiring interconnect diagram (document 04504) and interconnect list (document 04496) in Appendix D.

11.1.1. Warning Messages

The most common and/or serious instrument failures will result in a warning message displayed on the front panel. Table A-2 in Appendix A-3 contains a list of warning messages, along with their meaning and recommended corrective action.

It should be noted that if more than two or three warning messages occur at the same time, it is often an indication that some fundamental analyzer sub-system (power supply, relay board, motherboard) has failed rather than an indication of the specific failures referenced by the warnings. In this case, a combined-error analysis needs to be performed.

The analyzer will alert the user that a warning is active by displaying the keypad labels **MSG** and **CLR** on the front panel and a text message in the top center line of the display as shown in this example:

SAMPLE	**AZERO WARNING**	**NOX =123.4**
< TST TST >	**CAL**	**MSG CLR SETUP**

The analyzer will also issue a message to the serial port and cause the red FAULT LED on the front panel to blink.

To view or clear a warning messages press:

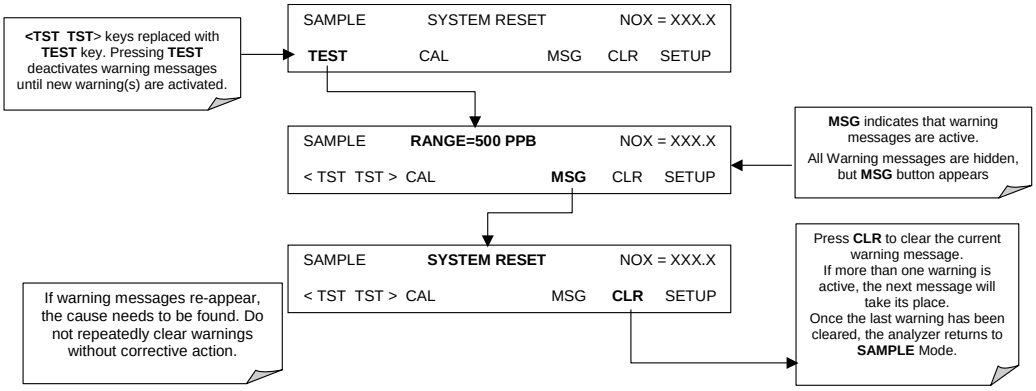


Figure 11-1: Viewing and Clearing Warning Messages

11.1.2. Fault Diagnosis with Test Functions

Besides being useful as predictive diagnostic tools, the TEST functions, viewable from the front panel, can be used to isolate and identify many operational problems when combined with a thorough understanding of the analyzer's theory of operation (Chapter 10). We recommend to use the APICOM remote control program to download, graph and archive TEST data for analysis and long-term monitoring of diagnostic data (Section 6.11.5).

The acceptable ranges for these test functions are listed in Appendix A-3. The actual values for these test functions on checkout at the factory were also listed in the *Final Test and Validation Data Sheet*, which was shipped with the instrument. Values outside the acceptable ranges indicate a failure of one or more of the analyzer's subsystems. Functions with values that are within the acceptable range but have significantly changed from the

measurements recorded on the factory data sheet may also indicate a failure or a maintenance item. A problem report worksheet has been provided in Appendix C (TAI part number 04503) to assist in recording the value of these test functions. The following table contains some of the more common causes for these values to be out of range.

Table 11-1: Test Functions - Possible Causes for Out-Of-Range Values

Test Function	Indicated Failure(s)
NOx STB	Unstable concentrations; leaks
SAMPLE Fl	Leaks; clogged critical flow orifice
OZONE FL	Leaks; clogged critical flow orifice
PMT	Calibration off; HVPS problem; no flow (leaks)
NORM PMT	AutoZero too high
AZERO	Leaks; malfunctioning NONOx or AutoZero valve; O_3 air filter cartridge exhausted
HVPS	HVPS broken; calibration off; preamp board circuit problems
RCELL TEMP	Malfunctioning heater; relay board communication (I^2C bus); relay burnt out
BOX TEMP	Environment out of temperature operating range; broken thermistor
PMT TEMP	TEC cooling circuit broken; relay board communication (I^2C bus); 12 V power supply
IZS TEMP (option)	Malfunctioning heater; relay board communication (I^2C bus); relay burnt out
MOLY TEMP	Malfunctioning heater; disconnected or broken thermocouple; relay board communication (I^2Z bus); relay burnt out; incorrect AC voltage configuration
RCEL (pressure)	Leak; malfunctioning valve; malfunctioning pump; clogged flow orifices
SAMP (pressure)	Leak; malfunctioning valve; malfunctioning pump; clogged flow orifices; sample inlet overpressure;
NOX SLOPE	HVPS out of range; low-level (hardware) calibration needs adjustment; span gas concentration incorrect; leaks
NOX OFF	Incorrect span gas concentration; low-level calibration off
NO SLOPE	HVPS out of range; low-level calibration off; span gas concentration incorrect; leaks
NO OFFS	Incorrect span gas concentration; low-level calibration off
Time of Day	Internal clock drifting; move across time zones; daylight savings time?

11.1.3. Using the Diagnostic Signal I/O Function

The signal I/O parameters found under the diagnostics (DIAG) menu combined with a thorough understanding of the instrument's theory of operation (Chapter 10) are useful for troubleshooting in three ways:

- The technician can view the raw, unprocessed signal level of the analyzer's critical inputs and outputs.
- All of the components and functions that are normally under instrument control can be manually changed.
- Analog and digital output signals can be manually controlled.

This allows to systematically observe the effect of these functions on the operation of the analyzer. Figure 11-2 shows an example of how to use the signal I/O menu to view the raw

voltage of an input signal or to control the state of an output voltage or control signal. The specific parameter will vary depending on the situation.

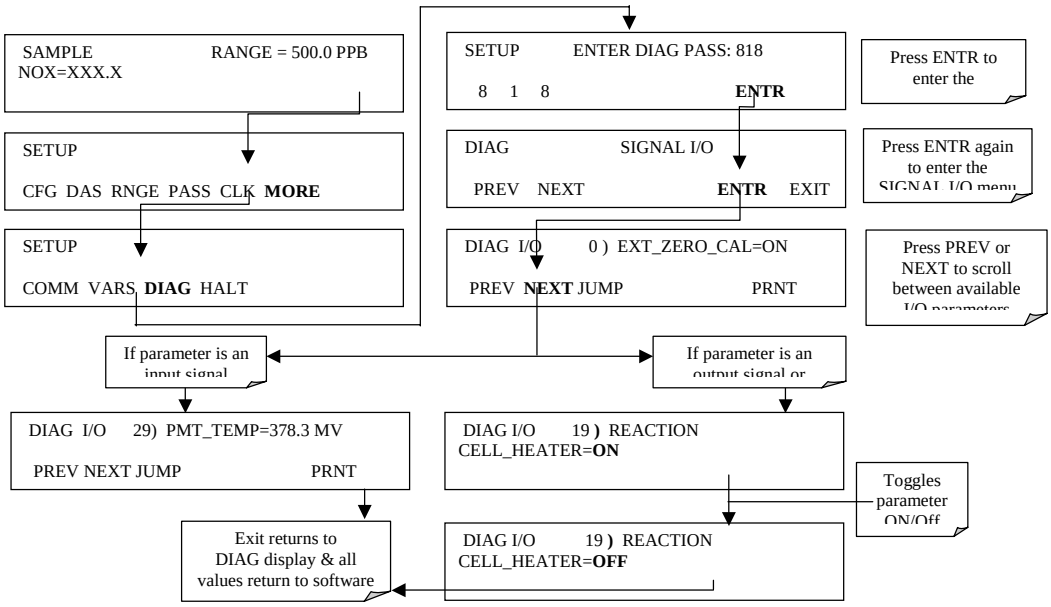


Figure 11-2: Switching Signal I/O Functions

11.1.4. Status LED's

Several color-coded, light-emitting diodes (LED) are located inside the instrument to determine if the analyzer's CPU, I^2C communications bus and the relay board are functioning properly.

11.1.4.1. Motherboard Status Indicator (Watchdog)

A red LED labeled DS5 in the upper portion of the motherboard (Figure 11-3), just to the right of the CPU board, flashes when the CPU is running the main program. After power-up, DS5 should flash on and off about once per second. If characters are visible on the front panel display but DS5 does not flash then the program files have become corrupted. Contact customer service because it may be possible to recover operation of the analyzer. If 30 - 60 seconds after a restart neither DS5 is flashing nor any characters are visible on the front panel display, the firmware may be corrupted or the CPU may be defective. If DS5 is permanently off or permanently on, the CPU board is likely locked up and the analyzer should not respond (either with locked-up or dark front panel).

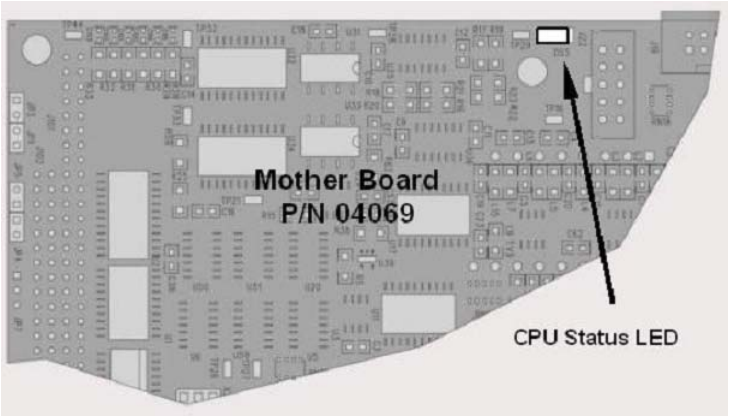


Figure 11-3: Motherboard Watchdog Status Indicator

11.1.4.2. CPU Status Indicator

The CPU board has two red LEDs, the lower of which is the watchdog timer (the device that pulses the motherboard watchdog). This LED is labeled **LED2** and blinks about twice per second (twice as fast as the motherboard LED) when operating normally. LED1 above LED2 should always be on. However, both CPU LEDs only indicate if the CPU is powered up properly and generally working. The lower LED can continue to blink even if the CPU or firmware are locked up.

11.1.4.3. Relay Board and Status LEDs

The most important status LED on the relay board is the red I^2C Bus watch-dog LED, labeled **D1**, which indicates the health of the I^2C communications bus. This LED is the left-most in LED row 1 in the center of the relay board when looking at the electronic components. If **D1** is blinking, then the other LEDs can be used in conjunction with the **DIAG** menu I/O functions to test hardware functionality by manually switching devices on and off and watching the corresponding LED go on or off.

Figure 11-4 illustrates the relay board layout including the two rows of LEDs, Table 11-2 lists the individual LED functions and the menu tree below shows how to access the manual control of the I/O functions. Note that only some or the LEDs may be functional in your analyzer model; the relay board layout is conceptualized for spare, future functionality and is also common to many of the E-series analyzers.

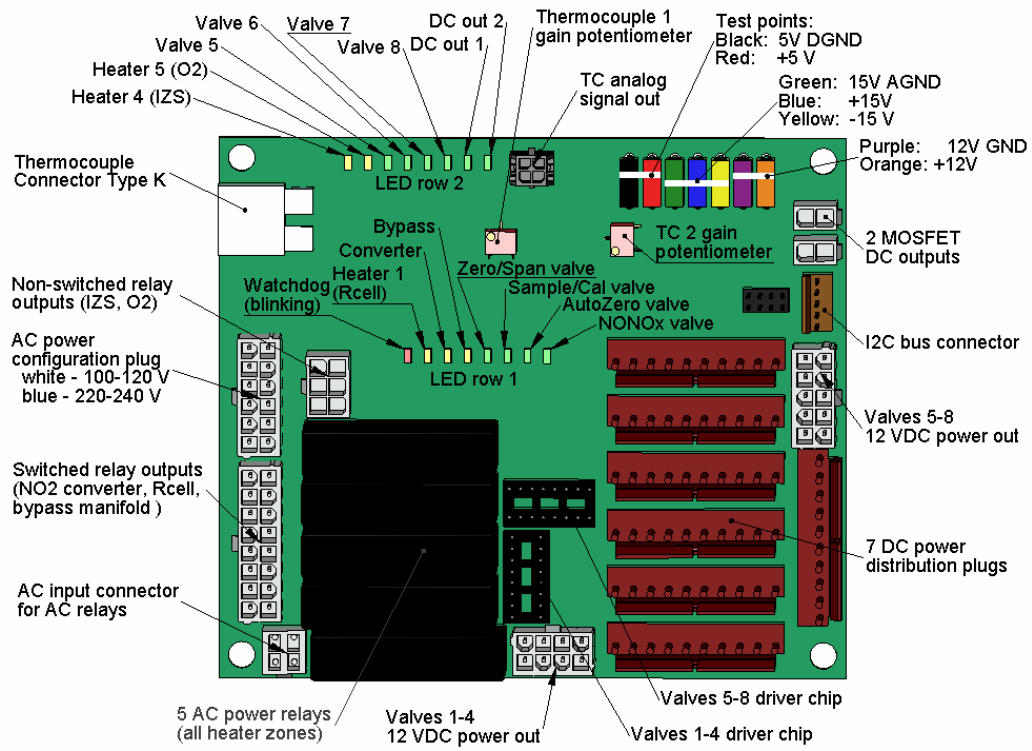


Figure 11-4: Relay Board PCA

To enter the signal I/O test mode to manually control I/O functions such as valves and heaters, press the following keys while observing the relay board LEDs when toggling:

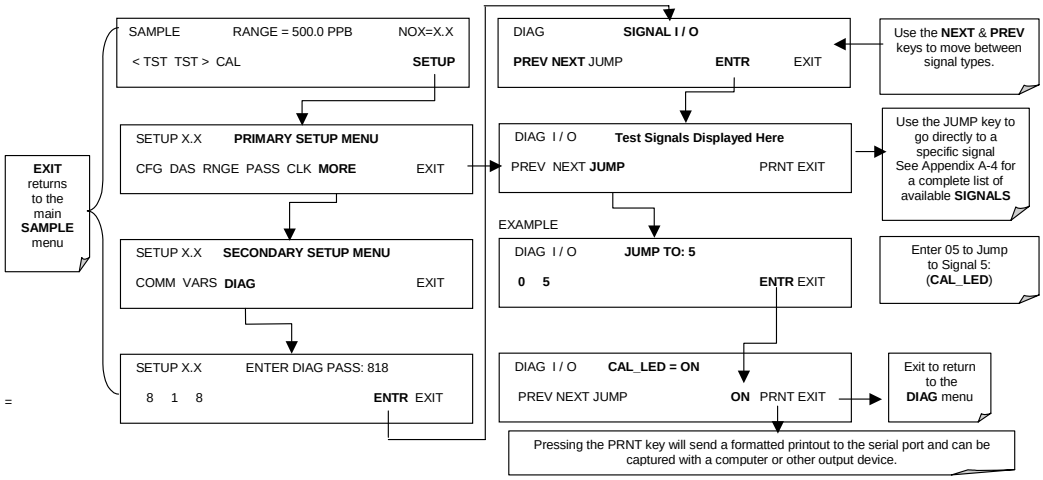


Table 11-2: Relay Board Status LEDs

LED	Color	Function	Fault Status	Indicated Failure(s)
LED Row 1 (center of board)				
D1	red	Watchdog Circuit; I^2C bus operation.	Continuously ON or OFF	Failed or halted CPU; faulty motherboard, keyboard, relay board; wiring between mother-board, keyboard or relay board; +5 V power supply
D2	yellow	Relay 0 - reaction cell heater	Continuously ON or OFF	Heater broken, thermistor broken
D3	yellow	Relay 1 - NO_2 converter heater	Continuously ON or OFF	Heater broken, thermocouple broken
D4 [1]	yellow	Relay 2 - manifold heater	Continuously ON or OFF	Heater broken, thermistor broken
D7 [2]	green	Valve 0 - zero/span valve status	Continuously ON or OFF	Valve broken or stuck, valve driver chip broken
D8 [2]	green	Valve 1 - sample/cal valve status	Continuously ON or OFF	Valve broken or stuck, valve driver chip broken
D9	green	Valve 2 - auto-zero valve status	Continuously ON or OFF	Valve broken or stuck, valve driver chip broken
D10	green	Valve 3 - NO/NO_x valve status	Continuously ON or OFF	Valve broken or stuck, valve driver chip broken
LED Row 2 (top of board)				
D5	yellow	Relay 3 - IZS heater	Continuously ON or OFF	Heater broken, thermistor broken
D6	yellow	Relay 4 – (O_2 sensor heater 9110EH/EM)	N/A	N/A
D11	green	Valve 4 – Spare	N/A	N/A
D12	green	Valve 5 – Spare	N/A	N/A
D13	green	Valve 6 – Spare	N/A	N/A
D14	green	Valve 7 – Spare	N/A	N/A
D15	green	Mosfet1/DC driver-Unused	N/A	N/A
D16	green	Mosfet2/DC driver -Unused	N/A	N/A

[1] Special configurations only

[2] Only active for instruments with Z/S valve or IZS options installed

11.2. Gas Flow Problems

The M9110E has two main flow paths, the sample flow and the flow of the ozone supply air. With IZS or zero/span valve option installed, there is a third (zero air) and a fourth (span gas) flow path, but either one of those is only controlled by critical flow orifices and not displayed on the front panel or stored to the iDAS. The full flow diagrams of the standard configuration and with options installed (Appendix D, document 04574) help in trouble-shooting flow problems. In general, flow problems can be divided into three categories:

- Flow is too high
- Flow is greater than zero, but is too low, and/or unstable
- Flow is zero (no flow)

When troubleshooting flow problems, it is essential to confirm the actual flow rate without relying on the analyzer's flow display. The use of an independent, external flow meter to perform a flow check as described in Section 6.7.8 is essential.

11.2.1. Zero or Low Flow Problems

11.2.1.1. Sample Flow is Zero or Low

The M9110E does not actually measure the sample flow but rather calculates it from a differential pressure between sample and vacuum manifold. On flow failure, the unit will display a **SAMPLE FLOW WARNING** on the front panel display and the respective test function reports **XXXX** instead of a value "0". This message applies to both a flow rate of zero as well as a flow that is outside the standard range (350-600 cm³/min). Refer to Section 0 for more information on sample flow.

If the analyzer displays **XXXX** for the sample flow, confirm that the external sample pump is operating and configured for the proper AC voltage. Whereas the M9110E can be internally configured for two different power regimes (100-120 V and 220-240 V, either 50 or 60 Hz), the external pump is physically different for each of three power regimes (100 V / 50 Hz, 115 V / 60 Hz and 230 V / 50 Hz). If the pump is not running, use an AC Voltmeter to make sure that the pump is supplied with the proper AC power. If AC power is supplied properly, but the pump is not running, replace the pump.

NOTE
Sample and vacuum pressures mentioned in this chapter refer to operation of the analyzer at sea level. Pressure values need to be adjusted for elevated locations, as the ambient pressure decreases by about 1 in-Hg per 300 m / 1000 ft.

If the pump is operating but the unit reports a **XXXX** gas flow, do the following three steps:

- Check for actual sample flow. To check the actual sample flow, disconnect the sample tube from the sample inlet on the rear panel of the instrument. Make sure that the unit is in basic SAMPLE mode. Place a finger over the inlet and see if it gets sucked in by the vacuum or, more properly, use a flow meter to measure the actual flow. If there is proper flow of around 450-550 cm³/min, contact customer service. If there is no flow or low flow, continue with the next step.
- Check pressures. Check that the sample pressure is at or around 28 in-Hg-A at sea level (adjust as necessary when in elevated location, the pressure should be about 1" below ambient atmospheric pressure) and that the RCEL pressure is below 10 in-Hg-A. The M9110E will calculate a sample flow up to about 14 in-Hg-A RCEL pressure but a good pump should always provide less than 10 in.
    - If both pressures are the same and around atmospheric pressure, the pump does not operate properly or is not connected properly. The instrument does not get any vacuum.
    - If both pressures are about the same and low (probably under 10 in-Hg-A, or ~20" on sample and 15" on vacuum), there is a cross-leak between sample flow path and vacuum, most likely through the Perma Pure dryer flow paths. See troubleshooting the Perma Pure dryer later in this chapter.

