**TÜV RHEINLAND**
**ENERGIE UND UMWELT GMBH**

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# Report on the supplementary testing for the demonstration of equivalence according to the reference methode of the T500U ambient air quality monitoring system manufactured by Teledyne API measuring $NO_2$

TÜV Report: 936/21224798/B
Cologne, March 03, 2015

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Report on the supplementary testing for the demonstration of equivalence according to the reference methode of the T500U ambient air quality monitoring system manufactured by Teledyne API measuring $NO_2$

| | |
|---|---|
| **Instrument tested:** | T500U |
| **Manufacturer:** | Teledyne API<br>9480 Carroll Park Drive<br>San Diego, CA, 92121-5201<br>USA |
| **Test period:** | May 2014 to March 2015 |
| **Date of report:** | March 03, 2015 |
| **Report number:** | TÜV Report: 936/21224798/B |
| **Editor:** | Dipl.-Ing. Martin Schneider<br>Tel.: +49 221 806-1614<br>martin.schneider@de.tuv.com |

**Scope of report:**

| | | | |
|---|---|---|---|
| Report | | 132 | pages |
| Manual | page | 120 | |
| Manual | of | 138 | pages |
| Total | | 258 | pages |

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# 1. Summary and certification proposal

## 1.1 Summary

Teledyne API commissioned TÜV Rheinland Energie und Umwelt GmbH to carry out performance testing of the T500U measuring system for the component $NO_2$.

Testing was performed in compliance with the following standards and guidelines:

- VDI 4202 Part 1: Performance criteria for performance tests of automated ambient air measuring systems; Point-related measurement methods for gaseous and particulate air pollutants, September 2010
- VDI 4203 Part 3: Testing of automated measuring systems Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants, September 2010
- EN 14211: Ambient air - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, August 2012
- Guide "Demonstration of equivalence of ambient air monitoring methods", of January 2010

The measuring system does **not** use the method of chemiluminescence which serves as a reference method in the EU. Instead it uses UV absorption (CAPS). Tests were performed in the laboratory as well as during a three months field test in Cologne.

The measured range was 0 – 500 µg/m³ (0 – 261 nmol/mol) $NO_2$.

The measuring system T500U uses UV absorption to measure $NO_2$. As the majority of tests in accordance with Standard EN 14211 is specifically designed to measure NO instead of $NO_2$, the criteria specified in 1.1 were applied to $NO_2$.

*Table 1: Measurement ranges during testing*

| Measured component | Measurement range [µg/m³] 1) | Mearsurement range [ppb] resp. [nmol/mol] |
|---|---|---|
| $NO_2$ | 0 – 500 | 0 - 261 |

1) The data refer to 20 °C and 101.3 kPa.

Minimum requirements were met during performance testing.

TÜV Rheinland Energie und Umwelt GmbH therefore suggests its type approval for continuous measurement of nitrogen dioxide concentrations in ambient air.

## 1.2 Certification proposal

Due to the positive results achieved, the following recommendation is put forward for the notification of the AMS as a type-approved measuring system:

**AMS designation:**

T500U for $NO_2$

**Manufacturer:**

ambient air quality monitoring system manufactured by Teledyne API, San Diego, USA

**Field of application:**

Continuous measurement of nitrogen dioxide concentrations in ambient air from stationary sources.

**Measured ranges during performance testing:**

| Component | Certification range | Unit |
|---|---|---|
| Nitrogen dioxide | 0 - 500 | µg/m³ |

**Softwareversion:**

Rev. 1.0.2 bld 22

**Restrictions:**

None

**Notes:**

1. The test report on the performance test is available online at www.qal1.de.
2. Equivalence with the reference measurement methods was verified for component $NO_2$, in accordance with guide “Demonstration of Equivalence of Ambient Air Monitoring Methods”.
3. Supplementary test for the demonstration of equivalence according to reference meth-ods of the publication in the german federal gazette from February 25, 2015 (BAnz. AT from April 02, 2015, B5, chapter III, No. 2.1)