  - If the sample and vacuum pressures are around their nominal values (28 and <10 in-Hg-A, respectively) and the flow still displays **XXXX**, carry out a leak check as described in Section 11.5.2
- If gas flows through the instrument during the above tests but goes to zero or is low when it is connected to zero air or span gas, the flow problem is not internal to the analyzer but likely caused by the gas source such as calibrators/generators, empty gas tanks, clogged valves, regulators and gas lines.
- If an IZS or Zero/Span valve option is installed in the instrument, press **CALZ** and **CALS**. If the sample flow increases, suspect a bad Sample/Cal valve.
- If none of these suggestions help, carry out a detailed leak check of the analyzer as described in Section 11.5.2.

11.2.1.2. Ozone Flow is Zero or Low

If there is zero or a low (<50 cm³/min) ozone flow, the unit displays an **OZONE FLOW WARNING** message on the front panel and a value between 0.0 and 50 cm³/min for the actual ozone flow as measured by the internal mass flow meter. In this case, carry out the following steps:

- Check the actual flow rate through the ozone dryer by using an external flow meter to the inlet port of the dryer. This inlet port is inside the analyzer at the end of the plastic particle filter (Section 9.3.2 for illustration). If there is nominal flow (about 140 cm³/min from 80 cm³/min O_3 flow and 60 cm³/min purge flow), consult customer service as there is a problem with the firmware or electronics.
- If the actual flow is low or zero, check if the pump operates properly. The **RCEL** pressure should be below 10 in-Hg-A at sea level. If it is above 10”, rebuild the pump (Section 9.3.4). Check the spare parts list in Appendix B on how to order pump rebuild kits.
- Check if the particle filter is clogged. **Briefly** remove the particle filter to see if this improves the flow. Be very cautious about handling the Perma Pure dryer fittings - refer to Section 9.3.2 on proper handling instructions. If the filter is clogged, replace it with a new unit. If taking off this filter does not solve the problem, continue to the next step. Do not leave the Perma Pure dryer without filter for more than a few seconds, as you may draw in dust, which will reduce the performance of the dryer.
- A leak between the flow meter and the reaction cell (where the flow-determining critical orifice is located) may cause a low flow (the system draws in ambient air through a leak after the flow meter). Check for leaks as described in Section 11.5.1. Repair the leaking fitting, line or valve and re-check.
- The most likely cause for zero or low ozone flow is a clogged critical flow orifice or sintered filter within the orifice assembly. The orifice that sets the ozone flow is located on the reaction cell. Check the actual ozone flow by disconnecting the tube from the reaction cell and measuring the flow going into the cell. If this flow is correct (~80 cm³/min), the orifice works properly. If this flow is low, replace or clean the orifice. The orifice holder assembly allows a quick and easy replacement of the orifice, refer to Section 9.3.10 on how to do this. Appendix B lists a spare part kit with a complete orifice assembly that allows a quick replacement with minimum instrument down-time. The clogged orifice can then be cleaned while the instrument is running with the replacement.

11.2.2. High Flow

Flows that are significantly higher than the allowed operating range (typically ±10-11% of the nominal flow) should not occur in the M9110E unless a pressurized sample, zero or span gas is supplied to the inlet ports. Ensure to vent excess pressure and flow just before the analyzer inlet ports.

When supplying sample, zero or span gas at ambient pressure, a high flow would indicate that one or more of the critical flow orifices are physically broken (very unlikely case), allowing more than nominal flow, or were replaced with an orifice of wrong specifications. If the flows are within 15% higher than normal, we recommend to re-calibrate the flow electronically using the procedure in Section 6.7.8, followed by a regular review of these flows over time to see if the new setting is retained properly.

11.2.3. Sample Flow is Zero or Low But Analyzer Reports Correct Flow

Note that the M9110E analyzer can report a correct flow rate even if there is no or a low actual sample flow through the reaction cell. The sample flow on the M9110E is only calculated from the sample pressure and critical flow condition is verified from the difference between sample pressure and vacuum pressure. If the critical flow orifice is partially or completely clogged, both the sample and vacuum pressures are still within their nominal ranges (the pump keeps pumping, the sample port is open to the atmosphere), but there is no flow possible through the reaction cell.

Although measuring the actual flow is the best method, in most cases, this fault can also be diagnosed by evaluating the two pressure values. Since there is no longer any flow, the sample pressure should be equal to ambient pressure, which is about 1 in-Hg-A higher than the sample pressure under normal operation. The reaction cell pressure, on the other hand, is significantly lower than under normal operation, because the pump no longer has to remove 500 cm^3/min of sample gas and evacuates the reaction cell much better. Those two indicators, taken together with a zero or low actual flow, indicate a clogged sample orifice.

The M9110E features a new orifice holder, which makes switching sample and ozone flow orifices very easy, refer to Section 9.3.10 on how to change the sample orifices and Appendix B for part numbers of these assemblies. Again, monitoring the pressures and flows regularly will reveal such problems, because the pressures would slowly or suddenly change from their nominal, mean values. TAI recommends to review all test data once per week and to do an exhaustive data analysis for test and concentration values once per month, paying particular attention to sudden or gradual changes in all parameters that are supposed to remain constant, such as the flow rates.

11.3. Calibration Problems

11.3.1. Negative Concentrations

Negative concentration values can be caused for several reasons:

- A slight, negative signal is normal when the analyzer is operating under zero gas and the signal is drifting around the zero calibration point. This is caused by the analyzer's zero noise and may cause reported concentrations to be negative for a few seconds at a time down to -20 ppb, but should randomly alternate with similarly

high, positive values. The M9110E has a built-in Auto-zero function, which should take care of most of these deviations from zero, but may yield a small, residual, negative value. If larger, negative values persist continuously, check if the Auto-zero function was accidentally turned off using the remote variables in Appendix A-2. In this case, the sensitivity of the analyzer may be drifting negative.

- A corruption of the Auto-zero filter may also cause negative concentrations. If a short, high noise value was detected during the AutoZero cycle, that higher reading will alter the Auto-zero filter value. As the value of the Auto-zero filter is subtracted from the current PMT response, it will produce a negative concentration reading. High AutoZero readings can be caused by
  - a leaking or stuck AutoZero valve (replace the valve),
  - by an electronic fault in the preamplifier causing it to have a voltage on the PMT output pin during the AutoZero cycle (replace the preamplifier),
  - by a reaction cell contamination causing high background (>40 mV) PMT readings (clean the reaction cell),
  - by a broken PMT temperature control circuit, allowing high zero offset (repair the faulty PMT cooler). After fixing the cause of a high Auto-zero filter reading, the M9110E will take 15 minutes for the filter to clear itself, or
  - by an exhausted chemical in the ozone scrubber cartridge (Section 9.3.3).
- Mis-calibration is the most likely explanation for negative concentration values. If the zero air contained some NO or NO_2 gas (contaminated zero air or a worn-out zero air scrubber) and the analyzer was calibrated to that concentration as "zero", the analyzer may report negative values when measuring air that contains little or no NO_X. The same problem occurs, if the analyzer was zero-calibrated using zero gas that is contaminated with ambient air or span gas (cross-port leaks or leaks in supply tubing or user not waiting long enough to flush pneumatic systems).
- If the response offset test functions for NO (**NO OFFS**) or NO_X (**NOX OFFS**) are greater than 150 mV, a reaction cell contamination is indicated. Clean the reaction cell according to Section 9.3.9.

11.3.2. No Response

If the instrument shows no response (display value is near zero) even though sample gas is supplied properly and the instrument seems to perform correctly.

- Check if the ozone generator is turned on. Usually, the analyzer issues a warning whenever the ozone generator is turned off. Go to **SETUP-MORE-DIAG-ENTR**, then scroll to the **OZONE GEN OVERRIDE** and see if it shows **ON**. If it shows **OFF**, turn it **ON** and **EXIT** the **DIAG** menu. If this is done and the ozone flow is correct, the analyzer should be properly supplied with ozone unless the generator itself is broken. A more detailed description of the ozone generator subsystem checks are in Section 11.5.167.
- Confirm the lack of response by supplying NO or NO_2 span gas of about 80% of the range value to the analyzer.
- Check the sample flow and ozone flow rates for proper values.
- Check for disconnected cables to the sensor module.
- Carry out an electrical test with the **ELECTRICAL TEST** procedure in the diagnostics menu, see Section 6.7.6. If this test produces a concentration reading, the analyzer's electronic signal path is correct.

- Carry out an optical test using the **OPTIC TEST** procedure in the diagnostics menu, see Section 6.7.5. If this test results in a concentration signal, then the PMT sensor and the electronic signal path are operating properly. If the M9110E passes both ETEST and OTEST, the instrument is capable of detecting light and processing the signal to produce a reading. Therefore, the problem must be in the pneumatics or the ozone generator.
- If NO_2 signal is zero while NO signal is correct, check the NO/NO_X valve and the NO_2 converter for proper operation.

11.3.3. Unstable Zero and Span

Leaks in the M9110E or in the external gas supply and vacuum systems are the most common source of unstable and non-repeatable concentration readings.

- Check for leaks in the pneumatic systems as described in Section 11.5.1. Consider pneumatic components in the gas delivery system outside the M9110E such as a change in zero air source (ambient air leaking into zero air line or a worn-out zero air scrubber) or a change in the span gas concentration due to zero air or ambient air leaking into the span gas line.
- Once the instrument passes a leak check, do a flow check (this chapter) to make sure that the instrument is supplied with adequate sample and ozone air.
- Confirm the sample pressure, sample temperature, and sample flow readings are correct and steady.
- Verify that the sample filter element is clean and does not need to be replaced.

11.3.4. Inability to Span - No SPAN Key

In general, the M9110E will not display certain keyboard choices whenever the actual value of a parameter is outside of the expected range for that parameter. If the calibration menu does not show a SPAN key when carrying out a span calibration, the actual concentration must be outside of the range of the expected span gas concentration, which can have several reasons.

- Verify that the expected concentration is set properly to the actual span gas concentration in the **CONC** sub-menu.
- Confirm that the NO_x span gas source is accurate. This can be done by comparing the source with another calibrated analyzer, or by having the NO_x source verified by an independent traceable photometer.
- Check for leaks in the pneumatic systems as described in Section 11.5.2. Leaks can dilute the span gas and, hence, the concentration that the analyzer measures may fall short of the expected concentration defined in the **CONC** sub-menu.
- If the low-level, hardware calibration has drifted (changed PMT response) or was accidentally altered by the user, a low-level calibration may be necessary to get the analyzer back into its proper range of expected values. One possible indicator of this scenario is a slope or offset value that is outside of its allowed range (0.7-1.3 for slope, -20 to 150 for offsets). See Section 11.6.5 on how to carry out a low-level hardware calibration.

11.3.5. Inability to Zero - No ZERO Key

In general, the M9110E will not display certain keyboard choices whenever the actual value of a parameter is outside of the expected range for that parameter. If the calibration menu does not show a ZERO key when carrying out a zero calibration, the actual gas concentration must be significantly different from the actual zero point (as per last calibration), which can have several reasons.

- Confirm that there is a good source of zero air. If the IZS option is installed, compare the zero reading from the IZS zero air source to a zero air source using NO_X-free air. Check any zero air scrubber for performance. It may need to be replaced (Section 9.3.7).
- Check to make sure that there is no ambient air leaking into zero air line. Check for leaks in the pneumatic systems as described in Section 11.5.

11.3.6. Non-Linear Response

The M9110E was factory calibrated to a high level of NO and should be linear to within 1% of full scale. Common causes for non-linearity are:

- Leaks in the pneumatic system. Leaks can add a constant of ambient air, zero air or span gas to the current sample gas stream, which may be changing in concentrations as the linearity test is performed. Check for leaks as described in Section 11.5.
- The calibration device is in error. Check flow rates and concentrations, particularly when using low concentrations. If a mass flow calibrator is used and the flow is less than 10% of the full scale flow on either flow controller, you may need to purchase lower concentration standards.
- The standard gases may be mislabeled as to type or concentration. Labeled concentrations may be outside the certified tolerance.
- The sample delivery system may be contaminated. Check for dirt in the sample lines or reaction cell.
- Calibration gas source may be contaminated (NO_2 in NO gas is common).
- Dilution air contains sample or span gas.
- Ozone concentration too low because of wet air in the generator. Generator system needs to be cleaned and dried with dry supply air. Check the Perma Pure dryer for leaks. This mostly affects linearity at the low end.
- Ozone stream may be contaminated with impurities. An exhausted ozone filter chemical will let compounds such as HNO_3 and ammonia derivatives break through to the reaction cell. Check the contents of the ozone filter cartridge and replace as necessary. This also will affect linearity mostly at the low level.
- Sample inlet may be contaminated with NO_X exhaust from this or other analyzers. Verify proper venting of the pump exhaust.
- Span gas overflow is not properly vented and creates a back-pressure on the sample inlet port. Also, if the span gas is not vented at all and does not supply enough sample gas, the analyzer may be evacuating the sample line. Make sure to create and properly vent excess span gas.
- Diffusion of oxygen into Teflon-type tubing over long distances. PTFE or related materials can act as permeation devices. In fact, the permeable membrane of NO_2 permeation tubes is made of PTFE. When using very long supply lines (> 1 m)

between high concentrations span gases and the dilution system, oxygen from ambient air can diffuse into the line and react with NO to form NO_2. This reaction is dependent on NO concentration and accelerates with increasing NO concentration, hence, affects linearity only at high NO levels. Using stainless steel for long span gas supply lines avoids this problem.

11.3.7. Discrepancy Between Analog Output and Display

If the concentration reported through the analog outputs does not agree with the value reported on the front panel, you may need to re-calibrate the analog outputs. This becomes more likely when using a low concentration or low analog output range. Analog outputs running at 0.1 V full scale should always be calibrated manually. See Section 6.7.3 for a detailed description of this procedure.

11.3.8. Discrepancy between NO and NO_X slopes

If the slopes for NO and NO_X are significantly different after software calibration (more than 1%), consider the following two problems

- NO_2 impurities in the NO calibration gas. NO gases often exhibit NO_2 on the order of 1-2% of the NO value. This will cause differences in the calibration slopes. If the NO_2 impurity in NO is known, it can easily be accounted for by setting the expected values for NO and NO_2 accordingly to different values, e.g., 448 ppb NO and 450 ppb NO_X. This problem is worse if NO gas is stored in a cylinder with balance air instead of balance gas nitrogen or large amounts of nitrous oxide (N_2O). The oxygen in the air slowly reacts with NO to yield NO_2, increasing over time.
- The expected concentrations for NO and NO_X in the calibration menu are set to different values. If a gas with 100% pure NO is used, this would cause a bias. See Section 7.2.2 on how to set expected concentration values.
- The converter efficiency parameter has been set to a value not equal to 1.000 even though the conversion efficiency is 1.0. The actual conversion efficiency needs to match the parameter set in the **CAL** menu. See Section 7.1.7 for more information on this feature.

An instrument calibration with the IZS option (and expected concentrations set to the same amount) will always yield identical slopes for NO and NO_X, as the instrument measures only NO_X and assumes NO to be the same (with NO_2 being zero).

11.4. Other Performance Problems

Dynamic problems (i.e. problems which only manifest themselves when the analyzer is monitoring sample gas) can be the most difficult and time consuming to isolate and resolve. The following section provides an itemized list of the most common dynamic problems with recommended troubleshooting checks and corrective actions.

11.4.1. Excessive noise

Excessive noise levels under normal operation usually indicate leaks in the sample supply or the analyzer itself. Make sure that the sample or span gas supply is leak-free and carry out a detailed leak check as described earlier in this chapter.

Another possibility of excessive signal noise may be the preamplifier board, the high voltage power supply and/or the PMT detector itself. Contact the factory on trouble-shooting these components.

11.4.2. Slow Response

If the analyzer starts responding too slow to any changes in sample, zero or span gas, check for the following:

- Dirty or plugged sample filter or sample lines.
- Sample inlet line is too long.
- Leaking NO/NO_X valve. Carry out a leak check.
- Dirty or plugged critical flow orifices. Check flows, pressures and, if necessary, change orifices (Section 9.3.10).
- Wrong materials in contact with sample - use glass, stainless steel or Teflon materials only. Porous materials, in particular, will cause memory effects and slow changes in response.
- Dirty reaction cell. Clean the reaction cell.
- Insufficient time allowed for purging of lines upstream of the analyzer. Wait until stability is low.
- Insufficient time allowed for NO or NO_2 calibration gas source to become stable. Wait until stability is low.
- NO_2 converter temperature is too low. Check for proper temperature.

11.4.3. Auto-zero Warnings

Auto-zero warnings occur if the signal measured during an auto-zero cycle is lower than –20 mV or higher than 200 mV. The Auto-Zero warning displays the value of the auto-zero reading when the warning occurs.

- If this value is higher than 150 mV, check that the auto-zero valve is operating properly. To do so, use the **SIGNAL I/O** functions in the **DIAG** menu to toggle the valve on and off. Listen if the valve is switching, see if the respective LED on the relay board is indicating functionality. Scroll the **TST** functions until **PMT** is displayed and observe the PMT value change between the two valve states.
- If the valve is operating properly, you should be able to hear it switch (once a minute under normal operation or when manually activated from the **SIGNAL I/O** menu), the PMT value should drop from span gas reading (e.g., 800-900 mV at 400 ppb NO) to less than 150 mV and the LED on the relay board should light up when the valve is activated. If the PMT value drops significantly but not to less than 150 mV, the valve is probably leaking across its ports. In this case, replace the valve. If the PMT value does not change at all, the valve is probably not switching at all. Check the power supply to the valve (12 V to the valve should turn on and off when measured with a voltmeter).

  Note that it takes only a small leak across the ports of the valve to show excessive auto-zero values when supplying high concentrations of span gas.
- Another reason for high (although not necessarily out-of-range) values for AutoZero could be the ozone air filter cartridge, if its contents has been exhausted and needs

to be replaced. This filter cartridge (Figure 3-2) filters chemicals that can cause chemiluminescence and, if saturated, these chemicals can break through to the reaction cell, causing an erroneously high AutoZero value (background noise).

- A dirty reaction cell can cause high AutoZero values. Clean the reaction cell according to Section 9.3.9.
- Finally, a high **HVPS** voltage value may cause excess background noise and a high **AZero** value. The HVPS value changes from analyzer to analyzer and could show nominal values between 450 and 800 V. Check the low-level hardware calibration of the preamplifier board and, if necessary, recalibrate exactly as described in Section 11.6.5 in order to minimize the **HVPS**.

11.5. Subsystem Checkout

The preceding sections of this manual discussed a variety of methods for identifying possible sources of failures or performance problems within the analyzer. In most cases this included a list of possible causes and, in some cases, quick solutions or at least a pointer to the appropriate sections describing them. This section describes how to determine if a certain component or subsystem is actually the cause of the problem being investigated.

11.5.1. Simple Vacuum Leak and Pump Check

Leaks are the most common cause of analyzer malfunction; This section presents a simple leak check, whereas Section 11.5.2 details a more thorough procedure. The method described here is easy, fast and detects, but does not locate, most leaks. It also verifies the sample pump condition.

- Turn the analyzer ON, and allow at least 30 minutes for flows to stabilize.
- Cap the sample inlet port (cap must be wrench-tight).
- After several minutes, when the pressures have stabilized, note the SAMP (sample pressure) and the RCEL (vacuum pressure) readings.
- If both readings are equal to within 10% and less than 10 in-Hg-A, the instrument is free of large leaks. It is still possible that the instrument has minor leaks.
- If both readings are < 10 in-Hg-A, the pump is in good condition. A new pump will create a pressure reading of about 4 in-Hg-A (at sea level).

11.5.2. Detailed Pressure Leak Check

If a leak cannot be located by the above procedure, obtain a leak checker similar to TAI part number 01960, which contains a small pump, shut-off valve, and pressure gauge to create both over-pressure and vacuum. Alternatively, a tank of pressurized gas, with the two stage regulator adjusted to ≤ 15 psi, a shutoff valve and pressure gauge may be used.

CAUTION
Once tube fittings have been wetted with soap solution under a pressurized system, do not apply or re-apply vacuum as this will cause soap solution to be sucked into the instrument, contaminating inside surfaces.
Do not exceed 15 psi when pressurizing the system.

- Turn OFF power to the instrument and remove the instrument cover.

- Install a leak checker or a tank of gas (compressed, oil-free air or nitrogen) as described above on the sample inlet at the rear panel.
- Disconnect the pump tubing on the outside rear panel and cap the pump port. If IZS or zero/span valves are installed, disconnect the tubing from the zero and span gas ports and plug them (Figure 3-3). Cap the DFU particle filter on the Perma Pure dryer (Figure 9-2).
- Pressurize the instrument with the leak checker or tank gas, allowing enough time to fully pressurize the instrument through the critical flow orifice. Check each tube connection (fittings, hose clamps) with soap bubble solution, looking for fine bubbles. Once the fittings have been wetted with soap solution, do not re-apply vacuum as it will draw soap solution into the instrument and contaminate it. Do not exceed 15 psi pressure.
- If the instrument has the zero and span valve option, the normally closed ports on each valve should also be separately checked. Connect the leak checker to the normally closed ports and check with soap bubble solution.
- If the analyzer is equipped with an IZS Option Connect the leak checker to the Dry Air inlet and check with soap bubble solution.
- Once the leak has been located and repaired, the leak-down rate of the indicated pressure should be less than 1 in-Hg-A (0.4 psi) in 5 minutes after the pressure is turned off.
- Clean surfaces from soap solution, re-connect the sample and pump lines and replace the instrument cover. Restart the analyzer.

11.5.3. Performing a Sample Flow Check

CAUTION
Use a separate, calibrated flow meter capable of measuring flows between 0 and 1000 cm³/min to measure the gas flow rate though the analyzer. Do not use the built in flow measurement viewable from the front panel of the instrument. This value is only calculated, not measured.

Sample flow checks are useful for monitoring the actual flow of the instrument, as the front panel display shows only a calculated value. A decreasing, actual sample flow may point to slowly clogging pneumatic paths, most likely critical flow orifices or sintered filters. To perform a sample flow check:

- Disconnect the sample inlet tubing from the rear panel SAMPLE port shown in Figure 3-3.
- Attach the outlet port of a flow meter to the sample inlet port on the rear panel. Ensure that the inlet to the flow meter is at atmospheric pressure.
- The sample flow measured with the external flow meter should be 500 cm³/min ± 10%. If a combined sample/ozone air Perma Pure dryer is installed (optional equipment), the flow will be 640 cm³/min ± 10% (500 cm³/min for the sample and 80 cm³/min for the ozone generator supply air and 60 cm³/min for the purge flow).
- Low flows indicate blockage somewhere in the pneumatic pathway.

11.5.4. AC Power Configuration

The M9110E can be easily configured for two main power regimes, 100-120 V and 220-240 V at either 50 or 60 Hz. The analyzer is correctly configured for the AC power voltage in use if the voltage selector plug is configured properly. See Figure 3-1 and Figure 11-4 for the location of this plug. The plug for 100-120 V should have white jumper wires, the plug for 220-240 V should have blue jumper wires. Note, that an analyzer configured for 230 V will still turn on at 115 V (and vice versa), but the heaters may burn out or not heat up fast enough. Internally, several LEDs should turn on as soon as the power is supplied. If an incorrect power configuration is suspected, check for the correct voltage and frequency at the line input on the rear panel.

Note that the analyzer will be severely damaged if 220-240 V is supplied to it when configured for 100-120 V. Never bypass the power switch or circuit breaker.

11.5.5. DC Power Supply

If you have determined that the analyzer's AC main power is working, but the unit is still not operating properly, there may be a problem with one of the instrument's switching power supplies, which convert AC power to 5 and ±15 V (PS1) as well as +12 V DC power (PS2). The supplies can either have no DC output at all or a noisy output (fluctuating).

To assist tracing DC Power Supply problems, the wiring used to connect the various printed circuit assemblies and DC powered components and the associated test points on the relay board follow a standard color-coding scheme as defined in Table 11-3.

Table 11-3: DC Power Test Point and Wiring Color Code

Name	Test Point#	Color	Definition
DGND	1	Black	Digital ground
+5V	2	Red	
AGND	3	Green	Analog ground
+15V	4	Blue	
-15V	5	Yellow	
+12R	6	Purple	12 V return (ground) line
+12V	7	Orange	

A voltmeter should be used to verify that the DC voltages are correct as listed in Table 11-5. An oscilloscope, in AC mode and with band limiting turned on, can be used to evaluate if the supplies are excessively noisy (>100 mV peak-to-peak).

Table 11-4: DC Power Supply Acceptable Levels

Power Supply	Voltage	CHECK relay board Test Points				Min V	Max V
		From Test Point		To Test Point			
		Name	#	Name	#		
PS1	+5	DGND	1	+5	2	+4.80	+5.25
PS1	+15	AGND	3	+15	4	+13.5	+16.0
PS1	-15	AGND	3	-15V	5	-14.0	-16.0
PS1	AGND	AGND	3	DGND	1	-0.05	+0.05
PS1	Chassis	DGND	1	Chassis	N/A	-0.05	+0.05
PS2	+12	+12V Ret	6	+12V	7	+11.8	+12.5
PS2	DGND	+12V Ret	6	DGND	1	-0.05	+0.05

11.5.6. I^2C Bus

Operation of the I^2C bus can be verified by observing the behavior of the LED labeled **D1** on the relay board in conjunction with the performance of the front panel display. Assuming that the DC power supplies are operating properly and the wiring from the motherboard to the keyboard as well as from the keyboard to the relay board is intact, the I^2C bus is operating properly if:

- D1 on the relay board is flashing or
- D1 is not flashing but pressing a key on the front panel results in a change to the display.

If the display is locked up or if the analyzer is not booting up at all, the I^2C bus may be the cause. Contact customer service if you suspect a problem with the I^2C bus.

11.5.7. Keyboard / Display Interface

The front panel keyboard, the display and the keyboard/display circuit board can be verified by observing the operation of the display when power is applied to the instrument and when a key is pressed on the front panel. Assuming that there are no wiring problems and that the DC power supplies are operating properly:

- The vacuum fluorescence display is working properly if, on power-up, a "-" character is visible on the upper left hand corner of the display.
- If there is no "-" character on the display at power-up but the **D1** LED on the relay board is flashing, the keyboard/display circuit may be bad.
- If the analyzer starts operation with a normal display but pressing a key on the front panel does not change the display, then there are three possible problems:
- One or more of the keys is bad,
- The interrupt signal between the keyboard and the motherboard is broken or
- The keyboard circuit is bad.

You can verify this failure by logging on to the instrument using APICOM or a terminal program. If the analyzer responds to remote commands and the display changes accordingly, the display wiring or the I^2C bus may be faulty.

11.5.8. Relay Board

The relay board circuit can most easily be checked by observing the condition of its status LEDs as described in Section 11.1.4.3, and the associated output when toggled on and off through the **SIGNAL I/O** function in the **DIAG** menu, see Section 11.1.3.

If the front panel display responds to key presses and D1 on the relay board is not flashing, then either the wiring between the keyboard and the relay board is bad, or the relay board itself is bad.

If D1 on the Relay board is flashing and the status indicator for the output in question (heater, valve, etc.) does not toggle properly using the **Signal I/O** function, then the associated device (valve or heater) or its control device (valve driver, heater relay) is malfunctioning. Several of the control devices are in sockets and can easily be replaced. The table below lists the control device associated with a particular function:

Table 11-5: Relay Board Control Devices

Function	Control Device	Socketed
All valves	U5	Yes
All heaters	K1-K5	Yes

11.5.9. Motherboard

11.5.9.1. A/D functions

A basic check of the analog to digital (A/D) converter operation on the motherboard is to use the **Signal I/O** function under the **DIAG** menu. Check the following two A/D reference voltages and input signals that can be easily measured with a voltmeter.

- Using the **Signal I/O** function (Section 11.1.3 and Appendix D), view the value of **REF_4096_MV** and **REF_GND**. If both are within 3 mV of their nominal values (4096 and 0) and are stable to within ±0.5 mV, the basic A/D converter is functioning properly. If these values fluctuate largely or are off by more than 3 mV, one or more of the analog circuits may be overloaded or the motherboard may be faulty.
- Choose one parameter in the Signal I/O function such as **SAMPLE_PRESSURE** (see previous section on how to measure it). Compare its actual voltage with the voltage displayed through the **SIGNAL I/O** function. If the wiring is intact but there is a difference of more than ±10 mV between the measured and displayed voltage, the motherboard may be faulty.

11.5.9.2. Analog Output Voltages

To verify that the analog outputs are working properly, connect a voltmeter to the output in question and perform an analog output step test as described in Section 6.7.2.

For each of the steps, taking into account any offset that may have been programmed into the channel (Section 6.7.3), the output should be within 1% of the nominal value listed in the table below except for the 0% step, which should be within 2-3 mV. If one or more of the steps is outside of this range, a failure of one or both D/A converters and their associated circuitry on the motherboard is likely.

Table 11-6: Analog Output Test Function - Nominal Values

		Full scale Output Voltage			
		100mV	1V	5V	10V
Step	**%**	**Nominal Output Voltage**			
1	0	0 mV	0	0	0
2	20	20 mV	0.2	1	2
3	40	40 mV	0.4	2	4
4	60	60 mV	0.6	3	6
5	80	80 mV	0.8	4	8
6	100	100 mV	1.0	5	10

11.5.9.3. Status Outputs

The procedure below can be used to test the Status outputs.

- Connect a cable between the "-" pin and the "▽" pin on the status output connector.

Table 11-7: Status Outputs Check

PIN #	Status
1	SYSTEM OK
2	CONC VALID
3	HIGH RANGE
4	ZERO CAL
5	SPAN CAL
6	DIAG MODE
7	SPARE
8	SPARE

- Connect a 1000 Ω resistor between the +5 V and the pin for the status output that is being tested.
- Connect a voltmeter between the "-" pin and the pin of the output being tested (Table 11-7).
- Under the **DIAG / SIGNAL I/O** menu (Section 11.1.3), scroll through the inputs and outputs until you get to the output in question. Alternately turn on and off the output noting the voltage on the voltmeter, it should vary between 0 volts for ON and 5 volts for OFF.

11.5.9.4. Control Inputs

The control input bits can be tested by the following procedure:

- Connect a jumper from the +5 V pin on the STATUS connector to the +5 V on the CONTROL IN connector.

- Connect a second jumper from the '-' pin on the STATUS connector to the A pin on the CONTROL IN connector. The instrument should switch from **SAMPLE** mode to **ZERO CAL R** mode.
- Connect a second jumper from the '-' pin on the STATUS connector to the B pin on the CONTROL IN connector. The instrument should switch from **SAMPLE** mode to **SPAN CAL R** mode.

In each case, the M9110E should return to SAMPLE mode when the jumper is removed.

11.5.10. CPU

There are two major types of CPU board failures, a complete failure and a failure associated with the Disk-On-Chip (DOC). If either of these failures occur, contact the factory.

For complete failures, assuming that the power supplies are operating properly and the wiring is intact, the CPU is faulty if on power-on:

- The vacuum fluorescence display does not show a dash in the upper left hand corner
- There is no activity from the primary RS-232 port (COM1) on the rear panel even if "? <RETURN>" is pressed.

In some rare circumstances, this failure may be caused by a bad IC on the motherboard, specifically U57, the large, 44 pin device on the lower right hand side of the board. If this is true, removing U57 from its socket will allow the instrument to start up but the measurements will be incorrect.

- If the analyzer stops during initialization (the vacuum fluorescence display shows some text), it is likely that the DOC, the firmware or the configuration and data files have been corrupted or that the wrong firmware was uploaded or does not have the correct filename.

11.5.11. RS-232 Communication

11.5.11.1. General RS-232 Troubleshooting

TAI analyzers use the RS-232 protocol as the standard, serial communications protocol. RS-232 is a versatile standard, which has been used for many years but, at times, is difficult to configure. TAI conforms to the standard pin assignments in the implementation of RS-232. Problems with RS-232 connections usually center around 4 general areas:

- Incorrect cabling and connectors. This is the most common problem. See Table 0-16 for connector and pin-out information and Section 6.9.3 for cable connections.
- The communications (baud) rate and protocol parameters are incorrectly configured. See Section 6.9.7 on how to set the baud rate.
- The COM port communications mode is set incorrectly (Section 6.9.6).
- If a modem is used, additional configuration and wiring rules must be observed. See Section 6.11.3.
- Incorrect setting of the DTE - DCE switch. Typically, the red LED is on as soon as you power up the analyzer. If not, contact the factory, as this indicates a problem with the motherboard. As the analyzer is connected to the computer with a cable,

the green LED should also illuminate. If not, set the DCE/DTE switch to the other position. See also Section 6.9.5.

- Note that some laptops do not enable their RS-232 port when in power-saving mode. In this case, connect the laptop and start either APICOM or a Hyperterminal window and start communicating with the analyzer. This will enable the serial port on the laptop and the green LED should illuminate. You may have to switch back and forth while communicating to get the right setting.

11.5.11.2. Modem or Terminal Operation

These are the general steps for troubleshooting problems with a modem connected to a TAI analyzer.

- Check cables for proper connection to the modem, terminal or computer.
- Check the correct position of the DTE/DCE as described in Section 6.9.5.
- Check the correct setup command (Section 6.11.3).
- Verify that the Ready to Send (RTS) signal is at logic high. The M9110E sets pin 7 (RTS) to greater than 3 volts to enable modem transmission.
- Make sure the baud rate, word length, and stop bit settings between modem and analyzer match, see Section 6.9.7.
- Use the RS-232 test function to send "w" characters to the modem, terminal or computer; See Section 6.9.8.
- Get your terminal, modem or computer to transmit data to the analyzer (holding down the space bar is one way). The green LED on the rear panel should flicker as the instrument is receiving data.
- Make sure that the communications software is functioning properly.

Further help with serial communications is available in a separate manual "RS-232 Manual", TAI part number 013500000, available online at http://www.Teledyne-api.com/manuals/.

11.5.12. PMT Sensor

The photo multiplier tube detects the light emitted by the reaction of NO with ozone. It has a gain of about 500000 to 1000000. It is not possible to test the detector outside of the instrument in the field. The best way to determine if the PMT is working properly is by using the optical test (**OTEST**), which is described in Section 6.7.5. The basic method to diagnose a PMT fault is to eliminate the other components using **ETEST**, **OTEST** and specific tests for other sub-assemblies.

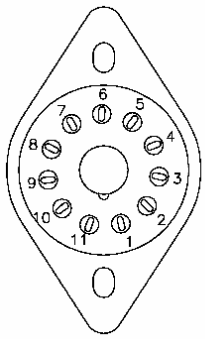
11.5.13. PMT Preamplifier Board

To check the correct operation of the preamplifier board, we suggest to carry out the optical and electrical tests described in Sections 6.7.5 and 6.7.6. If the ETEST fails, the preamplifier board may be faulty. Refer to Section 11.6.5 on hardware calibration through the preamplifier board.

11.5.14. High Voltage Power Supply

The HVPS is located in the interior of the sensor module and is plugged into the PMT tube (Section 10.3.2). It requires 2 voltage inputs. The first is +15 V, which powers the supply. The second is the programming voltage which is generated on the preamplifier board. Adjustment of the HVPS is covered in the factory calibration procedure in Section 11.6.5. This power supply has 10 independent power supply steps, one to each pin of the PMT. The following test procedure below allows you to test each step.

- Turn off the instrument.
- Remove the cover and disconnect the 2 connectors at the front of the NO_X sensor module.
- Remove the end cap from the sensor (4 screws).
- Remove the HVPS/PMT assembly from the cold block inside the sensor (2 plastic screws).
- Re-connect the 7 pin connector to the sensor end cap, and power-up the instrument. Scroll the front panel display to the **HVPS** test parameter. Divide the displayed **HVPS** voltage by 10 and test the pairs of connector points as shown in the figure.
- Check the overall voltage (should be equal to the **HVPS** value displayed on the front panel, for example 700 V) and the voltages between each pair of pins of the supply (should be 1/10th of the overall voltage, in this example 70 V):



HVPS PINS	VOLTAGE
11–1	70
1–2	70
2–3	70
3–4	70
4–5	70
5–6	70
6–7	70
7–8	70
8–9	70

- Turn off the instrument power, and reconnect the PMT, then reassemble the sensor.

If any faults are found in the test, you must obtain a new HVPS as there are no user serviceable parts inside the supply.

11.5.15. Pneumatic Sensor Assembly

The pressure/flow sensor circuit board, located behind the sensor assembly, can be checked with a voltmeter using the following procedure, which assumes that the wiring is intact and that the motherboard and the power supplies are operating properly. Refer to Figure 11-5 for trouble-shooting.

Measure the voltage across TP1 and TP2, it should be 10.0 ± 0.25 V. If not, the board is faulty. Measure the voltage across the leads of capacitor C2. It should be 5.0 ± 0.25 V, if not, the board may be faulty.

11.5.15.1. Reaction Cell Pressure

Measure the voltage across test points TP1 and TP5. With the sample pump disconnected or turned off, the voltage should be 4500 ± 250 mV. With the pump running, it should be 800-1700 mV depending on the performance of the vacuum pump. The lower the reaction cell pressure, the lower the resulting voltage is. If this voltage is significantly different, the pressure transducer S1 or the board may be faulty. If this voltage is between 2 and 5 V, the pump may not be performing well, check that the reaction cell pressure is less than 10 in-Hg-A (at sea level). Ensure that the tubing is connected to the upper port, which is closer to the sensor's contacts; the lower port does not measure pressure.

11.5.15.2. Sample Pressure

Measure the voltage across test points TP1 and TP4. With the sample pump disconnected or turned off, this voltage should be 4500 ± 250 mV. With the pump running, it should be about 0.2 V less as the sample pressure drops by about 1 in-Hg-A below ambient pressure. If this voltage is significantly different, the pressure transducer S2 or the board may be faulty. A leak in the sample system to vacuum may also cause this voltage to be between about 0.6 and 4.5. Make sure that the front panel reading of the sample pressure is at about 1 in-Hg-A less than ambient pressure. Ensure that the tubing is connected to the upper port, which is closer to the sensor's contacts; the lower port does not measure pressure.

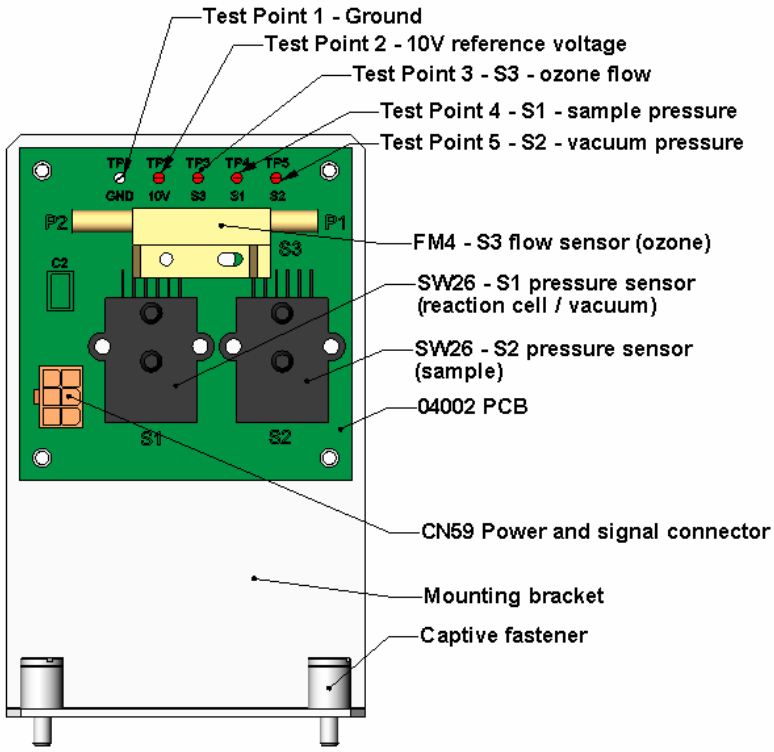


Figure 11-5: Pressure / Flow Sensor Assembly

11.5.15.3. Ozone Flow

Measure the voltage across TP1 and TP3. With proper ozone flow (80 cm³/min at the ozone dryer inlet), this should be approximately 2.0 ± 0.2 V (this voltage will vary with altitude). With flow stopped (pump turned off), the voltage should be approximately 0 V. If the voltage is incorrect, the flow sensor or the board may be faulty. A cross-leak to vacuum inside the Perma Pure dryer may also cause this flow to increase significantly, and the voltage will increase accordingly. Also, make sure that the gas flows from P1 to P2 as labeled on the flow sensor ("high" pressure P1 to "low" pressure P2 or "Port" 1 to "Port" 2).