**Test Report:**

TÜV Rheinland Energie und Umwelt GmbH, Cologne

Report No.: TÜV Report: 936/21224798/B dated March 03, 2015

## 1.3 Summary of test results

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| **4 Requirements on the instrument design** | | | | |
| **4.1 General requirements** | | | | |
| 4.1.1 Measured value display | Has to exist | The measuring system is fitted with a measured value display. | yes | 31 |
| 4.1.2 Easy maintenance | It should be possible to perform maintenance tasks with a reasonable effort from the outside. | Maintenance can be performed with usual tools in a reasonable time from the outside. | yes | 32 |
| 4.1.3 Functional check | Particular instruments required shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment. | The instrument tested does not have an internal device for functional checks. | yes | 35 |
| 4.1.4 Set-up times and warm-up times | Particulars shall be specified in the instruction manual. | Set-up times and warm-up times were determined. | yes | 34 |
| 4.1.5 Instrument design | The instruction manual shall include specifications of the manufacturer to this effect. | Specifications made in the instruction manual with regard to the instrument's design are complete and correct. | yes | 35 |
| 4.1.6 Unintended adjustment | Adjustment shall be protected. | The measuring system is protected against the unintended or unauthorised adjustment of instrument parameters via password. | yes | 38 |
| 4.1.7 Data output | Shall be provided digitally and/or as analogue signals. | Measuring signals are provided analogue (4-20 mA bzw. 0-10 V) and digitally (via TCP/IP, RS 232, USB). | yes | 39 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| **5. Performance characteristics** | | | | |
| 5.1 General | The manufacturer's specifications in the instruction manual shall not contradict the results of the performance test | No discrepancies between the instrument design and the instruction manuals were observed. | yes | 38 |
| **5.2 General requirements** | | | | |
| 5.2.1 Certification ranges | Need to comply with specifications of Table 1 of guideline VDI 4202 Part. | The measuring system can be assessed in the range of the relevant limit values. | yes | 39 |
| 5.2.2 Measuring range | The upper limit of measurement of the measuring systems shall be greater than or equal to the upper limit of the certification range. | By default the measuring range is set to 0 – 500 µg/m³ for $NO_2$. Other measuring ranges of max. 0 – 20 ppm are possible.<br>The upper limit of the measuring range is greater than the upper limit of the certification range. | yes | 40 |
| 5.2.3 Negative output signals | Shall be displayed (life zero). | The measuring system also displays negative signals. | yes | 41 |
| 5.2.4 Failure in the mains voltage | In case of failure in the mains voltage, uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured against loss, When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement. | In the event of power failure, the measuring system will be ready to be operated again and will automatically resume measurement when reconnected. | yes | 42 |
| 5.2.5 Operating states | The measuring system shall allow the control of important operating states by telemetrically transmitted status signals. | By means of various connectivity options and the "APICOM" software the measuring system can be monitored and controlled from an external PC. | yes | 43 |
| 5.2.6 Switch-over | Switch-over between measurement and functional check and/or calibration shall be possible telemetrically or manual intervention. | In general, all tasks related to functional checks may be performed directly on-site or monitored telemetrically using the remote control functions. | yes | 44 |
| 5.2.7 Maintenance interval | Preferably three months but at least two weeks. | The maintenance interval is four weeks as determined by the necessary maintenance tasks. | yes | 45 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| 5.2.8 Availability | At least 95 %. | Availability for both systems was 100 % incl. maintenance times during testing. | yes | 46 |
| 5.2.9 Instrument software | Shall be displayed during switch-on of the measuring system. The test institute shall be informed about changes in the instrument software, which influence the performance of the measuring system. | The instrument's software version is indicated in the display. Changes to the software will be communicated to the test institute. | yes | 47 |
| **5.3 Requirements on measuring systems for gaseous air pollutants** | | | | |
| 5.3.1 General remarks | Minimum requirements as stipulated in VDI 4202 Part 1. | The tests were performed on the basis of minimum requirements as stipulated VDI 4202 part 1 (September 2010) as well as standard EN 14211 (2012). | yes | 48 |
| 5.3.2 Repeatability standard deviation at zero point | The repeatability standard deviation at zero point shall not exceed the requirements listed in Table 1 of VDI 4202 part 1 (September 2010) and in table 2 of standard VDI 4202 part 1 (September 2010) in the certification range. | Please see section 7.1 8.4.5<br>Repeatability standard deviation | yes | 49 |
| 5.3.3 Repeatability standard deviation at reference point | The repeatability standard deviation at reference point shall not exceed the requirements stipulated in table 1of VDI 4202 part 1 (September 2010) and Table 2 of standard VDI 4202 part 1 (September 2010) in the certification range. | Please see section 7.1 8.4.5<br>Repeatability standard deviation. | yes | 50 |
| 5.3.4 Linearity (Lack-of-fit) | The analytical function describing the relationship between the output signal and the value of the air quality characteristic shall be linear. | Please refer to section 7.1 8.4.6<br>Deviation from linearity of the calibration function | yes | 51 |
| 5.3.5 Sensitivity coefficient of sample gas pressure | The sensitivity coefficient of sample gas pressure at reference point shall not exceed the requirements stipulated in table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.4.7<br>Sensitivity coefficient to sample gas pressure. | yes | 52 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| 5.3.6 Sensitivity coefficient of sample gas temperature | The sensitivity coefficient of sample gas temperature at reference point shall not exceed the requirements stipulated in table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.4.8 Sensitivity coefficient to sample gas temperature. | yes | 53 |
| 5.3.7 Sensitivity coefficient of surrounding temperature | The sensitivity coefficient of sample gas temperature at reference point shall not exceed the requirements stipulated in table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.4.9 Sensitivity coefficient to the surrounding temperature. | yes | 54 |
| 5.3.8 Sensitivity coefficient of supply voltage | The sensitivity coefficient of supply voltage shall not exceed the requirements specified in table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.4.10 Sensitivity coefficient to electrical voltage. | yes | 55 |
| 5.3.9 Cross-sensitivity | The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements specified in table 2 of standard VDI 4202 part 1 (September 2010) at zero and reference point. | The influence of cross-sensitivity also complies with the requirements of VDI 4202-1 for measuring principles that do not comply with the EN Standards. | yes | 56 |

| **Performance criterion** | **Minimum requirement** | **Test result** | **Met** | **Page** |
|---|---|---|---|---|
| 5.3.10 Averaging effect | For gaseous components the measuring system shall allow the formation of hourly averages.<br>The averaging effect shall not exceed the requirements specified in table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.4.12 Averaging test. | yes | 60 |
| 5.3.11 Standard deviation from paired measurements | The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test. It shall not exceed the requirements specified in table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.5.5 Reproducibility standard deviation for $NO_2$ under field conditions. | yes | 61 |
| 5.3.12 Long-term | The long-term drift at zero point and reference point shall not exceed the requirements specified in Table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.5.4 Long-term drift. | yes | 62 |
| 5.3.13 Short-term drift | The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 of standard VDI 4202 part 1 (September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test. | Please see section 7.1 8.4.4 Short-term drift. | yes | 63 |
| 5.3.14 Response time | The response time (rise) of the measuring system shall not exceed 180 s.<br>The response time (fall) of the measuring system shall not exceed 180 s.<br>The difference between the response time (rise) and response time (fall) of the measuring system shall not exceed 10 % of response time (rise) or 10 s, whatever value is larger. | Please see section 7.1 8.4.3 Response time. | yes | 64 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| 5.3.15 Difference be-tween sample and calibration port | The difference between the measured values obtained by feeding gas at the sample and calibration port shall not exceed the requirements Table 2 of standard VDI 4202 part 1 (September 2010). | Please see section 7.1 8.4.13 Difference sample/calibration. | yes | 65 |
| 5.3.16 Converter efficiency | In the case of measuring systems with a converter, the converter efficiency shall be at least 98 %. | Please refer to section 7.1 8.4.14 Converter efficiency. | yes | 66 |
| 5.3.17 Increase of $NO_2$ concentration due to residence in the measuring system | In case of $NO_x$ measuring systems the increase of $NO_2$ concentration due to residence in the measuring system shall not exceed the requirements specified in table 2 of standard VDI 4202 part 1 (September 2010). | Please refer to section 7.1 8.4.15 Residence time in the analyser. | yes | 67 |
| 5.3.18 Overall uncertainty | The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the applicable EU Directives on air quality listed in Annex A, Table A1 of standard VDI 4202 part 1 (September 2010). | The determination of uncertainty was performed in accordance with EN 14211(2012) and is detailed in section 7.1 8.6 Total uncertainty in accordance with Annex E of EN 14211 (2012). | yes | 68 |
| **8.4 Requirements of Standard EN 14211** | | | | |
| 8.4.3 Response time | Neither the response time (rise) nor the response time (fall) shall exceed 180 s. The difference between rise and fall response time shall not exceed 10 s. | The maximum permissible response time of 180 s is exceeded at no time. The maximum response time determined for system 1 at $NO_2$ 22 s and for system 2 at $NO_2$ 22 s. | yes | 69 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| 8.4.4 Short-term drift | The short-term drift at zero shall not exceed nmol/mol/12 h (= 2,50 µg/m³/12 h).<br>The short-term drift at span level shall not exceed 6.0 nmol/mol/12 h (= 7,50 µg/m³/12 h). | Short-term drift at zero point is 0,12 nmol/mol for system 1 and 0,20 nmol/mol for system 2.<br>Short-term drift at the reference point is -0,07 nmol/mol for system 1 and -1,33 nmol/mol for system 2. | yes | 73 |
| 8.4.5 Repeatability standard deviation | The repeatability standard deviation shall neither exceed 1.0 nmol/mol (i.e.1.25 µg/m³) at zero nor shall it exceed 3.0 nmol/mol (i.e.3.75 µg/m³) of the test gas concentration at reference point. | Repeatability standard deviation at zero point is 0,07 nmol/mol for system 1 and 0,05 nmol/mol for system 2. Repeatability standard deviation at reference point is 0,25 nmol/mol for system 1 and 0,15 nmol/mol for system 2. | yes | 77 |
| 8.4.6 Lack of fit of linearity of the calibration function | The lack of fit of linearity of the calibration function shall not exceed 5.0 nmol/mol (i.e.6.3 µg/m³) at zero point and 4 % of the measured value at concentrations above zero. | For system 1 there is a deviation of -0,39 nmol/mol from the regression line at zero point and maximum 0,77 % from the set value at concentrations greater than zero. For system 2 there is a deviation of -0,16 nmol/mol from the regression line at zero and maximum 0,69 % from from the set value at concentrations greater than zero. | yes | 79 |
| 8.4.7 Sensitivity coefficient to sample gas pressure | The sensitivity coefficient to sample gas pressure shall not exceed 8.0 nmol/mol/kPa (= 10 µg/m³/kPa). | For system 1, the sensitivity coefficient to the sample gas pressure is 0,08 nmol/mol/kPa.<br>For system 2 (002), the sensitivity coefficient to the sample gas pressure is 0,16 nmol/mol/kPa. | yes | 84 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| 8.4.8 Sensitivity coefficient to sample gas temperature | The sensitivity coefficient to sample gas temperature shall not exceed 3.0 nmol/mol/K (= 3,75 µg/m³/K). | For system 1, the sensitivity coefficient to sample gas temperature von 0,01 nmol/mol/K).<br>For system 2, the sensitivity coefficient to sample gas temperature is 0,01 nmol/mol/K). | yes | 86 |
| 8.4.9 Sensitivity coefficient to the surrounding temperature | The sensitivity coefficient to the surrounding temperature shall not exceed 3.0 nmol/mol/K (= 3,75 µg/m³/K). | The sensitivity coefficient to the surrounding temperature does not exceed the performance criteria of max. 3.0 nmol/mol/K. For both systems, the highest value $b_{st}$ is used for the purpose of evaluating uncertainty. For system 1 it is 0,097 nmol/mol/K and for system 2 0,143 nmol/mol/K. | yes | 88 |
| 8.4.10 Sensitivity coefficient to electrical voltage | The sensitivity coefficient to electrical voltage shall not exceed 0.30 nmol/mol/V (= 0,38 µg/m³/V). | The sensitivity coefficient of electrical voltage $b_v$ does not exceed the performance criteria of max. 0.30 nmol/mol/V stipulated in Standard EN 14211 at any point. For both systems, the highest value $b_v$ is used for the purpose of evaluating uncertainty. For system 1 it is 0,003 nmol/mol/V and for system 2 it is 0,004 nmol/mol/V. | yes | 93 |
| 8.4.11 Interferents | Interferents at zero concentration and at a concentration ct (at the level of the hourly limit = 200 µg/m³ for $NO_2$). Maximum responses for the components $H_2O$, $CO_2$ und $NH_3$ are ≤ 5,0 nmol/mol (= 6,25 µg/m³). | Cross-sensitivity at zero point is 0,09 nmol/mol for system 1 and -0,30 nmol/mol for system 2 at $H_2O$, -0,47 nmol/mol for system 1 and 0,60 nmol/mol for system 2 at $CO_2$ and 0,00 nmol/mol für System 1 und -0,24 nmol/mol for system 2 at $NH_3$.<br>Cross-sensitivity at the limit value $c_t$ is -0,03 nmol/mol for system 1 and -0,57 nmol/mol for system 2 at $H_2O$, 1,43 nmol/mol for system 1 and 0,43 nmol/mol for system 2 at $CO_2$ and 0,80 nmol/mol for system 1 and 1,41 nmol/mol at $NH_3$. | yes | 93 |
| 8.4.12 Averaging test | The influence of averaging shall not exceed 7 % of the instrument reading. | This is in complete compliance with the performance characteristics stipulated in standard EN 14211. | yes | 96 |
| 8.4.13 Difference sample/calibration port | The difference in response of the analyser to feeding through the sample or calibration port must be ≤ 1 %. | This is in complete compliance with the performance characteristics stipulated in standard EN 14211. | yes | 99 |