11.5.16. NO_2 Converter

The NO_2 converter assembly can fail in two ways, an electrical failure of the band heater and/or the thermocouple control circuit and a performance failure of the converter itself.

1) NO_2 converter heater failures can be divided into two possible problems:

- Temperature is reported properly but heater does not heat to full temperature. In this case, the heater is either disconnected or broken or the power relay is broken.
    - Disconnect the heater cable coming from the relay board and measure the resistance between any two of the three heater leads with a multi-meter. The resistance between A and B should be about 1000 Ω and that between A and C should be the same as between B and C, about 500 Ω each. If any of these resistances is near zero or without continuity, the heater is broken.
- Temperature reports zero or overload (near 500° C). This indicates a disconnected or failing thermocouple or a failure of the thermocouple circuit.
    - First, check that the thermocouple is connected properly and the wire does not show signs of a broken or kinked pathway. If it appears to be properly connected, disconnect the yellow thermocouple plug (marked **K**) from the relay board and measure the voltage (not resistance) between the two leads with a multi-meter capable of measuring in the low mV range. The voltage should be about 12 mV (ignore the sign) at 315° C and about 0 mV at room temperature.
    - Measure the continuity with an Ohm-meter. It should read close to zero Ω. If the thermocouple does not have continuity, it is broken. If it reads zero voltage at elevated temperatures, it is broken. To test the thermocouple at room temperature, heat up the converter can (e.g., with a heat gun) and see if the voltage across the thermocouple leads changes. If the thermocouple is working properly, the electronic circuit is broken. In both cases, consult the factory.

2) If the converter appears to have performance problems (conversion efficiency is outside of allowed range of 96-102%), check the following:

- Conversion efficiency setting in the CAL menu. If this value is different from 1.000, this correction needs to be considered. Section 7.1.7 describes this parameter in detail.
- Accuracy of NO_2 source (GPT or gas tank standard). NO_2 gas standards are typically certified to only ±2% and often change in concentrations over time. You should get the standard re-certified every year. If you use GPT, check the accuracy of the ozone source.
- Age of the converter. The NO_2 converter has a limited operating life and may need to be replaced every ~3 years or when necessary (e.g., earlier if used with continuously high NO_2 concentrations). We estimate a lifetime of about 10000 ppm-hours (a

cumulative product of the NO_2 concentration times the exposure time to that concentration). However, this lifetime heavily depends on many factors such as absolute concentration (temporary or permanent poisoning of the converter is possible), sample flow rate and pressure inside the converter, converter temperature, duty cycle etc. This lifetime is only an estimated reference and not a guaranteed lifetime.

- In some cases with excessive sample moisture, the oxidized molybdenum metal chips inside the converter cartridge may bake together over time and restrict air flow through the converter, in which case it needs to be replaced. To avoid this problem, we recommend the use of a sample gas conditioner (Section 5.9). Section 9.3.8 describes how to replace the NO_2 converter cartridge.
- With no NO_2 in the sample gas and a properly calibrated analyzer, the NO reading is negative, while the NO_2 reading remains around zero. The converter destroys NO and needs to be replaced.
- With no NO_2 in the sample gas and a properly calibrated analyzer, the NO_X reading is significantly higher than the actual (gas standard) NO concentration. The converter produces NO_2 and needs to be replaced.

11.5.17. O_3 Generator

The ozone generator can fail in two ways, electronically (printed circuit board) and functionally (internal generator components). Assuming that air is supplied properly to the generator, the generator should automatically turn on 30 minutes after the instrument is powered up or if the instrument is still warm. See Section 0 for ozone generator functionality. Accurate performance of the generator can only be determined with an ozone analyzer connected to the outlet of the generator. However, if the generator appears to be working properly but the sensitivity or calibration of the instrument is reduced, suspect a leak in the ozone generator supply air.

A leak in the dryer or between the dryer and the generator can cause moist, ambient air to leak into the air stream, which significantly reduces the ozone output. The generator will produce only about half of the nominal O_3 concentration when run with moist, ambient air instead of dried air. In addition, moist supply air will produce large amounts of nitric acid in the generator, which can cause analyzer components downstream of the generator to deteriorate and/or causes significant deposit of nitrate deposits on the reaction cell window, reducing sensitivity and causing performance drift. Carry out a leak check as described earlier in this chapter.

11.5.18. IZS Option

The zero/span valves and IZS options need to be enabled in the software (contact the factory on how to do this). See Figure 3-12 for a flow diagram with zero/span valve or IZS option and Figure 3-2 to locate these options in the rear left corner of the instrument.

- Check for the physical presence of the valves or the IZS option.
- Check front panel for correct software configuration. When the instrument is in SAMPLE mode, the front panel display should show **CALS** and **CALZ** buttons in the second line of the display. The presence of the buttons indicates that the option has been enabled in software. In addition, the IZS option is enabled if the TEST functions show a parameter named IZS TEMP.

The semi-permeable PTFE membrane of the permeation tube is severely affected by humidity. Variations in humidity between day and night are usually enough to yield very variable output results. If the instrument is installed in an air-conditioned shelter, the air is usually dry enough to produce good results. If the instrument is installed in an environment with variable or high humidity, variations in the permeation tube output will be significant. In this case, a dryer for the supply air is recommended (dew point should be –20° C or less).

The IZS option is heated with a proportional heater circuit and the temperature is maintained at 50° C ±1° . Check the front panel display or the **IZS_TEMP** signal voltage using the **SIGNAL I/O** function under the **DIAG** Menu (Section 11.1.3). At 50° C, the temperature signal from the IZS thermistor should be around 2500 mV.

11.5.19. Box Temperature

The box temperature sensor (thermistor) is mounted on the motherboard below the bottom edge of the CPU board when looking at it from the front. It cannot be disconnected to check its resistance. Box temperature will vary with, but will usually read about 5° C higher than, ambient (room) temperature because of the internal heating zones from the NO_2 converter, reaction cell and other devices.

- To check the box temperature functionality, we recommend to check the **BOX_TEMP** signal voltage using the **SIGNAL I/O** function under the **DIAG** Menu (Section 11.1.3). At about 30° C, the signal should be around 1500 mV.
- We recommend to use a certified or calibrated external thermometer / temperature sensor to verify the accuracy of the box temperature by placing it inside the chassis, next to the thermistor labeled **XT1** (above connector J108) on the motherboard.

11.5.20. PMT Temperature

PMT temperature should be low and constant. It is more important that this temperature is maintained constant than it is to maintain it low. The PMT cooler uses a Peltier, thermo-electric cooler element supplied with 12 V DC power from the switching power supply PS2. The temperature is controlled by a proportional temperature controller located on the preamplifier board. Voltages applied to the cooler element vary from 0.1 to 12 VDC. The temperature set point (hard-wired into the preamplifier board) will vary by ±1°C due to component tolerances. The actual temperature will be maintained to within 0.1° C around that set point. On power-up of the analyzer, the front panel enables the user to watch that temperature drop from about ambient temperature down to its set point of 6-8° C. If the temperature fails to adjust after 30 minutes, there is a problem in the cooler circuit. If the control circuit on the preamplifier board is faulty, a temperature of –1° C is reported.

11.6. Repair Procedures

This section contains some procedures that may need to be performed when a major component of the analyzer requires repair or replacement. Note that maintenance procedures (e.g., replacement of regularly changed expendables) are discussed in Chapter 9 (Maintenance) are not listed here. Also note that Teledyne-API customer service may have a more detailed service note for some of the below procedures. Contact customer service.

11.6.1. Disk-on-Chip Replacement

Replacing the Disk-on-Chip (DOC) will cause all of the instrument configuration parameters to be lost unless the replacement chip carries the exact same firmware version. iDAS data will always be lost and, if possible, should be downloaded prior to changing the DOC. If the analyzer is equipped with at least one EEPROM flash chip (standard configuration), the configuration settings are stored on the EEPROM. It is recommended to document all analyzer parameters that may have been changed, such as calibration, range, auto-cal, analog output, serial port and other settings before replacing the CPU chip. Refer to Figure 10-13 for locating the DOC and other CPU components.

- Ground yourself to prevent electrostatic damage to electronic components.
- Turn off power to the instrument, fold down the rear panel by loosening the mounting screws. You may have to lift up the analyzer cover to prevent some connectors on the CPU board to brush against the cover.
- When looking at the electronic circuits from the back of the analyzer, locate the Disk-on-Chip on the CPU board. The chip should carry a label with analyzer model number (M9110E), firmware revision (example: M9110E_C7.EXE), date and initials of the programmer. Remove the IC with a dedicated IC removal tool or by gently prying it up from the socket. Do not bend the connector pins.
- Reinstall the new Disk-on-Chip, making sure the notch at the end of the chip matches the notch in the socket. It may be necessary to straighten the pins somewhat to fit them into the socket. Gently but firmly press the chip all the way in. Do not bend the pins.
- Close the rear panel, replace the cover and turn on power to the machine.

Generally, all of the setup information will need to be re-entered, including analog input and output calibration unless the firmware revision has not changed and the analyzer is equipped and properly configured with an EEPROM chip. Note especially that the A/D converter must be re-calibrated, and all information collected in step 1 above must be re-entered before the instrument will function correctly. The analyzer typically issues an **ANALOG CALIBRATION WARNING** if the analog circuitry was not calibrated within 10 minutes after restart.

11.6.2. Flash Chip Replacement or Upgrade

The M9110E CPU board can accommodate up to two EEPROM flash chips. The standard configuration is one chip with 64 kb of storage capacity, which is used to store the analyzer configuration as created during final checkout at the factory. Replacing this chip will erase that configuration, which will be recreated with a new copy when restarting the analyzer. However, if the firmware and/or the DOC is changed at the same time, all analyzer configuration settings and iDAS data will be lost. Adding a second EEPROM chip to the existing chip will double memory but this procedure will require a BIOS configuration and is not a standard sales option. Also make sure that you receive a fully formatted EEPROM chip for replacement. Contact the factory for details.

- Ground yourself to prevent electrostatic damage to electronic components.
- Turn off power to the instrument, fold down the rear panel by loosening the mounting screws. If necessary, lift the cover to prevent the rear panel connectors from brushing against it.

- When looking at the electronic circuits from the back of the analyzer, locate the EEPROM chip in the left-most socket of the CPU board. The chip is almost square with one corner cut off, the socket is shaped accordingly and the chip is recessed into the socket. Remove the old chip by using a special tool or gently pry the chip out using a very fine screwdriver. Make sure not to bend or destroy any of the contacts of the socket. When upgrading the CPU with a second chip, no removal is necessary as the second socket should be empty.
- Reinstall the new or additional EEPROM chip, making sure the cut-off edge matches that of the socket. Press the chip symmetrically and straight all the way in.
- Close the rear panel and cover and turn on power to the machine.
- If a front panel message **Flash Format INVALID** appears on start-up, the EEPROM was not properly formatted. Contact the factory for a proper replacement.

11.6.3. O_3 Generator Replacement

The ozone generator is a black, brick-shaped device with printed circuit board attached to its rear and two tubes extending out the right side in the front of the analyzer. To replace the ozone generator:

- Turn off the analyzer power, remove the power cord and the analyzer cover.
- Disconnect the 1/8" black tube from the white ozone scrubber cartridge and the ¼" clear tube from the plastic extension tube at the brass fitting nearest to the ozone generator. Unplug the electrical connection on the rear side of the brick.
- Unscrew the two mounting screws that attach the ozone generator to the chassis and take out the entire assembly.
- If you received a complete replacement generator with circuit board and mounting bracket attached, simply reverse the above steps to replace the current generator. Make sure to carry out a leak check and a recalibration after the analyzer warmed up for about 30 minutes.

11.6.4. Sample and Ozone Dryer Replacement

The M9110E standard configuration is equipped with a dryer for the ozone supply air. An optional dryer is available for the sample stream and a combined dryer for both gas streams can also be purchased. To change one or all of these options:

- Turn off power to the analyzer and pump, remove the power cord and the analyzer cover. Locate the dryers in the center of the instrument, between sensor and NO_2 converter. They are mounted to a bracket, which can be taken out when unscrewing the two mounting screws (if necessary).
- Disconnect all tubing that extends out of the dryer assembly, those are usually the purge tube connecting to the vacuum manifold, the tube from the exit to the ozone flow meter (ozone dryer) or to the NO/NO_x valve (sample dryer) or two tubes to the ozone flow meter and the NO/NO_X valve (combo-dryer). Take extra care not to twist any of the white plastic fittings on the dryer, which connect the inner drying tube to the outer purge tube. See Section 9.3.2 and Figure 9-2.
- Note the orientation of the dryer on the bracket. Cut the tie wraps that hold the dryer to the mounting bracket and take out the old dryer. If necessary, unscrew the two mounting screws on the bracket and take out the entire assembly.

- Attach the replacement dryer to the mounting bracket in the same orientation as the old dryer. Fix the dryer to the bracket using new tie wraps. Cut off excess length of the wraps.
- Put the assembly back into the chassis and tighten the mounting screws.
- Re-attach the tubes to vacuum manifold, flow meter and/or NO/NO_x valve using at least two wrenches and take extra care not to twist the dryer's white plastic fittings, as this will result in large leaks that are difficult to trouble-shoot and fix.
- Carry out a detailed leak check (Section 11.5.2), close the analyzer, power up pump and analyzer and re-calibrate the instrument after it stabilizes

11.6.5. PMT Sensor Hardware Calibration

The sensor module hardware calibration is used in the factory to adjust the slope and offset of the PMT output and to optimize the signal output and HVPS. If the instrument's slope and offset values are outside of the acceptable range and all other more obvious causes for this problem have been eliminated, the hardware calibration can be used to adjust the sensor as has been done in the factory. This procedure is also recommended after replacing the PMT or the preamplifier board.

- With the instrument running, set the instrument reporting range to **SNGL** (Section 6.5.3).
- Perform a full zero calibration using zero air (Section 7.2, 7.4, or7.5).
- Locate the preamplifier board (Figure 3-2).
- Locate the following components on the preamplifier board (Figure 11-6):
  - HVPS coarse adjustment switch (Range 0-9, then A-F).
  - HVPS fine adjustment switch (Range 0-9, then A-F).
  - Gain adjustment potentiometer (Full scale is 10 turns).
- Turn the gain adjustment potentiometer 12 turns clockwise to its maximum setting.
- While feeding 400 ppb NO (or 80% range value) to the analyzer and waiting until the **STABIL** value is below 0.5 ppb, look at the front panel and scroll to the **NORM PMT** value. This value should always be two times the span gas concentration in ppb. With 400 ppb NO, the **NORM PMT** should show 800 mV on a properly calibrated analyzer.
- Set the HVPS coarse adjustment to its minimum setting (0). Set the HVPS fine adjustment switch to its maximum setting (F).
- Set the HVPS coarse adjustment switch to the lowest setting that will give you just above 800 mV **NORM PMT** signal (2x span gas ppb value). The coarse adjustment typically increments the NORM PMT signal in 100-300 mV steps.

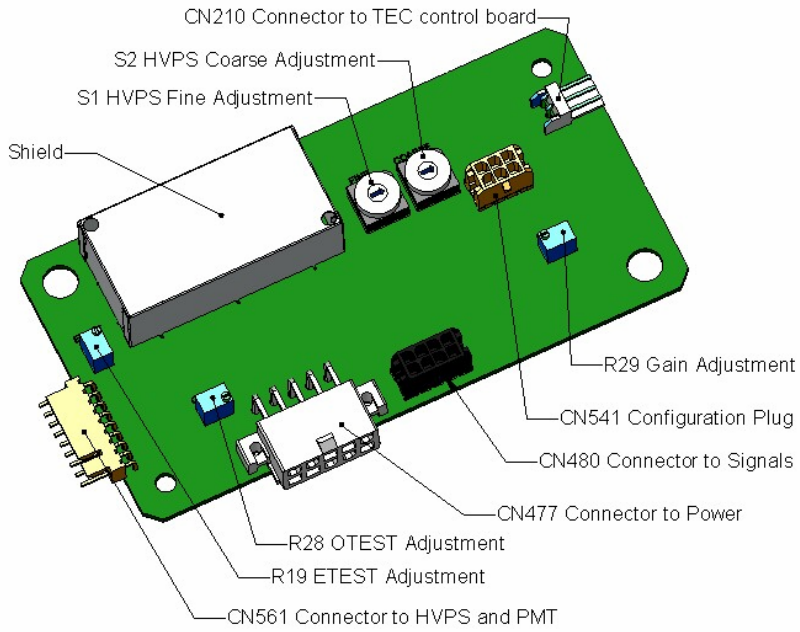


Figure 11-6: Pre-Amplifier Board Layout

- Adjust the HVPS fine adjustment such that the **NORM PMT** value is 800-830 mV. The fine adjustment typically increments the **NORM PMT** value by about 30 mV. It may be necessary to go back and forth between coarse and fine adjustments if the proper value is at the threshold of the min/max coarse setting.

NOTE
Do not overload the PMT by accidentally setting both adjustment switches to their maximum setting. Start at the lowest setting and increment slowly. Wait 10 seconds between adjustments.

- If the **NORM PMT** value set above is now between 790-810, skip this step. Otherwise, adjust the **NORM PMT** value with the gain potentiometer down to 800±10 mV (in general: 2x the span gas concentration value in ppb). This is the final very-fine adjustment.
- Note that during adjustments, the **NORM PMT** value may be fluctuating, as the analyzer continues to switch between NO and NO_X streams as well as between measure and AutoZero modes. You may have to mentally average the values of NO and NO_X response for this adjustment.
- Perform a software span calibration (Section 7.2, 7.4, or7.5) to normalize the sensor response to its new PMT sensitivity.
- Review the slope and offset values, the slopes should be 1.000±0.300 and the offset values should be 0.0±20 mV (-20 to +150 mV is allowed).

11.6.6. Replacing the PMT, HVPS or TEC

The photo multiplier tube (PMT) should last for the lifetime of the analyzer. However, in some cases, the high voltage power supply (HVPS) or the thermo-electric cooler (TEC) may fail. In case of PMT, HVPS or TEC failure, the sensor assembly needs to be opened in order to change one of these components. Refer to Figure 11-7 for the structure of the 9110E sensor assembly and follow the steps below for replacement of one of its components. We recommend to ensure that the PMT, HVPS or TEC modules are, indeed, faulty to prevent unnecessary opening of the sensor.

- Power down the analyzer, disconnect the power cord, remove the cover and disconnect all pneumatic and electrical connections from the sensor assembly.
- Whereas it is possible for a skilled technician to change the PMT or HVPS through the front panel with the sensor assembly mounted to the analyzer, we recommend to remove the entire assembly and carry this procedure out on a clean, anti-static table with the user wearing an anti-static wrist strap to prevent static discharge damage to the assembly or its circuits.
- If the TEC is to be replaced, remove the reaction cell assembly at this point by unscrewing two holding screws. This is necessary only if the PMT cold block is to be removed. This step is not necessary if the HVPS or the PMT only are exchanged.