| Performance criterion | Minimum requirement | Test result | Met | Page |
|---|---|---|---|---|
| 8.4.14 Converter efficiency | The converter efficiency must be ≥ 98 %. | The analyser does not use a converter. Therefore this criterion is not relevant. | - | 101 |
| 8.4.15 Residence time in the analyser time in the analyser | Residence time in the analyser must be ≤ 3,0 s. | The residence time inside the analyser is 2.5 s. | yes | 103 |
| 8.5.4 Long term drift | The long term drift at zero must be ≤ 5,0 nmol/mol (= 6,25 µg/m³).<br>The long-term drift at span level must be ≤ 5 % of the certification range (= 13,05 µg/m³ at a measurement range of 0 to 261 nmol/mol). | The maximum long term drift at zero Nullpunkt Dl,z is 0,30 nmol/mol for system 1 and 0,28 nmol/mol for system 2. The maximum long term drift at span point Dl,s is -1,58 % for system 1 and -1,82 % for system 2. | yes | 104 |
| 8.5.6 Period of unattended operation | The maintenance interval must be at least two weeks. | The maintenance interval is subject to the necessary maintenance tasks and is 4 weeks. | yes | 110 |
| 8.5.5 Reproducibility standard deviation for $NO_2$ under field conditions | The reproducibility standard deviation under field conditions shall not exceed 5 % of the average over a period of three months. | The reproducibility standard deviation for $NO_2$ under field conditions was 1.21 % of the average over a period of three months in the field. The requirements of standard EN 14211 are met. | yes | 108 |
| 8.5.7 Availability of the analyser | The availability oft he analyser must be ≥ 90 %. | The availability is 100 %. This complies with the requirements of standard EN 14211. | yes | 111 |

# 2. Task definition

## 2.1 Nature of the test

Ambient air Quality monitoring system manufactured by Teledyne API has commissioned TÜV Rheinland Energie und Umwelt GmbH to carry out the supplementary test for the demonstration of equivalence according to the reference methode of the T500U measuring system. The test was a complete performance test.

## 2.2 Objective

The instrument is designed to measure the concentration of nitrogen dioxide in ambient air in the concentration range of 0 to 500 µg/m³.

TheT500U measuring system uses UV absorbtion to measure $NO_2$ (CAPS). Since the majority of test criteria specified in EN 14211 explicitly refers to NO rather than $NO_2$, they are equally applied to $NO_2$ rather than NO.

Performance testing was to be carried out in accordance with current standards taking into consideration the latest developments.Testing was performed on the basis of the following standards and guidelines:

- VDI 4202 part 1: Performance criteria for performance tests of automated ambient air measuring systems Point-related measurement methods for gaseous and particulate air pollutants, of September 2010
- VDI 4203 part 3: Testing of automated measuring systems - Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants, of September 2010
- EN 14211: Ambient air - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, of August 2012
- Guide to the demonstration of equivalence of ambient air monitoring methods, of January 2010

# 3. Description of the analyser tested

## 3.1 Measuring principle

The T500U is an optical absorption spectrometer which is able to directly measure $NO_2$ according to the Cavity Attenuated Phase Shift (CAPS) method. The CAPS method uses blue UV light from an LED with a wavelength of 450 nm, a measuring cell equipped with highly reflective mirrors on both sides to elongate the optical path, and a vacuum photo detector. All components are integrated into the optical measuring cell, which is located on a spot that is kept in a constant temperature of 45 °C. This is to prevent humidity on the mirrors as well as influences of fluctuating temperatures.

$NO_2$ is determined directly by means of optical absorption. This measuring principle is stipulated in the Lambert-Beer Law. The absorption (loss of light) here is directly in proportion to the light path and the absorbing gas concentration.

$$A = \varepsilon l c$$

(A = cbsorption, ε= molar absorptions coefficient, l= lengh of light path, c = concentration)

Ultraviolet light from the modulating LED is sent to the cell located behind mirror A. Light intensity is then measured by a detector which itself is modulated with a slightly different frequency. The detector is located behind mirror B and measures an exponentially increasing signal, if the LED is switched on. If the LED is switched-off, the intensity drops as well. As both mirrors are highly reflective at 450 nm (the highest absorption range of $NO_2$), it takes a particular amount of time to reach a maximum in presence of an absorbing gas. In presence of $NO_2$ the light path is significantly shorten. This has two effects on the light intensity measured by the detector:

- The maximum of light is less
- The maximum is reached earlier

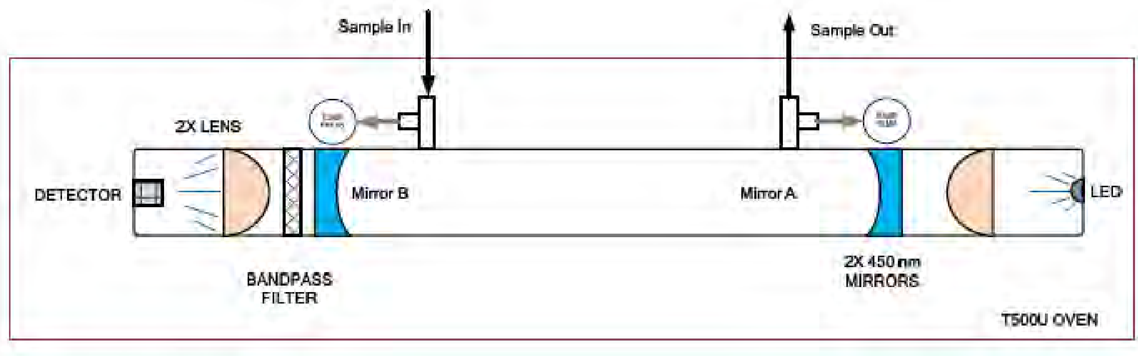



Figure 1: T500U optical absorption cellthe

In this way a phase shift to the modulating LED is measured. The phase shift is greater with zero gas and decreases when $NO_2$ is contained.

The LED as well as the detector is modulated, so that the measured signal is performed in a significantly lower frequency (related to the difference between the modulating frequencies). This signal is easier to process for the system's hardware.

Now the system transfers the phase shift into a concentration. By means of the CAPS method the phase shift remains constant for each concentration, even if the intensity is reduced due to aging of the LED.

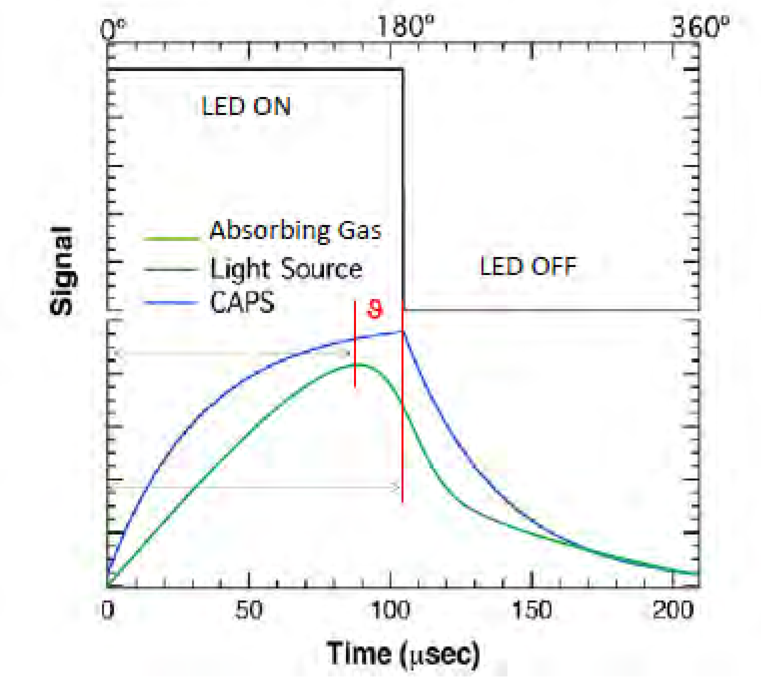



Figure 2: Illustration of phase shift with increasing $NO_2$ concentration

## 3.2 Analyser scope and set-up

The analyser T500U uses the „Cavity Attenuated Phase Shift“ (CAPS) method to directly measure $NO_2$. T500U operates similary to an optical spectrometer, however the absorption (weakening of light) is directly in proportion to the lengh of the path and the concentration to the gas being measured.

Main components of the T500U are: an optical cell, a pair of highly reflective mirrors at 450 nm, an LED as light source and  a vacuum photo detector.

The LED is located behind a mirror on one end of the cell and the detector is behind the other mirror on the opposite end of the cell. The LED sends ultraviolet light pulses into the measuring cell. Light reflected by the mirrors and generates a long path length. This light path extends the photon’s durability using a data acquisition system that is timed to the measurement.Together with an algorithm the measured absorption is converted into a phase shift of which the $NO_2$ is derived from.