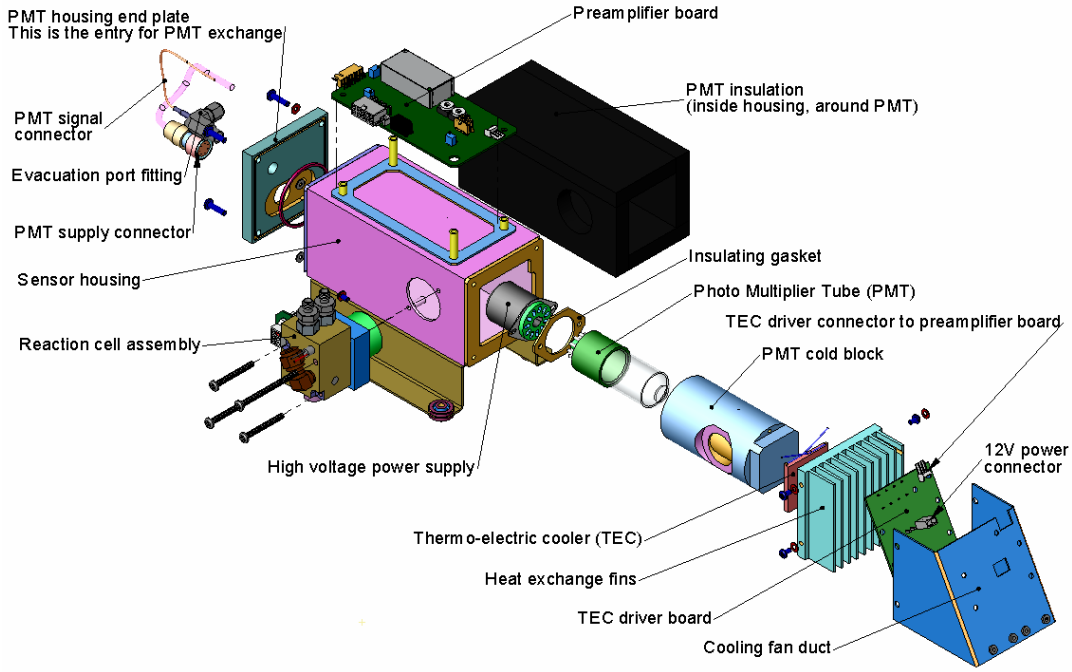


Figure 11-7: M9110E Sensor Assembly

- Remove the two connectors on the PMT housing end plate facing towards the front panel. Remove the end plate itself (4 screws with plastic washers). Remove the dryer packages inside the PMT housing. Along with the plate, slide out the OPTIC TEST LED and the thermistor that measures the PMT temperature. Both may be

coated with a white, thermal conducting paste. Do not contaminate the inside of the housing with this grease, as it may contaminate the PMT glass tube on re-assembly.

- Unscrew the PMT assembly, which is held to the cold block by two plastic screws. Discard the plastic screws and replace with new screws at the end of this procedure (the threads get stripped easily and it is recommended to use new screws).
- Carefully take out the assembly consisting of the HVPS, the gasket and the PMT.
- Change the PMT or the HVPS or both, clean the PMT glass tube with a clean, anti-static wipe and do not touch it after cleaning.
- If the cold block or TEC is to be changed, disconnect the TEC driver board from the preamplifier board, remove the cooler fan duct (4 screws on its side) including the driver board, disconnect the driver board from the TEC and set the sub-assembly aside.
- Remove the end plate with the cooling fins (4 screws) and slide out the PMT cold block assembly, which contains the TEC.
- Unscrew the TEC from the cooling fins and the cold block and replace it with a new unit.
- Re-assemble this TEC subassembly in reverse order. Make sure to use thermal grease between TEC and cooling fins as well as between TEC and cold block and that the side opening in the cold block will face the reaction cell when assembled. Evenly tighten the long mounting screws for good thermal conductivity.

CAUTION
The thermo-electric cooler needs to be mounted flat to the heat sink. If there is any significant gap, the TEC might burn out. Make sure to apply heat sink paste before mounting it and tighten the screws evenly and cross-wise.

- Re-insert the TEC subassembly in reverse order. Make sure that the O-ring is placed properly and the assembly is tightened evenly.
- Re-insert the PMT/HVPS subassembly in reverse order and don't forget the gasket between HVPS and PMT. Use new plastic screws to mount the PMT assembly on the PMT cold block.
- Insert the LED and thermistor into the cold block, insert new drying packages and carefully replace the end plate by making sure that the O-ring is properly in place. Improperly placed O-rings will cause leaks, which – in turn – cause moisture to condense on the inside of the cooler and likely cause a short in the HVPS.
- Reconnect the cables and the reaction cell (evenly tighten these screws), replace the sensor assembly into the chassis and fasten with four screws and washers.
- Reconnect all electrical and pneumatic connections, leak check the system and power up the analyzer.
- Verify the basic operation of the analyzer using the ETEST and OTEST features or zero and span gases, then carry out a hardware calibration of the analyzer (Section 11.6.5) followed by a software calibration.

11.7. Technical Assistance

If this manual and its trouble-shooting / repair sections do not solve your problems, technical assistance may be obtained from Teledyne Analytical Instruments, Customer Service, 16830 Chestnut St. City of Industry, CA 91748. Phone: 626-934-1673. Fax: 626-

961-2538. Email: ask_tai@teledyne.com. Before you contact customer service, fill out the problem report form in Appendix C

USER NOTES:

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APPENDIX A-1: M9110E Software Menu Trees and Index, Revision C.8

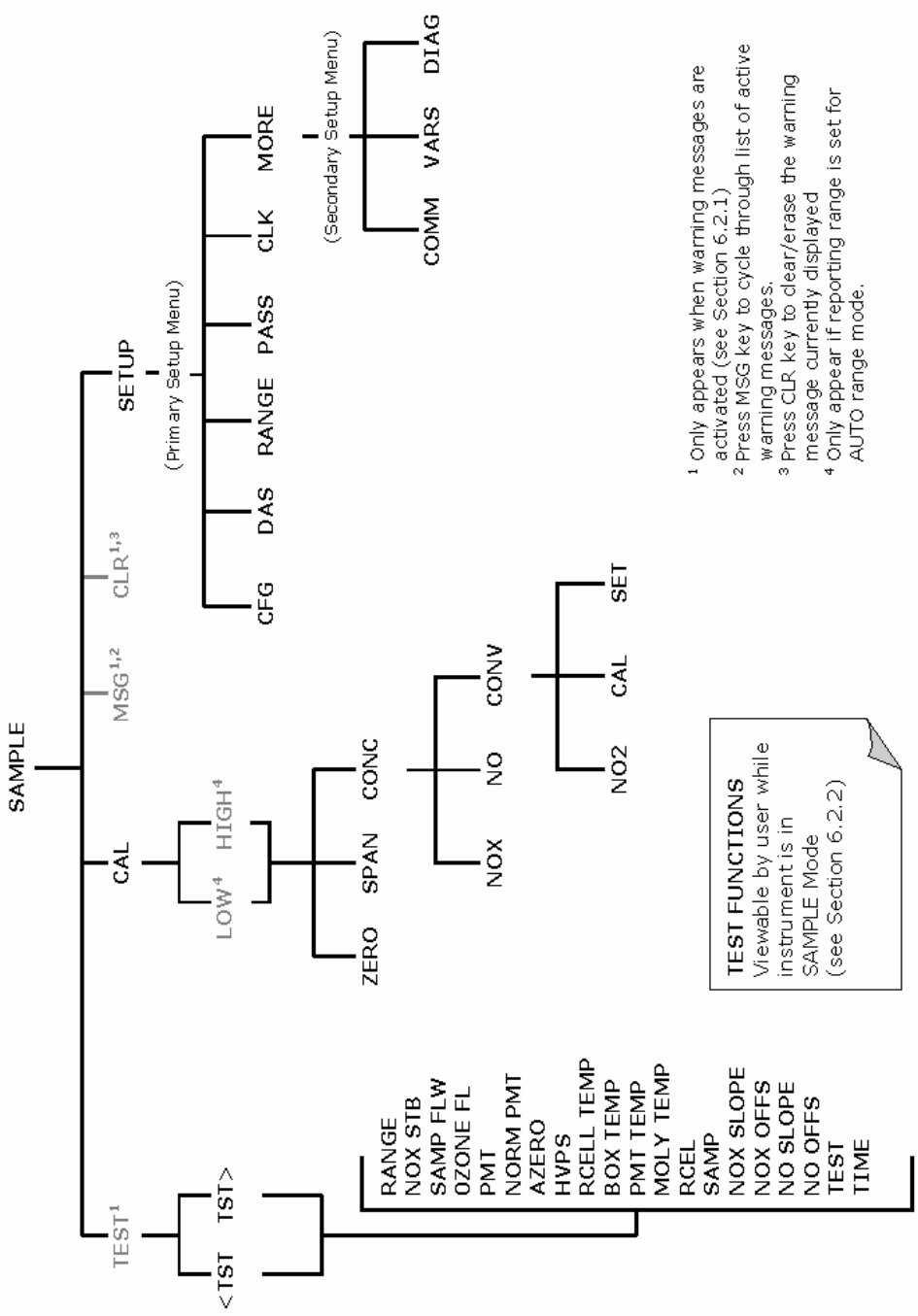

Figure A-1: Basic Sample Display Menu

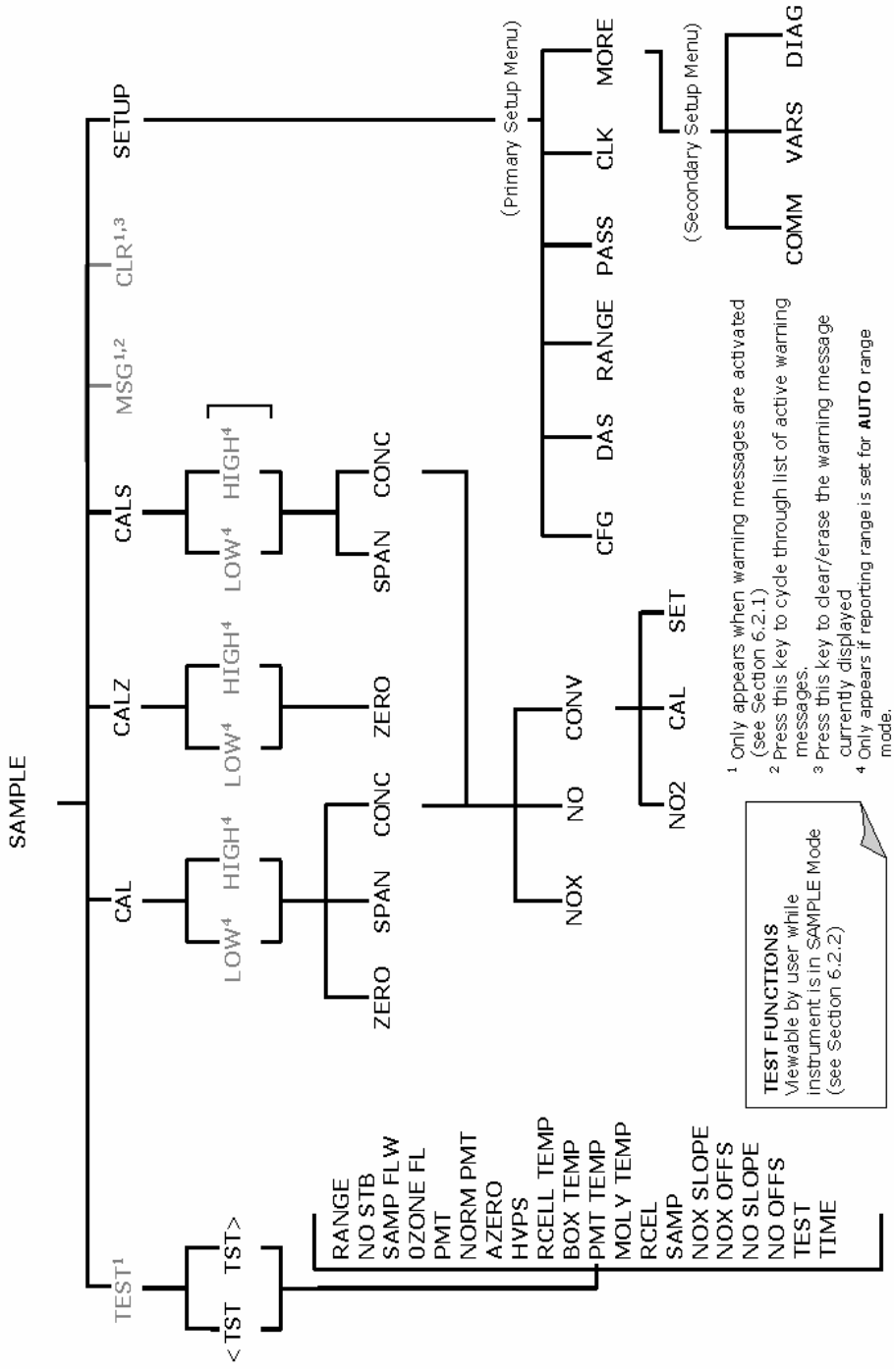

Figure A-2: Sample Display Menu - Units with Z/S Valve or IZS Option installed

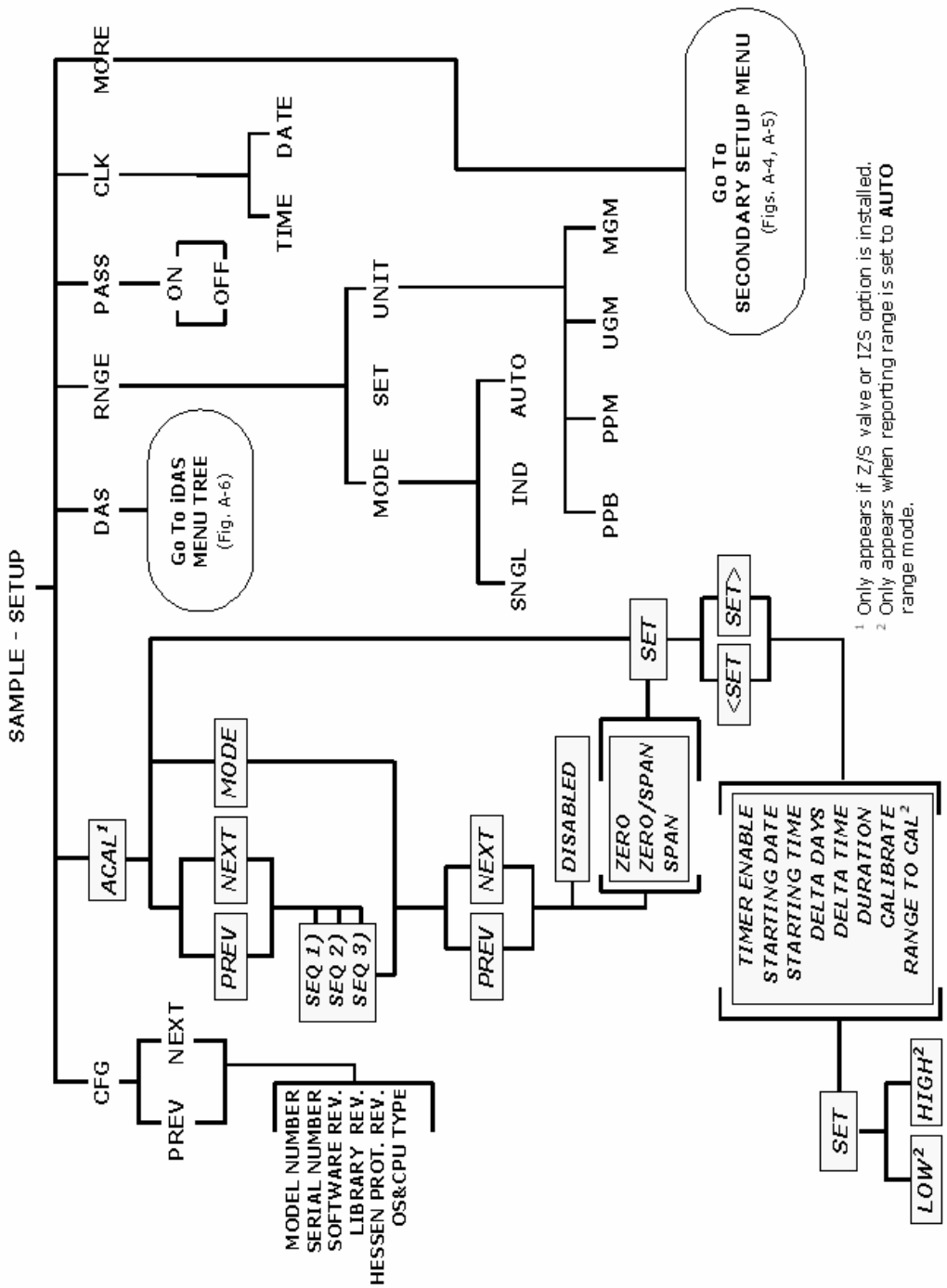

Figure A-3: Primary Setup Menu (Except iDAS)

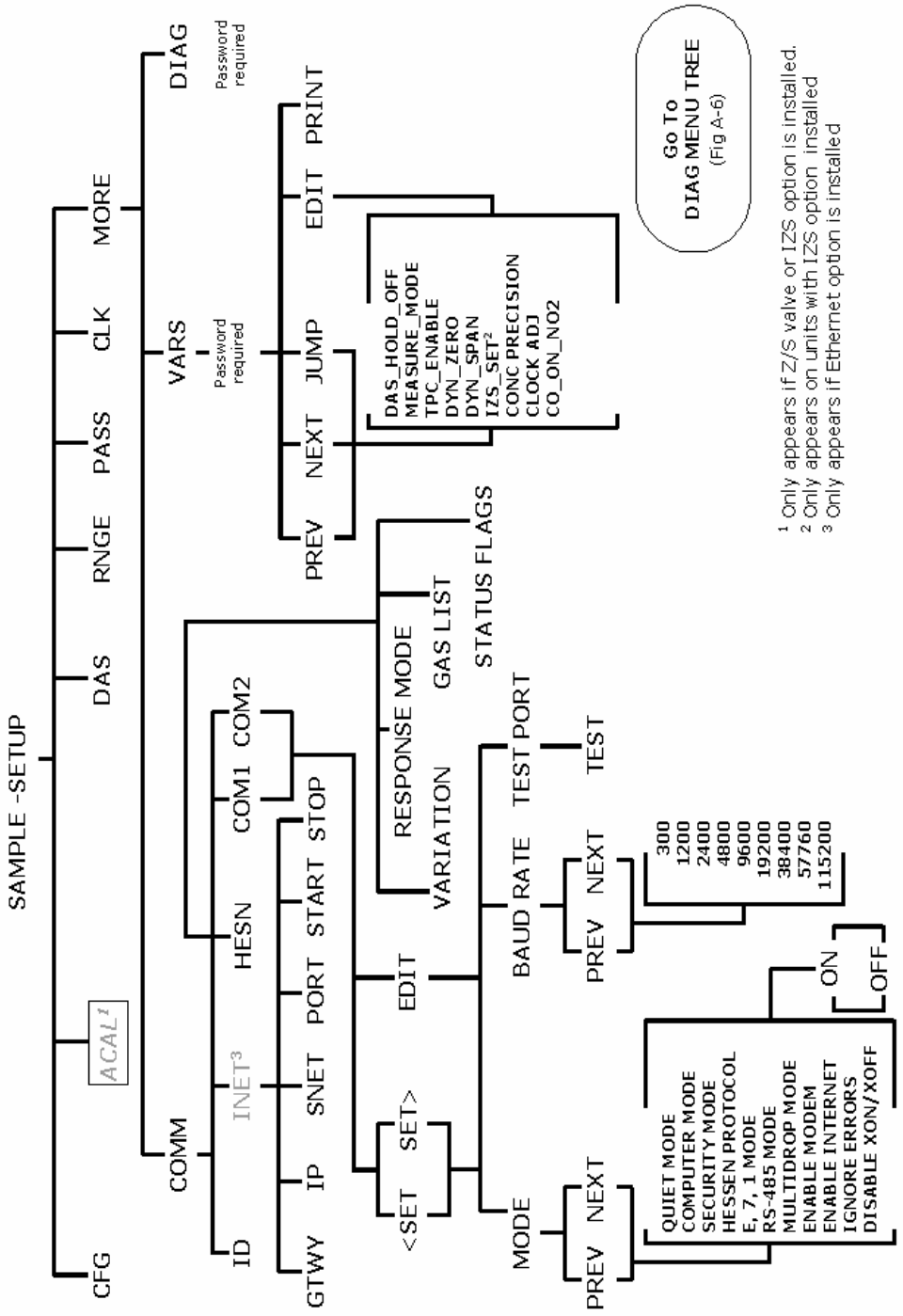

Figure A-4: Secondary Setup Menu (COMM & VARS)