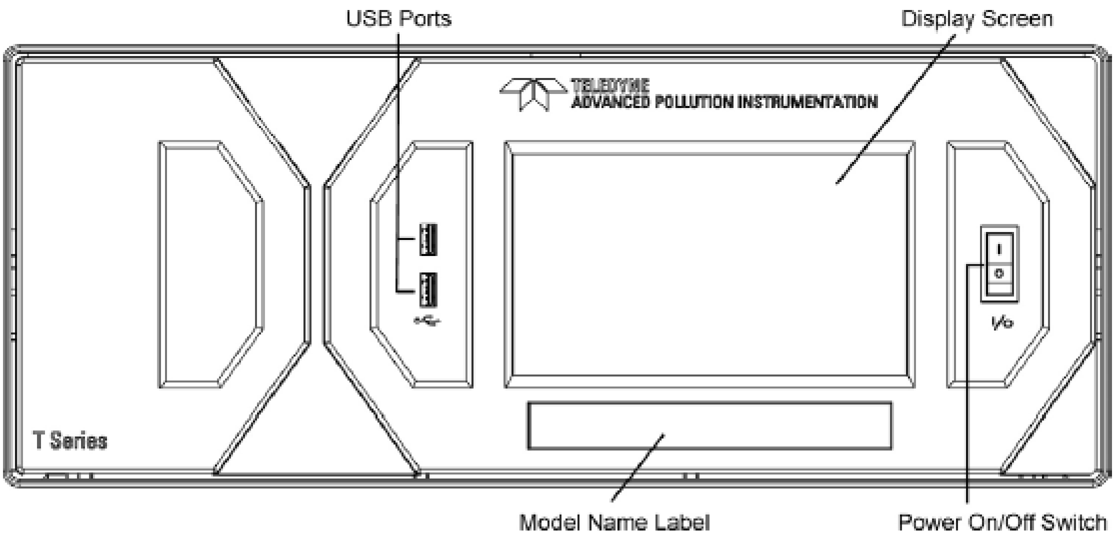



Figure 3: T500U front panel

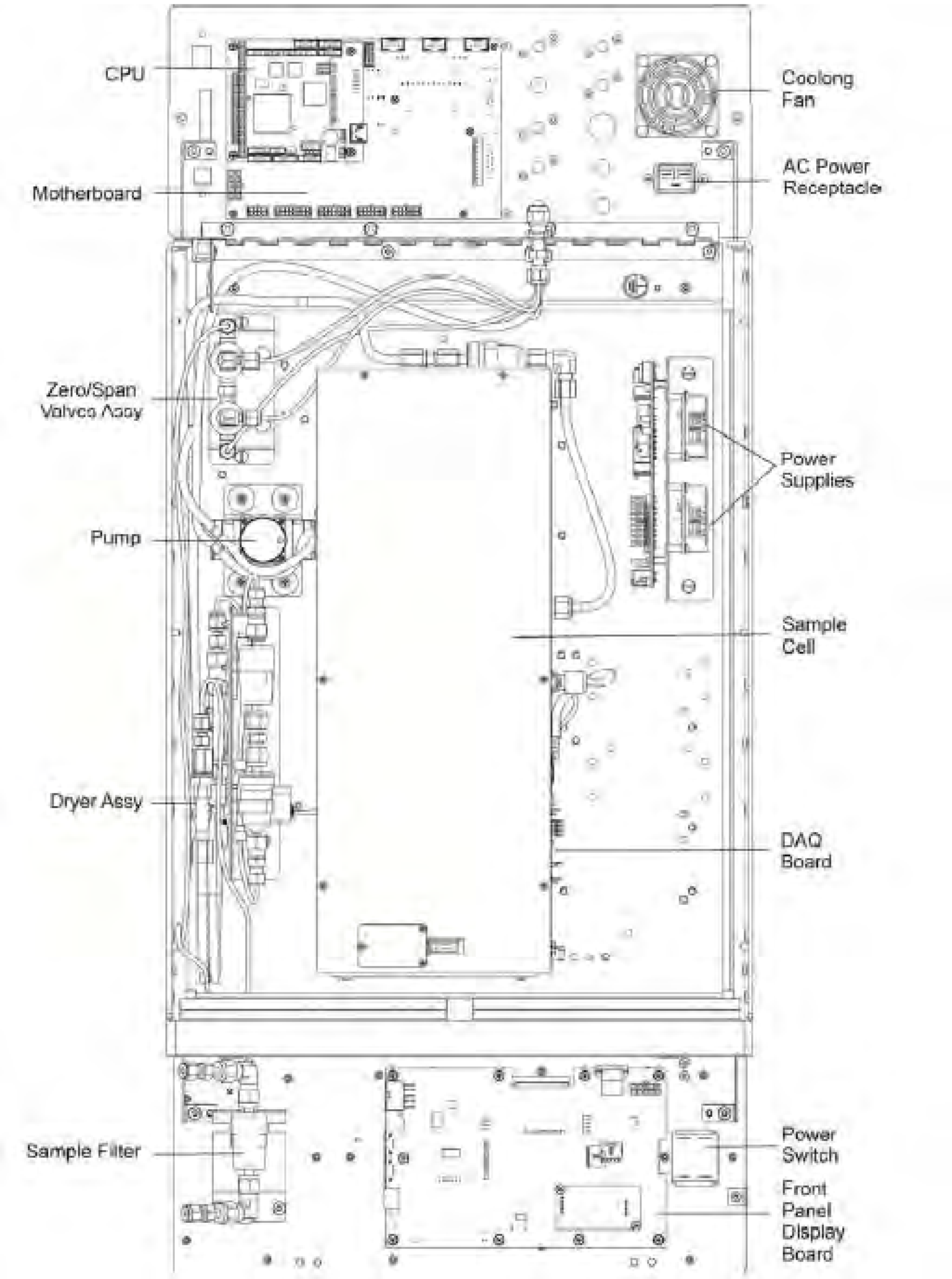



Figure 4: Internal components of the T500U

Table 2 lists important technical features T500U.

*Table 2: Technical data of the T500U(as provided by the manufacturer)*

| Parameter | Description |
|---|---|
| Range | Min: 0-5 ppb Max: 0-1 ppm $NO_2$ (User-selectable) |
| Measurement Units | ppb, ppm, µg/m³, mg/m³ (User-selectable) |
| Zero Noise | <0.020 ppb |
| Span Noise | <0.2% of reading + 0.020 ppb |
| Zero Drift | <0.1 ppb / 24 hours |
| Span Drift | <0.5% of reading / 24 hours |
| Lower Detectable Limit | 0.04 ppb |
| Lag Time | ~8 seconds (limited by volumetric flow rate) |
| Rise/ Fall Time | <30 Seconds to 95% |
| Linearity | < 1% Full Scale |
| Precision | 0.5% of reading above 5 ppb |
| Sample Flow Rate | 900 cm³/min ±10% |
| AC Power | Rating: 110 - 120 V~ 60 Hz 3.0 A; 220 - 240 V~ 50 Hz 3.0 A<br>Typical Power Consumption: 80 W; 80 W |
| Analog Output Ranges | 10V, 5V, 1V, 0.1V (selectable) |
| Analog Output Resolution | 1 part in 4096 of selected full-scale voltage |
| Communications | |
| Standard I/O | 1 Ethernet: 10/100Base-T<br>2 RS-232 (300 – 115,200 baud)<br>2 USB device ports<br>8 opto-isolated digital outputs<br>6 opto-isolated digital inputs (3 defined, 3 spare)<br>4 analog outputs |
| Optional I/O | 1 USB com port<br>1 RS485<br>8 analog inputs (0-10V, 12-bit)<br>4 digital alarm outputs<br>Multidrop RS232<br>3 4-20mA current outputs |
| Operating Temperature | 5-40 °C |
| Humidity Range | 0-95% RH, Non-Condensing |
| Dimensions HxWxD | 7" x 17" x 23.5" (178 x 432 x 597 mm)<br>(19" rack mount, 5U, 24" deep) |
| Weight | 33 lbs (15 kg) |
| Environmental Conditions | • Installation Category (Over Voltage Category ) II Pollution Degree 2<br>• Intended for Indoor Use Only at Altitudes ≤ 2000m |

# 4. Test programme

## 4.1 General remarks

Performance testing was carried out with two complete and identical instruments with the serial numbers:

System 1: SN 63 and
System 2: SN 65.

During the test software version Rev 1.0.2 bld 22 was implemented.

Performance testing consisted of a laboratory test which aimed to specify performance characteristics and a field test over a period of several months.

This report presents a heading for each test criterion along with the number and description as stipulated in the respective standard [1.2.3.4].

## 4.2 Laboratory test

In the laboratory test two T500U measuring systems of identical design, serial numbers SN: 63 and SN: 65 were tested. In compliance with the standards [2.3] the following test criteria were tested:

Description of operating states:

- Description of operating states
- General requirements
- Adjustment of the calibration line
- Short-term drift
- Repeatability standard deviation
- Sensitivity of the sample gas pressure
- Sensitivity of the sample gas temperature
- Sensitivity coefficient of surrounding temperature
- Sensitivity coefficient of supply voltage
- Cross-sensitivities
- Response time
- Difference sample/calibration port

Measured values were recorded using an external data logger.

Results obtained during the laboratory tests are reported in section 6.