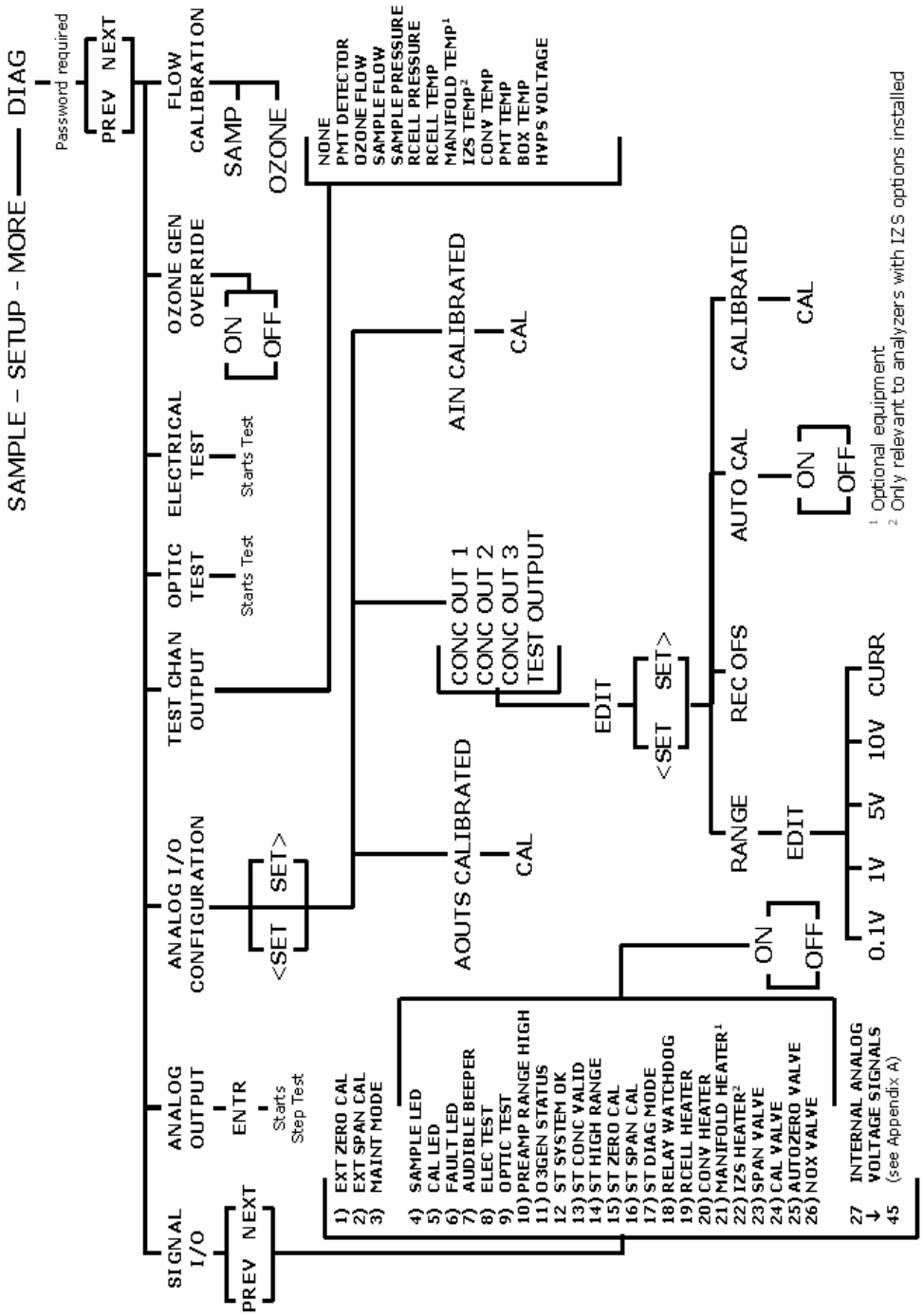

Figure A-5: Secondary Setup Menu (DIAG)

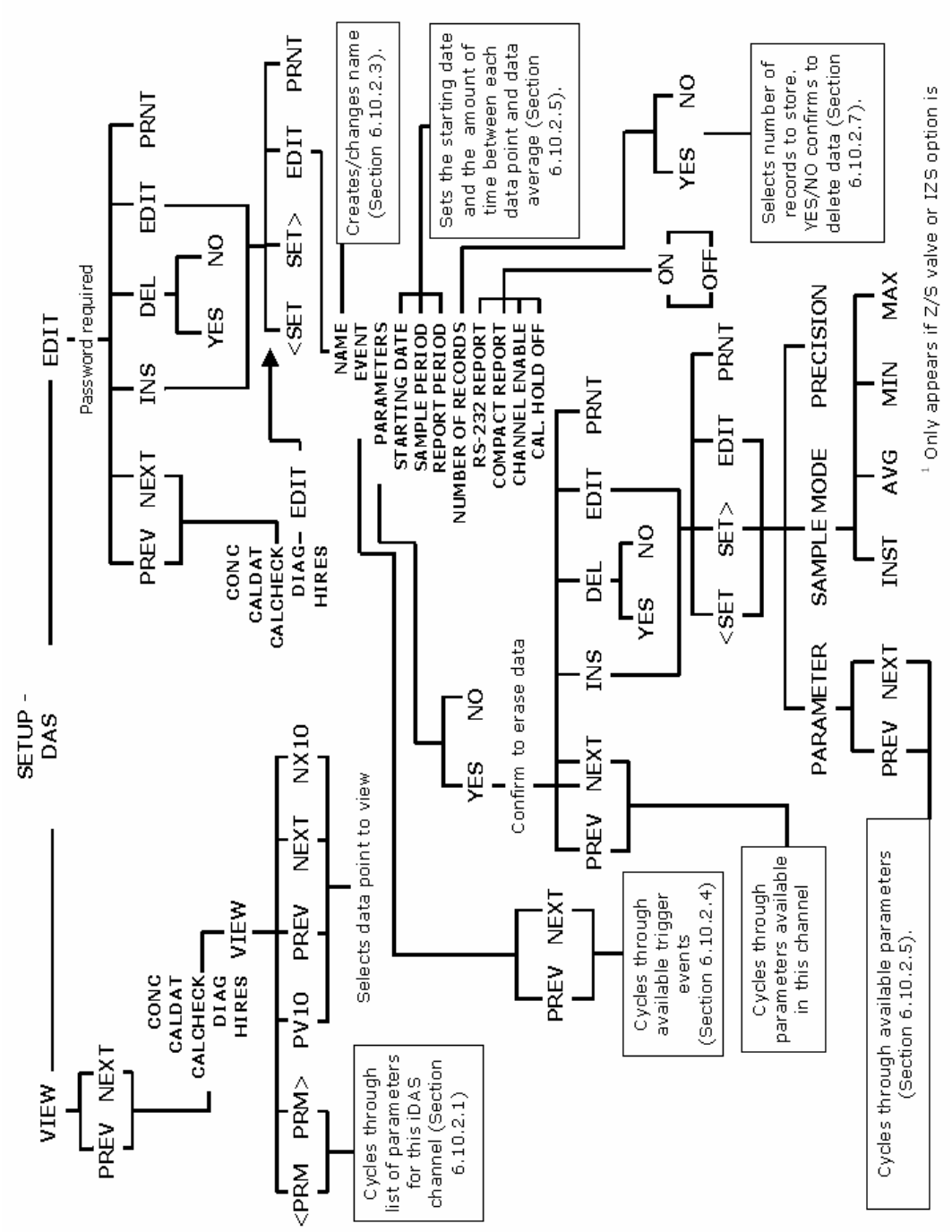

Figure A-6: Internal Data Acquisition (iDAS) Menu

APPENDIX A-2: Setup Variables For Serial I/O, Revision C.8

Table A-1: M9110E Setup Variables, Revision C.8

Please note that variables listed below under "Setup Variables Available Through serial I/O" should not be changed unless specifically instructed by Teledyne-API customer service or engineering! Changing those variables may cause significant problems with analyzer performance. Only those variables listed under "Setup Variables Available through Front Panel Display And serial I/O" are those see on the front panel display and should be changed by the user if necessary.

Setup Variable	Numeric Units	Default Value	Value Range	Description
Setup Variables Available through Front Panel Display And serial I/O				
DAS_HOLD_OFF	Minutes	15	0.5-20	Duration of DAS hold off period.
MEASURE_MODE	—	NO-NOX, NOX [8]	NO NO_X NOX-NO	Gas measure mode: single gas or switching. Enclose value in double quotes (") when setting from the RS-232 interface.
TPC_ENABLE	—	ON	OFF, ON	ON enables temperature/ pressure compensation; OFF disables it.
DYN_ZERO	—	OFF	ON, OFF	ON enables remote dynamic zero calibration; OFF disables it.
DYN_SPAN	—	OFF	ON, OFF	ON enables remote dynamic span calibration; OFF disables it.
IZS_SET [1]	ºC	50 Warnings: 45-55	30-70	IZS temperature set point and warning limits.
CONC_PRECISION	—	AUTO	AUTO 0 1 2 3 4	Number of digits to display to the right of the decimal point for concentrations on the display. Enclose value in double quotes (") when setting from the RS-232 interface.
CLOCK_ADJ	Sec./Day	0	-60-60	Time-of-day clock speed adjustment.
CAL_ON_NO2	—	OFF	ON, OFF	ON enables span calibration on pure NO_2; OFF disables it.
Setup Variables Available Through serial I/O				
LANGUAGE_SELECT	—	ENGL	ENGL, SECD EXTN	Selects the language to use for the user interface. Enclose value in double quotes (") when setting from the RS-232 interface.
MAINT_TIMEOUT	Hours	2	0.1-100	Time until automatically switching out of software-controlled maintenance mode.
BXTEMP_TPC_GAIN	—	0.3	0-10	Box temperature compensation attenuation factor.
RCTEMP_TPC_GAIN	—	0	0-10	Reaction cell temperature compensation attenuation factor.
RCPRESS_TPC_GAIN	—	0	0-10	Reaction cell pressure compensation attenuation factor.

Setup Variable	Numeric Units	Default Value	Value Range	Description
SPRESS_TPC_GAIN	—	0	0-10	Sample pressure compensation attenuation factor.
CE_FACTOR1	—	1	0.8-1.2	Moly converter efficiency factor for range 1.
CE_FACTOR2	—	1	0.8-1.2	Moly converter efficiency factor for range 2.
CONV_TIME	—	1 SEC	33 MS 66 MS 133 MS 266 MS 533 MS 1 SEC 2 SEC	Conversion time for PMT detector channel. Enclose value in double quotes (") when setting from the RS-232 interface.
SG_CONV_TIME	—	33 MS	*Same as above.*	Conversion time for PMT detector channel in single-gas measure modes. Enclose value in double quotes (") when setting from the RS-232 interface.
FILT_SIZE	Samples	42	1-500	Moving average filter size.
SG_FILT_SIZE	Samples	60	1–500	Moving average filter size in single-gas measure modes.
FILT_ADAPT	—	ON	ON, OFF	ON enables adaptive filter; OFF disables it.
FILT_OMIT_DELTA	PPM	0.05	0.005-0.1	Absolute change in concentration to omit readings.
FILT_OMIT_PCT	%	10	5-50	Percent change in concentration to omit readings.
FILT_SHORT_DELT	PPM	0.04	0.005-0.1	Absolute change in concentration to shorten filter.
FILT_SHORT_PCT	%	8	5-50	Percent change in concentration to shorten filter.
FILT_ASIZE	Samples	6	1-30	Moving average filter size in adaptive mode.
SG_FILT_ASIZE	Samples	10	1–500	Moving average filter size in adaptive mode, in single-gas measure modes.
FILT_DELAY	Seconds	120	0-200	Delay before leaving adaptive filter mode.
SG_FILT_DELAY	Seconds	60	0–200	Delay before leaving adaptive filter mode in single-gas measure modes.
NOX_DWELL	Seconds	2.5	0.1-30	Dwell time after switching valve to NO_X position.
SG_NOX_DWELL	Seconds	1	0.1–30	Dwell time after switching valve to NO_X position in single-gas measure modes.
NOX_SAMPLE	Samples	2	1-30	Number of samples to take in NO_X mode.
NO_DWELL	Seconds	1.5	0.1-30	Dwell time after switching valve to NO position.

Setup Variable	Numeric Units	Default Value	Value Range	Description
SG_NO_DWELL	Seconds	1	0.1–30	Dwell time after switching valve to NO position in single-gas measure modes.
NO_SAMPLE	Samples	2	1-30	Number of samples to take in NO mode.
SG_NO_SAMPLE	Samples	1	1–30	Number of samples to take in NO mode in single-gas measure modes.
USER_UNITS	—	PPB	PPB PPM UGM MGM	Concentration units for user interface. Enclose value in double quotes (") when setting from the RS-232 interface.
DIL_FACTOR	—	1	1-1000	Dilution factor. Used only if is dilution enabled with *FACTORY_OPT* variable.
AZERO_ENABLE	—	ON	ON, OFF	ON enables auto-zero; OFF disables it.
AZERO_FREQ	Minutes	1	0-60	Auto-zero frequency.
AZERO_DWELL	Seconds	2	0-60	Dwell time after opening or closing auto-zero valve.
AZERO_SAMPLE	Samples	2	1-10	Number of auto-zero samples to average.
SG_AZERO_SAMP	Samples	2	1–10	Number of auto-zero samples to average in single-gas measure modes.
AZERO_FSIZE	Samples	15	1-50	Moving average filter size for auto-zero samples.
AZERO_LIMIT	mV	200	0-1000	Maximum auto-zero offset allowed.
NOX_SPAN1	Conc.	400	4-20000	Target NO_X concentration during span calibration of range 1.
NO_SPAN1	Conc.	400	4-20000	Target NO concentration during span calibration of range 1.
NO2_SPAN1	Conc.	400	4-20000	Target NO_2 concentration during converter efficiency calibration of range 1.
NOX_SLOPE1	PPB/mV[3,5] PPM/mV[4]	1	0.25-4	NO_X slope for range 1.
NOX_OFFSET1	mV	0	-10000-10000	NO_X offset for range 1.
NO_SLOPE1	PPB/mV[3,5] PPM/mV[4]	1	0.25-4	NO slope for range 1.
NO_OFFSET1	mV	0	-10000-10000	NO offset for range 1.
NOX_SPAN2	Conc.	400	4-20000	Target NO_X concentration during span calibration of range 2.
NO_SPAN2	Conc.	400	4-20000	Target NO concentration during span calibration of range 2.

Setup Variable	Numeric Units	Default Value	Value Range	Description
NO2_SPAN2	Conc.	400	4-20000	Target NO_2 concentration during converter efficiency calibration of range 2.
NOX_SLOPE2	$PPB/mV^{3,5}$ PPM/mV^{4}	1	0.25-4	NO_X slope for range 2.
NOX_OFFSET2	mV	0	-10000-10000	NO_X offset for range 2.
NO_SLOPE2	$PPB/mV^{3,5}$ PPM/mV^{4}	1	0.25-4	NO slope for range 2.
NO_OFFSET2	mV	0	-10000-10000	NO offset for range 2.
RANGE_MODE	—	SNGL	SNGL, IND, AUTO	Range control mode. Enclose value in double quotes (") when setting from the RS-232 interface.
PHYS_RANGE1	PPM	2	0.1-2500	Low pre-amp range.
PHYS_RANGE2	PPM	20	0.1-2500	High pre-amp range.
CONC_RANGE1	Conc.	500	10-20000	D/A concentration range 1 or range for NO_X.
CONC_RANGE2 [1]	Conc.	500	10-20000	D/A concentration range 2 or range for NO.
CONC_RANGE3 [1]	Conc.	500	10-20000	D/A concentration range 3 or range for NO_2.
RCELL_SET	ºC	50 Warnings: 45-55	30-70	Reaction cell temperature set point and warning limits.
MANIFOLD_SET [1]	ºC	50 Warnings: 45-55	30-70	Manifold temperature set point and warning limits (if installed).
CONV_TYPE	—	MOLY	NONE, MOLY, CONV, O3KL	Converter type. "CONV" is mini-hicon, O3KL is O_3 killer only (no converter installed). Enclose value in double quotes (") when setting from the RS-232 interface.
CONV_SET	ºC	315 Warnings: 305-325	0-800	Converter temperature set point and warning limits for moly converter.
CONV_TEMP_TRIG	Cycles	10	0-100	Number of converter temperature errors required to trigger warning.
BOX_SET	ºC	30 Warnings: 7-48	0-70	Nominal box temperature set point and warning limits.
PMT_SET	ºC	7 Warnings: 5-12	0-40	PMT temperature warning limits. Set point is not used.
SFLOW_SET	cc/m	500 Warnings: 350–600	0–1000	Sample flow warning limits. Set point is not used.
SAMP_FLOW_SLOPE	—	1	0.001-100	Slope term to correct sample flow rate.
OFLOW_SET	cc/m	80	0–500	Ozone flow warning limits. Set point is not used.
OZONE_FLOW_SLOPE	—	1	0.001-100	Slope term to correct ozone flow rate.

Setup Variable	Numeric Units	Default Value	Value Range	Description
RCELL_SAMP_RATIO	—	0.53	0.1-2	Maximum reaction cell pressure / sample pressure ratio for valid sample flow calculation.
STD_BOX_TEMP	ºK	298 Valid limits: 278-338	1-500	Standard box temperature and valid limits for temperature compensation.
STD_RCELL_TEMP	ºK	323 Valid limits: 278-338	1-500	Standard reaction cell temperature and valid limits for temperature compensation.
STD_RCELL_PRESS	"Hg	7 Valid limits: 0.5-12	0.1-50	Standard reaction cell pressure and valid limits for pressure compensation.
STD_SAMP_PRESS	"Hg	29.92 Valid limits: 0.5-32	0.1-50	Standard sample pressure and valid limits for pressure compensation.
PRESS_FILT_SIZE [5]	Samples	60	1-120	Sample and reaction cell pressure moving average filter size.
PRESS_SAMP_FREQ [5]	Minutes	2	0.1-60	Sample and reaction cell pressure sampling frequency.
RS232_MODE	—	0	0-65535	RS-232 COM1 mode flags. Add values to combine flags. 1 = quiet mode 2 = computer mode 4 = enable security 8 = enable iChip support 16 = enable Hessen protocol 32 = enable multidrop 64 = enable modem 128 = ignore RS-232 line errors 256 = disable XON / XOFF support 1024 = enable RS-485 mode 2048=even parity, 7 data bits, 1 stop bit 4096 = enable command prompt
BAUD_RATE	—	19200	300, 1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200	RS-232 COM1 baud rate. Enclose value in double quotes (") when setting from the RS-232 interface.
MODEM_INIT	—	"AT Y0 &D0 &H0 &I0 S0=2 &B0 &N6 &M0 E0 Q1 &W0"	Any character in the allowed character set. Up to 100 characters long.	RS-232 COM1 modem initialization string. Sent verbatim plus carriage return to modem on power up or manually. Enclose value in double quotes (") when setting from the RS-232 interface.
RS232_MODE2	BitFlag	11	0-65535	RS-232 COM2 mode flags. *(Same settings as RS232_MODE)*

Setup Variable	Numeric Units	Default Value	Value Range	Description
BAUD_RATE2	—	115200	300, 1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200	RS-232 COM2 baud rate. Enclose value in double quotes (") when setting from the RS-232 interface.
MODEM_INIT2	—	"AT Y0 &D0 &H0 &I0 S0=2 &B0 &N6 &M0 E0 Q1 &W0"	Any character in the allowed character set. Up to 100 characters long.	RS-232 COM2 modem initialization string. Sent verbatim plus carriage return to modem on power up or manually. Enclose value in double quotes (") when setting from the RS-232 interface.
RS232_PASS	Password	940331	0-999999	RS-232 log on password.
MACHINE_ID	ID	200	0-9999	Unique ID number for instrument.
GATEWAY_IP_ADDR [1]	—	"000.000.000.000"	Any string of digits and decimal points.	Gateway IP address.
INST_IP_ADDRESS [1]	—	"000.000.000.000"	Any string of digits and decimal points.	Instrument IP address.
INST_SUBNET_MASK [1]	—	"255.255.255.0"	Any string of digits and decimal points.	Instrument subnet mask.
INST_TCP_PORT [1]	—	3000	1024-65535	Instrument TCP port.