## 4.3 Field test

The field test was performed in the period from 20 June 2014 to 22 September 2014 with the two complete and identical instruments which had already been used for the laboratory test. Serial numbers:

| | |
|---|---|
| System 1: | SN 63 |
| System 2: | SN 65 |

The following criteria were tested in the field:

- Long-term drift
- Maintenance interval
- Availability
- Reproducibility standard deviation under field conditions

# 5. Reference Measurement Method

**Test gases used to adjust the analyser during the test (tested systems and TÜV-measuring systems):**

(The mentioned test gases were used during the entire test and, where necessary, diluted with the help of a sample divider or a mass flow control station.)

| | |
|---|---|
| Zero gas: | Synthetic air |
| **Test gas $NO_2$:** | **1,67mg/m³ in synthetic air** |
| Number of test gas cylinder: | DI50346 |
| Manufacturer / date of manufacture: | Praxair / 28 April 2014 |
| Stability guarantee / certified: | 12 months |
| Checking of the certificate by / on: | 08 May 2014 / in-house |
| Rel. uncertainty according to certificate: | 2 % |

# 6. Test results according to VDI 4203 part 3

## 6.1 4.1.1 Measured value display

*The measuring system shall be fitted with measured value display.*

## 6.2 Equipment

No additional equipment is required.

## 6.3 Testing

It was checked whether the measuring system has a measured value display.

## 6.4 Evaluation

The measuring system is fitted with a measured value display.

## 6.5 Assessment

The measuring system is fitted with a measured value display.
Does this comply with the performance criterion ? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 4.1.2 Easy maintenance

*Necessary maintenance of the measuring systems should be possible without larger effort, if possible from outside.*

## 6.2 Equipment

No additional equipment is required.

## 6.3 Testing

The necessary regular maintenance tasks were performed in accordance with the instruction manual.

## 6.4 Evaluation

The user will have to perform the following maintenance tasks:

1. Checking of the instrument status:
   The status of the instrument can be checked and monitored by way of visual inspections of the display.
2. Checking and replacing the particulate filter at the sample gas inlet.
   The frequency with which particulate filters need to be replaced depend on the dust concentration in the ambient air.

## 6.5 Assessment

Maintenance can be performed with usual tools in a reasonable time.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Maintenance tasks were performed during the test in accordance with the tasks and procedures described in the manual. Complying with these procedures, no difficulties were identified. It was thus easily possible to perform maintenance with the usual tools.

## 6.1 4.1.3 Functional check

*If the operation or the functional check of the measuring system requires particular instruments, they shall be considered as part of the measuring system and be applied in the corresponding sub-tests and included in the assessment.*
*Test gas units included in the measuring system shall indicate their operational readiness to the measuring system by a status signal and shall provide direct as well as remote control via the measuring system.*

## 6.2 Equipment

Manual

## 6.3 Testing

The instrument tested does not have a particular device for functional checks. The operating status of the AMS is continually monitored; potential problems will be displayed via an array of different error messages.

The functional check was performed with external test gases.

## 6.4 Evaluation

The tested instrument does not have an internal device for functional checks. The operational status of the AMS is continually monitored and potential problems are displayed via an array of different error messages.

It is possible to perform external zero point and reference point checks by means of test gases.

## 6.5 Assessment

The instrument tested does not have an internal device for functional checks.

Does this comply with the performance criterion? no

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 4.1.4 Set-up times and warm-up times

*The set-up times and warm-up times shall be specified in the instruction manual.*

## 6.2 Equipment

The testing of this performance criterion requires the additional provision of a clock.

## 6.3 Testing

The measuring systems were put into operation in accordance with the specifications provided by the manufacturer. The set-up times and warm-up times needed were recorded separately.

Required structural measures prior to AMS installation such as the setup of a sampling system in the analytical chamber were not assessed here.

## 6.4 Evaluation

The manual does not provide information on the set-up times. It is evident that this would depend on the specific conditions of the measurement site as well as on the voltage supply available. As the T500U measuring system is a compact analyser, the set-up time is mainly comprised of:

- Establishing the voltage supply
- Connecting necessary tubes (sampling, exhaust air)

A set-up time of approx. 0.5 h was determined for various changes in positions in the laboratory (i.e. installation/dismounting in the climate chamber) and installation in the field.

When switched on from a completely cold state the instrument requires at least 60 minutes until the reading stabilises. This time is required to bring the internal converter to operating temperature.

The measuring system has to be mounted at a place where it is protected from changes in the weather, for instance in an air conditioned measuring container.

## 6.5 Assessment

Set-up times and warm-up times were determined.

The measuring system may be operated at different measurement sites without undue effort. The time required for setting up the system is approx. 0.5 h and the warm-up time amounts to 1–2 h depending on the time required for stabilisation.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 4.1.5 Instrument design

*The instruction manual shall include specifications of the manufacturer regarding the design of the measuring system. The main elements are:*
*instrument shape (e.g.bench mounting, rack mounting, freemounting)*
*mounting position (e.g.horizontal or vertical mounting)*
*safety requirements*
*dimensions*
*weight*
*power consumption.*

## 6.2 Equipment

Testing was performed using a measuring instrument for the determination of the power consumption as well as weighing scales.

## 6.3 Testing

The set-up of the provided instruments was compared to the description in the instruction manuals. The power consumption was determined for 24 h during normal operation in the field test.

## 6.4 Evaluation

The measuring system has to be mounted horizontally (e.g. on a table or in a rack) and protected against weather. The temperature at the installation site may not exceed the range of 0 ° to 30 °C.

The dimensions and weight of the measuring system correspond to the specifications in the instruction manual.

According to the manufacturer, the power consumption of the measuring system is 80 W. In a 24-h test the overall power consumption was determined. The power consumption as specified by the manufacturer was not exceeded at any time during the test.

## 6.5 Assessment

The specifications of the manual with regard to instrument design are complete and correct.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not required in terms of this criterion.

## 6.1 4.1.6 Unintended adjustment

*It shall be possible to secure the adjustment of the measuring system against illicit or unintended adjustment during operation.*

## 6.2 Equipment

No additional equipment is required to test this performance criterion.

## 6.3 Durchführung der Prüfung

The measuring system may be operated using the display and control panel on the front side of the instrument or from an external computer connected to the RS232 or Ethernet ports.

The instrument does have a built-in mechanism (password protection) to protect it against unintended or unauthorized re-adjustment. Changing parameters or adjusting sensors is only possible by pushing several sequences of keys.

## 6.4 Evaluation

Instrument parameters which affect measurement characteristics need to be typed in manually by using a password. It is not possible to make unintended adjustments.

## 6.5 Assessment

The measuring system is protected against the unintended or unauthorised adjustment of instrument parameters via password.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not required in terms of this criterion.

## 6.1 4.1.7 Data output

*The output signals shall be provided digitally (e.g. RS 232) and/or as analogue signals (e.g. 4 mA to 20 mA).*

## 6.2 Equipment

PC and network connection, Datenlogger Yokogawa DX112-3-2

## 6.3 Testing

The analyser can be connected via the following communication connections: RS232, USB, digital and analogue in- and outputs, TCP/IP (optional). Additionally, the analyser is equipped with four analogue outputs.

## 6.4 Evaluation

Measuring signals are provided on the rear panel as follows:

Analogue: 4 - 20 mA or 0 -10 V, concentration range adjustable

Digital: RS232, USB, digital in and outputs, TCP/IP (optional)

## 6.5 Assessment

Measuring signals are provided analogue (4-20 mA bzw. 0-10 V) and digitally (via TCP/IP, RS 232, USB).

It is possible to connect peripheral equipment via the relevant ports (i.e. analogue inputs).

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Figure 5 shows a rear panel view of the system with the measured value outputs.

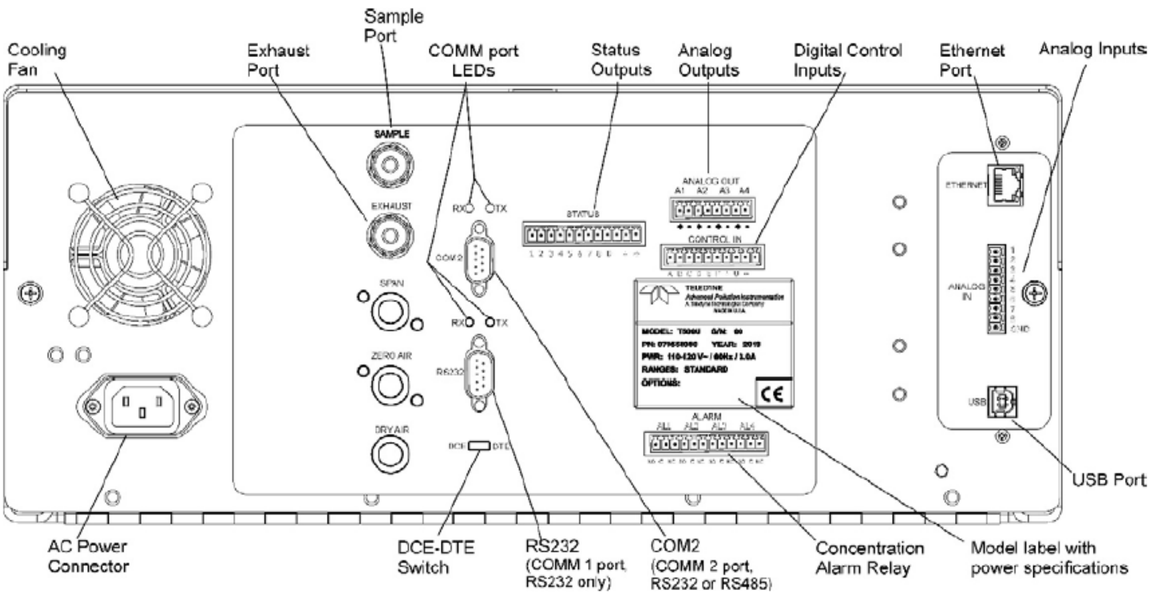



*Figure 5: Rear view of the T500U*

## 6.1 5.1 General

*The manufacturer's specifications in the instruction manual shall be by no means better than the results of the performance test.*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

The test results were compared to the specifications in the instruction manual.

## 6.4 Evaluation

Discrepancies between the first draft of the manual and the actual instrument design have been corrected.

## 6.5 Assessment

No discrepancies between the instrument design and the instruction manuals were observed.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.1 Certification range

*The certification range intended for testing shall be determined.*

## 6.2 Equipment

No additional equipment is required to test this performance criterion.

## 6.3 Testing

The certification range intended for testing shall be determined.

## 6.4 Evaluation

VDI Guideline 4202 Sheet 1 and Standard EN 14211 stipulate the following minimum requirements for the certification ranges of continuous ambient air monitoring systems for nitrogen dioxide:

*Table 3: Certification ranges VDI 4202 Sheet 1 and EN 14211*

| Measured component | Lower limit CR | Upper limit CR | Limit value | Assessment period |
|---|---|---|---|---|
| | in µg/m³ | in µg/m³ | in µg/m³ | |
| Nitrogen dioxide | 0 | 500 | 200 | 1 h |

## 6.5 Assessment

The measuring system can be assessed in the range of the relevant limit values.
Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.2 Measuring range

*The upper limit of measurement of the measuring systems shall be greater or equal to the upper limit of the certification range.*

## 6.2 Equipment

No additional equipment was needed to test this performance criterion.

## 6.3 Testing

It was determined whether the upper limit of the measuring range was greater or equal to the upper limit of the certification range.

## 6.4 Evaluation

In principle, the measuring system allows for measuring ranges from max. 0 – 1 ppm.

| | |
|---|---|
| Possible measuring range: | 0 - 1 ppm |
| Upper limit of the certification range for $NO_2$: | 500 µg/m³ |

## 6.5 Assessment

By default the measuring range is set to 0 – 500 µg/m³ for $NO_2$. Other measuring ranges of max. 0 – 1 ppm are possible.

The upper limit of the measuring range is larger than the respective upper limit of the certification range.