Setup Variable	Numeric Units	Default Value	Value Range	Description
TEST_CHAN_ID	—	NONE	NONE, PMT DE-TECTOR, OZONE FLOW, SAMPLE FLOW, SAMPLE PRESSUR E, RCELL PRESSUR E, RCELL TEMP, MANIFOL D TEMP, IZS TEMP, CONV TEMP, PMT TEMP, CHASSIS TEMP, HVPS VOLTAGE	Diagnostic analog output ID. Enclose value in double quotes (") when setting from the RS-232 interface.
COMMAND_PROMPT	—	"Cmd> "	Any character in the allowed character set. Up to 100 character s long.	RS-232 interface command prompt. Displayed only if enabled with *RS232_MODE* variable. Enclose value in double quotes (") when setting from the RS-232 interface.
REMOTE_CAL_MODE [3]	—	LOW	LOW, HIGH	Range to calibrate during remote calibration. Enclose value in double quotes (") when setting from the RS-232 interface.
PASS_ENABLE	—	OFF	ON, OFF	ON enables passwords; OFF disables them.
STABIL_GAS	—	NOX	NO, NO2, NOX	Selects gas for stability measurement. Enclose value in double quotes (") when setting from the RS-232 interface.
STABIL_FREQ	Seconds	10	1-300	Stability measurement sampling frequency.
STABIL_SAMPLES	Samples	25	2-40	Number of samples in concentra-tion stability reading.
HVPS_SET	Volts	650 Warnings: 400-900	0-2000	High voltage power supply warning limits. Set point is not used.

Setup Variable	Numeric Units	Default Value	Value Range	Description
RCELL_PRESS_SET	In-Hg	6 Warnings: 0-15	0-100	Reaction cell pressure warning limits. Set point is not used.
RCELL_CYCLE	Seconds	10	0.5-30	Reaction cell temperature control cycle period.
RCELL_PROP	1/ºC	1	0-10	Reaction cell PID temperature control proportional coefficient.
RCELL_INTEG	—	0.1	0-10	Reaction cell PID temperature control integral coefficient.
RCELL_DERIV	—	0 (disabled)	0-10	Reaction cell PID temperature control derivative coefficient.
MANIFOLD_CYCLE [1]	Seconds	5	0.5-30	Manifold temperature control cycle period.
MANIFOLD_PROP [1]	1/ºC	0.2	0-10	Manifold PID temperature control proportional coefficient.
MANIFOLD_INTEG [1]	—	0.1	0-10	Manifold PID temperature control integral coefficient.
MANIFOLD_DERIV [1]	—	0.5	0-10	Manifold PID temperature control derivative coefficient.
SLOPE_CONST	—	8	0.1-100	Slope constant factor to keep visible slope near 1.
I2C_RESET_ENABLE	—	ON	OFF, ON	I^2C bus automatic reset enable.
ALARM_TRIGGER	Cycles	10	1–100	Number of valve cycles to trigger concentration alarm.
DISP_INTENSITY	—	HIGH	HIGH, MED, LOW, DIM	Front panel display intensity. Enclose value in double quotes (") when setting from the RS-232 interface.
SERIAL_NUMBER	—	"00000000 "	Any character in the allowed character set. Up to 100 charac-ters long.	Unique serial number for instrument. Enclose value in double quotes (") when setting from the RS-232 interface. Format: YYDDDNNNNS (year, Day of Year, Number, Special)

Setup Variable	Numeric Units	Default Value	Value Range	Description
CLOCK_FORMAT	—	"TIME=%H:%M:%S"	Any character in the allowed character set. Up to 100 charac-ters long.	Time-of-day clock format flags. Enclose value in double quotes (") when setting from the RS-232 interface. "%a" = Abbreviated weekday name. "%b" = Abbreviated month name. "%d" = Day of month as decimal number (01 – 31). "%H" = Hour in 24-hour format (00 – 23). "%I" = Hour in 12-hour format (01 – 12). "%j" = Day of year as decimal number (001 – 366). "%m" = Month as decimal number (01 – 12). "%M" = Minute as decimal number (00 – 59). "%p" = A.M./P.M. indicator for 12-hour clock. "%S" = Second as decimal number (00 – 59). "%w" = Weekday as decimal number (0 – 6; Sunday is 0). "%y" = Year without century, as decimal number (00 – 99). "%Y" = Year with century, as decimal number. "%%" = Percent sign.
FACTORY_OPT	—	0	0-65535	Factory option flags. Add values to combine flags. 1 = enable dilution factor 2 = display units in concentration field 4 = zero/span valves installed 8 = low span valve installed 16 = IZS and zero/span valves installed 32 = enable software-controlled maintenance mode 64 = display temperature in converter warning message 128 = enable switch-controlled maintenance mode 256 = enable simultaneous display of all gas concentrations 512 = enable manifold tempera-ture control

[1] Optional Equipment

APPENDIX A-3: Warnings and Test Measurements, Revision C.8

Table A-2: M9110E Warning Messages, Revision C.8

Name	Message Text	Description
WSYSRES	SYSTEM RESET	Instrument was power-cycled or the CPU was reset.
WDATAINIT	DATA INITIALIZED	Data storage was erased.
WCONFIGINIT	CONFIG INITIALIZED	Configuration storage was reset to factory configuration or erased.
WSAMPFLOW	SAMPLE FLOW WARN	Sample flow outside of warning limits specified by *SFLOW_SET* variable.
WOZONEFLOW	OZONE FLOW WARNING	Ozone flow outside of warning limits specified by *OFLOW_SET* variable.
WOZONEGEN	OZONE GEN OFF	Ozone generator is off. This is the only warning message that automatically clears itself. It clears itself when the ozone generator is turned on.
WRCELLPRESS	RCELL PRESS WARN	Reaction cell pressure outside of warning limits specified by *RCELL_PRESS_SET* variable.
WBOXTEMP	BOX TEMP WARNING	Chassis temperature outside of warning limits specified by *BOX_SET* variable.
WRCELLTEMP	RCELL TEMP WARNING	Reaction cell temperature outside of warning limits specified by *RCELL_SET* variable.
WMANIFOLDTEMP [4]	MANIFOLD TEMP WARN	Bypass or dilution manifold temperature outside of warning limits specified by *MANIFOLD_SET* variable.
WIZSTEMP	IZS TEMP WARNING	IZS temperature outside of warning limits specified by *IZS_SET* variable.
WCONVTEMP	CONV TEMP WARNING	Converter temperature outside of warning limits specified by *CONV_SET* variable.
WPMTTEMP	PMT TEMP WARNING	PMT temperature outside of warning limits specified by *PMT_SET* variable.
WAUTOZERO	AZERO WRN XXX.X MV	Auto-zero reading above limit specified by *AZERO_LIMIT* variable. Value shown in message indicates auto-zero reading at time warning was displayed.
WHVPS	HVPS WARNING	High voltage power supply output outside of warning limits specified by *HVPS_SET* variable.
WDYNZERO	CANNOT DYN ZERO	Contact closure zero calibration failed while *DYN_ZERO* was set to *ON*.
WDYNSPAN	CANNOT DYN SPAN	Contact closure span calibration failed while *DYN_SPAN* was set to *ON*.
WREARBOARD	REAR BOARD NOT DET	Rear board was not detected during power up.
WRELAYBOARD	RELAY BOARD WARN	Firmware is unable to communicate with the relay board.
WFRONTPANEL	FRONT PANEL WARN	Firmware is unable to communicate with the front panel.
WANALOGCAL	ANALOG CAL WARNING	The A/D or at least one D/A channel has not been calibrated.

[1] Optional equipment only

Table A-3: M9110E Test Measurements, Revision C.8

TEST Function	Message Text	Valid Data Range	Description
RANGE	RANGE=500.0 PPB	50-20000 ppb	Analog output range in single or auto-range modes.
RANGE1	RANGE1=500.0 PPB [3]	50-20000 ppb	D/A #1 range in independent range mode.
RANGE2	RANGE2=500.0 PPB [3]	50-20000 ppb	D/A #2 range in independent range mode.
RANGE3	RANGE3=500.0 PPB [3]	50-20000 ppb	D/A #3 range in independent range mode.
NOX STB	NOX STB=0.5 PPB	≤ 1 ppb with zero air	Concentration stability (standard deviation based on *STABIL_FREQ* and *STABIL_SAMPLES*)
SAMPLE FL	SAMPLE FL= 500 CC/M	500 ± 50 cm³/min	Sample flow rate
OZONE FL	Ozone fl= 80 CC/M	80 ± 15 cm³/min	FLow rate of ozone generator supply air
PMT	PMT= 000 MV	0-5000 mV for 0-20000 ppb	PMT response
NORM PMT	NORM PMT=800.0 MV	0-5000 mV for 0-20000 ppb	Normalized PMT response
AZERO	AZERO= 40 MV	-20 to 150 V	Auto-zero value, used to normalize PMT
HVPS	HVPS=700 V	400-900 ° C	High voltage power supply voltage of the PMT.
RCELL TEMP	RCELL TEMP= 50.0 C	50 ± 1 ° C	Reaction cell temperature
BOX TEMP	BOX TEMP= 30.0 C	~9 to ~45° C	Box temperature; is about 5° C higher than ambient temperature
PMT TEMP	PMT TEMP= 7.0 C	7 ± 2 ° C	PMT temperature, cooled with thermo-electric cooler
MF TEMP[1]	MF TEMP=50.8 C	50 ± 1 ° C	Manifold temperature (optional)
IZS TEMP[1]	IZS TEMP= 50.0 C	50 ± 1 ° C	Internal zero/span option temperature
MOLY TEMP	MOLY TEMP= 315 C	315 ± 5 ° C	NO_2 converter temperature
RCEL pressure	RCEL= 5.0 IN-HG-A	<10 in-Hg-A	Reaction cell (=vacuum) pressure
SAMP pressure	SAMP= 29.0 IN-HG-A	Ambient - ~1 in-Hg-A	Sample pressure, usually about 1 less than ambient, atmospheric pressure.
NO_X SLOPE	NOX SLOPE= 0.000	1.0 ± 0.3	Slope of linear fit for NO_X response, computed during calibration
NOX OFF	NOX OFF= 0.0 MV	-50 to 150 mV	Offset of linear fit for NO_X response, computed during calibration.
NO SLOPE	NO SLOPE= 0.000	1.0 ± 0.3	Slope of linear fit for NO response, computed during calibration
NO OFFS	NO OFFS= 0.0 MV	-50 to 150 mV	Offset of linear fit for NO response, computed during calibration.
Time of Day	TIME=15:11:24	00:00:00 to 23:59:59	Current instrument time (24-hour format)

APPENDIX A-4: M9110E Signal I/O Definitions, Revision C.8

Table A-4: M9110E Signal I/O Definitions, Revision C.8

Signal Name	Bit or Channel Number	Description
Internal inputs, U7, J108, pins 9-16 = bits 0-7, default I/O address 322 hex		
	0-7	Spare
Internal outputs, U8, J108, pins 1-8 = bits 0-7, default I/O address 322 hex		
ELEC_TEST	0	1 = electrical test on 0 = off
OPTIC_TEST	1	1 = optic test on 0 = off
PREAMP_RANGE_HI	2	1 = select high preamp range 0 = select low range
O3GEN_STATUS	3	0 = ozone generator on 1 = off
	4-5	Spare
I2C_RESET	6	1 = reset I^2C peripherals 0 = normal
I2C_DRV_RST	7	0 = hardware reset 8584 chip 1 = normal
Control inputs, U11, J1004, pins 1-6 = bits 0-5, default I/O address 321 hex		
EXT_ZERO_CAL	0	0 = go into zero calibration 1 = exit zero calibration
EXT_SPAN_CAL	1	0 = go into span calibration 1 = exit span calibration
	2-5	Spare
	6-7	Always 1
Control inputs, U14, J1006, pins 1-6 = bits 0-5, default I/O address 325 hex		
	0-5	Spare
	6-7	Always 1
Control outputs, U17, J1008, pins 1-8 = bits 0-7, default I/O address 321 hex		
	0-7	Spare
Control outputs, U21, J1008, pins 9-12 = bits 0-3, default I/O address 325 hex		
	0-3	Spare
Alarm outputs, U21, J1009, pins 1-12 = bits 4-7, default I/O address 325 hex		
	4-7	Spare
A status outputs, U24, J1017, pins 1-8 = bits 0-7, default I/O address 323 hex		
ST_SYSTEM_OK	0	0 = system OK 1 = any alarm condition
ST_CONC_VALID	1	0 = conc. valid 1 = hold off or other conditions
ST_HIGH_RANGE	2	0 = high auto-range in use 1 = low auto-range
ST_ZERO_CAL	3	0 = in zero calibration 1 = not in zero

Signal Name	Bit or Channel Number	Description
ST_SPAN_CAL	4	0 = in span calibration 1 = not in span
ST_DIAG_MODE	5	0 = in diagnostic mode 1 = not in diagnostic mode
	6-7	Spare
B status outputs, U27, J1018, pins 1-8 = bits 0-7, default I/O address 324 hex		
	0-7	Spare
Front panel I^2C keyboard, default I^2C address 4E hex		
MAINT_MODE	5 (input)	0 = maintenance mode 1 = normal mode
LANG2_SELECT	6 (input)	0 = select second language 1 = select first language (English)
SAMPLE_LED	8 (output)	0 = sample LED on 1 = off
CAL_LED	9 (output)	0 = cal. LED on 1 = off
FAULT_LED	10 (output)	0 = fault LED on 1 = off
AUDIBLE_BEEPER	14 (output)	0 = beeper on (for diagnostic testing only) 1 = off
Relay board digital output (PCF8575), default I^2C address 44 hex		
RELAY_WATCHDOG	0	Alternate between 0 and 1 at least every 5 seconds to keep relay board active
RCELL_HEATER	1	0 = reaction cell heater on 1 = off
CONV_HEATER	2	0 = converter heater on 1 = off
MANIFOLD_HEATER [2]	3	0 = bypass or dilution manifold heater on 1 = off
IZS_HEATER	4	0 = IZS heater on 1 = off
	5	Spare
SPAN_VALVE	6	0 = let span gas in 1 = let zero gas in
CAL_VALVE	7	0 = let cal. gas in 1 = let sample gas in
AUTO_ZERO_VALVE	8	0 = let zero air in 1 = let sample gas in
NOX_VALVE	9	0 = let NO_X gas into reaction cell 1 = let NO gas into reaction cell
	10-15	Spare
Rear board primary MUX analog inputs, MUX default I/O address 32A hex		
PMT_SIGNAL	0	PMT detector
HVPS_VOLTAGE	1	HV power supply output
PMT_TEMP	2	PMT temperature
	3	Spare

Signal Name	Bit or Channel Number	Description
	4	Temperature MUX
	5	Spare
	6	Spare
SAMPLE_PRESSURE	7	Sample pressure
RCELL_PRESSURE	8	Reaction cell pressure
REF_4096_MV	9	4.096V reference from MAX6241
OZONE_FLOW	10	Ozone flow rate
TEST_INPUT_11	11	Diagnostic test input
CONV_TEMP	12	Converter temperature
TEST_INPUT_13	13	Diagnostic test input
	14	DAC loopback MUX
REF_GND	15	Ground reference
Rear board temperature MUX analog inputs, MUX default I/O address 326 hex		
BOX_TEMP	0	Internal box temperature
RCELL_TEMP	1	Reaction cell temperature
IZS_TEMP	2	IZS temperature
	3	Spare
	4	Spare
TEMP_INPUT_5	5	Diagnostic temperature input
TEMP_INPUT_6	6	Diagnostic temperature input
MANIFOLD_TEMP [2]	7	Bypass or dilution manifold temperature
Rear board DAC MUX analog inputs, MUX default I/O address 327 hex		
DAC_CHAN_0	0	DAC channel 0 loopback
DAC_CHAN_1	1	DAC channel 1 loopback
DAC_CHAN_2	2	DAC channel 2 loopback
DAC_CHAN_3	3	DAC channel 3 loopback
Rear board analog outputs, default I/O address 327 hex		
CONC_OUT_1	0	Concentration output #1 (NO_X)
CONC_OUT_2	1	Concentration output #2 (NO)
CONC_OUT_3	2	Concentration output #3 (NO_2)
TEST_OUTPUT	3	Test measurement output

[1] Hessen protocol.
[2] Factory option.

APPENDIX A-5: M9110E Trigger Events and iDAS Functions, Revision C.8

Table A-5: M9110E DAS Trigger Events, Revision C.8

Trigger Name	Description
Events that can be accessed through the front panel	
ATIMER	Automatic timer expired
EXITZR	Exit zero calibration mode

EXITHS	Exit high span calibration mode
EXITMP	Exit multi-point calibration mode
SLPCHG	Slope and offset recalculated
Events that can be accessed through the remote interface	
EXITDG	Exit diagnostic mode
AZEROW	Auto-zero warning
OFLOWW	Ozone flow warning
RPRESW	Reaction cell pressure warning
RTEMPW	Reaction cell temperature warning
MFTMPW [1]	Bypass or dilution manifold temperature warning
IZTMPW [1]	IZS temperature warning
CTEMPW	Converter temperature warning
PTEMPW	PMT temperature warning
SFLOWW	Sample flow warning
BTEMPW	Box temperature warning
HVPSW	HV power supply warning

Table A-6: M9110E iDAS Functions, Revision C.8

Name	Description	Units
PMTDET	PMT detector reading	mV
NXSLP1	NO_X slope for range #1	—
NXSLP2	NO_X slope for range #2	—
NOSLP1	NO slope for range #1	—
NOSLP2	NO slope for range #2	—
NXOFS1	NO_X offset for range #1	mV
NXOFS2	NO_X offset for range #2	mV
NOOFS1	NO offset for range #1	mV
NOOFS2	NO offset for range #2	mV
NXZSC1	NO_X concentration for range #1 during zero/span calibration, just before computing new slope and offset	ppb [2]
NXZSC2	NO_X concentration for range #2 during zero/span calibration, just before computing new slope and offset	ppb [2]
NOZSC1	NO concentration for range #1 during zero/span calibration, just before computing new slope and offset	ppb [2]
NOZSC2	NO concentration for range #2 during zero/span calibration, just before computing new slope and offset	ppb [2]
N2ZSC1	NO_2 concentration for range #1 during zero/span calibration, just before computing new slope and offset	ppb [2]
N2ZSC2	NO_2 concentration for range #2 during zero/span calibration, just before computing new slope and offset	ppb [2]
NXCNC1	NO_X concentration for range #1	ppb [2]
NXCNC2	NO_X concentration for range #2	ppb [2]
NOCNC1	NO concentration for range #1	ppb [2]

Name	Description	Units
NOCNC2	NO concentration for range #2	ppb [2]
N2CNC1	NO_2 concentration for range #1	ppb [2]
N2CNC2	NO_2 concentration for range #2	ppb [2]
STABIL	Concentration stability	ppb [2]
AZERO	Auto zero offset (range de-normalized)	mV
O3FLOW	Ozone flow rate	cm^3/min
RCPRES	Reaction cell pressure	in-Hg-A
RCTEMP	Reaction cell temperature	°C
MFTEMP [1]	Bypass or dilution manifold temperature	°C
IZTEMP [1]	IZS block temperature	°C
CNVEF1	Converter efficiency factor for range #1	—
CNVEF2	Converter efficiency factor for range #2	—
CNVTMP	Converter temperature	°C
PMTTMP	PMT temperature	°C
SMPFLW	Sample flow rate	cm^3/min
SMPPRS	Sample pressure	in-Hg-A
BOXTMP	Internal box temperature	°C
HVPS	High voltage power supply output	V
REFGND	Ground reference (REF_GND)	mV
RF4096	4096 mV reference (REF_4096_MV)	mV
TEST11	Diagnostic test input (TEST_INPUT_11)	mV
TEST13	Diagnostic test input (TEST_INPUT_13)	mV
TEMP5	Diagnostic temperature input (TEMP_INPUT_5)	°C
TEMP6	Diagnostic temperature input (TEMP_INPUT_6)	°C

[1] Factory option.
[2] Standard instrument units.

APPENDIX A-6: Terminal Command Designators, Revision C.8

Table A-7: Terminal Command Designators, Revision C.8

Command	Additional Command Syntax	Description
? [ID]		Display help screen and this list of commands
LOGON [ID]	password	Establish connection to instrument
LOGOFF [ID]		Terminate connection to instrument
T [ID]	SET ALL|name|hexmask	Display test(s)
	LIST [ALL|name|hexmask] [NAMES|HEX]	Print test(s) to screen
	name	Print single test
	CLEAR ALL|name|hexmask	Disable test(s)
W [ID]	SET ALL|name|hexmask	Display warning(s)
	LIST [ALL|name|hexmask] [NAMES|HEX]	Print warning(s)
	name	Clear single warning
	CLEAR ALL|name|hexmask	Clear warning(s)
C [ID]	ZERO|LOWSPAN|SPAN [1|2]	Enter calibration mode
	ASEQ number	Execute automatic sequence
	COMPUTE ZERO|SPAN	Compute new slope/offset
	EXIT	Exit calibration mode
	ABORT	Abort calibration sequence
D [ID]	LIST	Print all I/O signals
	name[=value]	Examine or set I/O signal
	LIST NAMES	Print names of all diagnostic tests
	ENTER name	Execute diagnostic test
	EXIT	Exit diagnostic test
	RESET [DATA] [CONFIG] [exitcode]	Reset instrument
	PRINT ["name"] [SCRIPT]	Print iDAS configuration
	RECORDS ["name"]	Print number of iDAS records
	REPORT ["name"] [RECORDS=number] [FROM=<start date>][TO=<end date>][VERBOSE|COMPACT|HEX] (Print DAS records)(date format: MM/DD/YYYY(or YY) [HH:MM:SS]	Print iDAS records
	CANCEL	Halt printing iDAS records
V [ID]	LIST	Print setup variables
	name[=value [warn_low [warn_high]]]	Modify variable
	name="value"	Modify enumerated variable
	CONFIG	Print instrument configuration
	MAINT ON|OFF	Enter/exit maintenance mode
	MODE	Print current instrument mode
	DASBEGIN [<data channel definitions>] DASEND	Upload iDAS configuration
	CHANNELBEGIN propertylist CHANNELEND	Upload single iDAS channel
	CHANNELDELETE ["name"]	Delete iDAS channels

The command syntax follows the command type, separated by a space character. Strings in [brackets] are optional designators. The following key assignments also apply.

Terminal Key Assignments	
ESC	Abort line
CR (ENTER)	Execute command
Ctrl-C	Switch to computer mode
Computer Mode Key Assignments	
LF (line feed)	Execute command
Ctrl-T	Switch to terminal mode

USER NOTES:

APPENDIX B: Spare Parts and Expendables

NOTE
Use of replacement parts other than those supplied by Teledyne-API may result in non-compliance with European standard EN 61010-1.

The following listings contain spare parts for individual ordering as well as recommended stocking levels for operation of multiple analyzers to minimize downtime for any one analyzer unit.

The expendables (chemicals, filters, O-rings etc) are not included in the spare parts listing, neither are optional analyzer components as listed in Chapter 5.

Table B-1: M9110E Individual Spare Parts List

Part Number	Description	Notes
000940100	CD, ORIFICE, 0.003" GREEN	Flow Control Orifice, 40 cm³/min, high concentration sample flow
000940400	CD, ORIFICE, 0.004" BLUE	Flow Control Orifice, 80 cm³/min, standard ozone flow
000940500	CD, ORIFICE, 0.007" ORANGE	Flow Control Orifice, 250 cm³/min, optional sample and/or ozone flow
000940600	CD, ORIFICE, 0.010" BROWN	Flow Control Orifice, 500 cm³/min, standard sample flow
002270000	GASKET, WINDOW	Gasket for reaction cell window
002730000	CD, FILTER, 665NM	Reaction cell optical glass filter
003290000	THERMISTOR, BASIC	Thermistor for reaction cell. Also used in IZS option, bypass manifold and O_2 sensor.
009070000	COOLER, T.E	Thermo-electric PMT cooler
010150101	ASSY, MOLY CONVERTER WELDED CARTRIDGE	NO_2 converter cartridge, guts only without heater and thermocouple
011930000	CD, PMT, NOX, M200AR928	Photo multiplier tube (PMT)
013140000	ASSY, COOLER FAN, M200A	92 mm PMT cooling fan under PMT housing
014080100	ASSY, HVPS, SOX/NOX	PMT socket and high voltage power supply including LED and thermistor housing.
016290000	WINDOW, SAMPLE FILTER, 47MM	Replacement glass window for sample filter
024710000	ASSY, TUBING, TU0000001, 6FT	Clear FEP tubing, 1/8" OD, ~1.8 m
024720000	ASSY, TUBING, TU0000002, 6FT	Black FEP tubing, 1/8" OD, ~1.8 m
024750000	ASSY, TUBING, TU0000009, 6FT	Clear PVC tubing, 1/4" OD, ~1.8 m
037860000	ORING, TEFLON, RETAINING RING, 47MM	Sample filter retaining ring
040010000	ASSY, FAN REAR PANEL, E SERIES	60 mm main chassis fan on rear panel
040300100	ASSY, 115V CONFIG PLUG, M9110E	Power configuration plug for 115 V AC
040300200	ASSY, 230V CONFIG PLUG, M9110E	Power configuration plug for 230 V AC
040690100	PCA, E SERIES MTHRD W/MICROFITS,	Analyzer Motherboard

Part Number	Description	Notes
	AMBIENT	
040900000	ORIFICE HOLDER, M9110E REACTION CELL	Orifice holder only; does not include fitting, O-rings or any orifice assembly parts
041710000	CPU, CONFIGURATION, "E" SERIES	CPU board including EEPROM. Needs 043890100 disk-on-chip with software
043890100	DOC, w/SOFTWARE, M9110E	Disk-on-chip with all required software, needed for 041710000 CPU board.
042580000	PCA, KEYBOARD, E-SERIES, W/V-DETECT	Front panel keyboard and display board. Requires separate display DS0000009
044190000	ASSY, OZONE FILTER UNIT	Cartridge includes all fittings, chemical and mounting screws
044470001	044470001 MOD, O3 FILTER FITTING, FT294, M9110E	FT 294 with pressed-in sintered filter. O_3 filter requires two
045500100	ASSY, ORIFICE HOLDER, 4 MIL	Complete assembly to replace critical orifice, O-rings, sintered filter, spring and fitting FT10 for the ozone supply gas. Nominal 80 cm^3/min
045500300	ASSY, ORIFICE HOLDER, 10 MIL	As previous, except for the sample gas. Nominal 500 cm^3/min
045500200	ASSY, ORIFICE HOLDER, 7 MIL	As previous, except for the optional bypass manifold or high ozone flow. Nominal 250 cm^3/min
045500400	ASSY, ORIFICE HOLDER, 3 MIL	Same as previous, 40 cm^3/min flow
045500500	ASSY, ORIFICE HOLDER, no orifice	Same as previous, without orifice
DS0000009	DISPLAY	Vacuum fluorescence display. Mounts on 042580000 keyboard PCA.
FL0000001	FILTER, SS	Filter for flow control assembly (All Versions)
FM0000004	FLOWMETER	Ozone supply air flow meter
FT0000010	CONNECTOR-ORING, SS, 1/8"	Fitting to cap orifice holder
FT0000190	NUT, DELRIN, 1/4-28, 1/8 TUBE	Replacement nut for FT294, O_3 filter fitting
FT0000267	BURKERT FERRULE TOOL	For O_3 filter assembly fittings
FT0000303	FERRULE, 1/4-28, 1/8 TUBE, FOR FT294	Replacement ferrule for FT294, O_3 filter fitting
HE0000017	HEATER, 12W/120V (50W/240V) CE APPROVED	Reaction cell heater cartridge. Also used in IZS option, bypass manifold and O_2 sensor.
HW0000020	SPRING	Spring for flow control assembly
HW0000036	TFE TAPE, 1/4" (48 FT/ROLL)	Teflon tape for NPT threaded fittings
IC0000208	IC QUAD DARLINGTON POWER DRIVER UDN2540B	Valve driver chip on relay board
KIT000115	OPTION, SAMPLE GAS CONDITIONER, M200A/ E	Ozone air or sample air dryer only, without bracket
OR0000001	ORING, 2-006VT	O-ring for flow control assemblies (2 per assy)
OR0000002	ORING, 2-023V	O-ring seals ends of reaction cell (2 required)
OR0000034	ORING, 2-011V FT10	O-ring for FT 10 (one per fitting)
OR0000039	ORING, 2-012V	O-ring for orifice holder (one per fitting)
OR0000044	ORING, 2-125V	O-ring seals reaction cell to PMT housing

Part Number	Description	Notes
PS0000029	EOS SWITCHING PS, +5V, +/-15V, 40W	5 V and ±15V power supply for all electronics
PS0000031	EOS SWITCHING PS, 12V, 60W	12 V Power supply for PMT cooler and valves
RL0000015	RELAY, DPDT, GORDOS PREFERRED	Power relays for heater circuits. M9110E needs two, IZS, bypass manifold and O_2 sensor options one more each
SW0000025	PWR SWITCH/CIRCUIT BREAKER, VDE CE 6.75A	Power switch on front panel
VA0000007	VALVE, 3-WAY SS, 12VDC	Valve for NO/NO_X and AutoZero as well as both IZS option valves
WR0000008	POWER CORD, 10A	Main power cord

Table B-2: M9110E Expendables List

Part Number	Description	Notes	Qty[1]
002270100	GASKET, WINDOW (12 PACK)	12 gaskets for reaction cell optical filter	1
005960000	AKIT, EXP KIT, ACTIVATED CHARCOAL, 2.5 KG	Black activated charcoal for zero air scrubber (~50 refills)	50 g
005970000	AKIT, EXP KIT, PURAFIL, 2.5 KG	Pink Purafil chemisorbant for zero air scrubber cartridge (~35 refills)	70 g
009690200	AKIT,TFE FLTR ELEM'S, 47MM, (100)	100 filters for 47 mm, 1µm sample filter	1
009690300	AKIT, TFE FLTR ELEM'S, 47MM, (25)	25 filters for 47 mm, 1µm sample filter	1
046040000	AKIT, CH-43, (300 g)	Refill for ozone air filter cartridge (~30 refills)	1
FL0000001	FILTER, SS	Sintered filters for orifice assemblies	1
HW0000020	SPRING	Spring for all orifice assemblies	1
OR0000001	ORING, 2-006VT	Viton O-rings for all orifice assemblies	2
[1] Quantity needed for one replacement			

Expendables kits:

Part Number	Description	Notes	Qty[2]
014030000	**AKIT, M200A EXP KIT-IZS**	**Expendables kit for IZS option**	
This kit contains the following items			
005960000	AKIT, EXP KIT, ACTIVATED CHARCOAL, 2.5 KG	Black activated charcoal for zero air scrubber (~50 refills)	2.5 kg
005970000	AKIT, EXP KIT, PURAFIL, 2.5 KG	Pink Purafil chemisorbant for zero air scrubber cartridge (~35 refills)	2.5 kg
FL0000001	FILTER, SS	Sintered stainless steel filter	2
FL0000003	FILTER, DFU	Particle filter between scrubber and analyzer	1
OR0000001	ORING, 2-006VT	O-ring to seal critical orifice	4

[2] Quantity included in one kit.			
Part Number	**Description**	**Notes**	**Qty[2]**
046060000	**AKIT, ORIFICE EXPENDABLES, M9110Ex**	**Expendables kit for one orifice assembly**	
This kit contains the following items			
FL0000001	FILTER, SS	Sintered stainless steel filter	1
HW0000020	SPRING	Spring to hold assembly in place	1
OR0000001	ORING, 2-006VT	O-ring to seal critical orifice	2
[2] Quantity included in one kit.			

USER NOTES:

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RECOMMENDED SPARE PARTS STOCKING LEVELS
9110E

		UNITS				
PART NO.	**DESCRIPTION**	**1**	**2- 5**	**6-10**	**11-20**	**21-30**
010150100	Subassy, Moly Con Cartridge				1	1
011310000 *	Assy, Dryer, NOX		1	2	3	4
011930000	PMT, NOX				1	1
014080100	Assy, HVPS, SOX/NOX				1	1
014610000	Replacement Cooler Assembly		1	2	3	3
039550200	PCA, Relay Card, M100E/M9110E, w/Relays			1	1	2
040010000	Assy, Fan Rear Panel, E Series	1	1	2	4	4
040030800	PCA, Press Sensor (2X), Flow, E Series			1	2	3
040420200	Assy, O3 Brick, M9110EH, High Output					1
040690100	E Series Mother Board				1	2
041710000	CPU, Configuration "E" Series				1	1
041800200	PCA, PMT Preamp, M9110E/EH				1	1
042580000	PCA, Keyboard, E- Series, W/V-Detect				1	1
044610000	Assy, Valves, Moly Hicon, M9110E/EH				1	2
045500100	4 Mil Orifice Holder	1	1	2	2	4
045500300	10 Mil Orifice Holder	1	1	2	2	4
DS0000009	Display				1	1
FM0000004	Flowmeter			1	2	3
HE0000017	Heater, 12V, 120W(50V, 240W) CE approved	1	1	2	2	3
OR0000034	O-Ring, 2-011V			2	5	10
OR0000044	O-Ring, 2-125V			2	5	10
OR0000045	O-Ring, 2-226V			2	5	10
PS0000029	EOS, Switching PS +5V, +/-15V, 40W		1	1	1	2
PS0000031	EOS Switching PS, 12V, 60W		1	1	1	2
PU0000005 *	Pump, Thomas 607, 115V/60Hz					1
RL0000015	Relay DPDT	1	1	1	2	3
VA0000007	Valve			1	2	4

* Dryer Combination 041500000

Use PI0000006 for 50Hz applications

IZS Option						
VA0000007	Valve		1	2	2	4

USER NOTES:

Warranty/Repair Questionnaire Model 9110E

TELEDYNE INSTRUMENTS
Advanced Pollution Instrumentation
A Teledyne Technologies Company

CUSTOMER: _____ PHONE: _____

CONTACT NAME: _____ FAX NO. _____

SITE ADDRESS: _____

MODEL 9110E SERIAL NO.: _____FIRMWARE REVISION: _____

1. ARE THERE ANY FAILURE MESSAGES? _____

_____

_____

PLEASE COMPLETE THE FOLLOWING TABLE: **(NOTE: *DEPENDING ON OPTIONS INSTALLED, NOT ALL TEST PARAMETERS SHOWN BELOW WILL BE AVAILABLE IN YOUR INSTRUMENT*)**
*IF OPTION IS INSTALLED

PARAMETER	RECORDED VALUE	ACCEPTABLE VALUE
RANGE	PPB/PPM	50 PPB TO 20 PPM
NOx STAB	PPB/PPM	≤ 1 PPB WITH ZERO AIR
SAMPLE FLOW	CM^3	500 ± 50
OZONE FLOW	CM^3	80 ± 15
PMT SIGNAL WITH ZERO AIR	MV	-20 TO 150
PMT SIGNAL AT SPAN GAS CONC	MV PPB	0-5000MV 0-20,000 PPB
NORM PMT SIGNAL AT SPAN GAS CONC	MV PPB	0-5000MV 0-20000PPB
AZERO	MV	-20 TO 150
HVPS	V	400 – 900
RCELL TEMP	ºC	50 ± 1
BOX TEMP	ºC	AMBIENT ± 5ºC
PMT TEMP	ºC	7 ± 2ºC
IZS TEMP*	ºC	50 ± 1ºC
MOLY TEMP	ºC	315 ± 5ºC
RCEL PRESS	IN-HG-A	<10
SAMP PRESS	IN-HG-A	AMBIENT ± 1
NOx SLOPE		1.0 ± 0.3
NOx OFFSET		50 TO 150
NO SLOPE		1.0 ± 0.3
NO OFFSET		50 TO 150
ETEST	PMT MV	2000 ± 1000
OTEST	PMT MV	2000 ± 1000
Values are in the Signal I/O		
REF_4096_MV	MV	4096mv ±2mv and Must be Stable
REF_GND	MV	0± 0.5 and Must be Stable

Warranty/Repair Questionnaire Model 9110E

TELEDYNE INSTRUMENTS
Advanced Pollution Instrumentation
A Teledyne Technologies Company

2. WHAT IS THE RCELL & SAMPLE PRESSURES WITH THE SAMPLE INLET ON REAR OF MACHINE CAPPED?

RCELL PRESS -_____IN-HG-A **SAMPLE PRESSURE** - _____IN-HG-A

3. WHAT ARE THE FAILURE SYMPTOMS? _____

_____

_____

4. WHAT TEST HAVE YOU DONE TRYING TO SOLVE THE PROBLEM? _____

_____

_____

_____

_____

_____

5. IF POSSIBLE, PLEASE INCLUDE A PORTION OF A STRIP CHART PERTAINING TO THE PROBLEM. CIRCLE PERTINENT DATA.
6. THANK YOU FOR PROVIDING THIS INFORMATION. YOUR ASSISTANCE ENABLES TELEDYNE API TO RESPOND FASTER TO THE PROBLEM THAT YOU ARE ENCOUNTERING.

TELEDYNE API CUSTOMER SERVICE
EMAIL: ask_tai@teledyne.com
PHONE: (626) 934-1673 FAX: (626) 961-2538

APPENDIX D: Diagrams and Schematics

Table D-1: List of Included Diagrams and Schematics

#	Document #	Document Title	Number of pages
1	04574	Document, M9110E Detailed Pneumatic Diagrams for all configurations (similar to Figure 3-11 and Figure 3-12)	5
2	04504	Document, M9110E Electronic Interconnect Diagram	1
3	04496	Document, M9110E Electronic Interconnect Listing	2
4	01669	PCA 016680300, Ozone generator board	1
5	01840	PCA Thermo-electric cooler board	1
6	03632	PCA 03631, 0-20mA Driver	1
7	03956	PCA 039550200, Relay Board	3
8	04070	PCA 04069, Motherboard, E-series	8
9	04259	PCA 04258, Keyboard & Display Driver	1
10	04354	PCA 04003, Pressure/Flow Transducer Interface	1
11	04395	PCA 4394, Ethernet board (optional equipment)	1
12	04181	PCA 041800200, PMT pre-amplifier board	3
Total number of pages as Z-folds			28

USER NOTES: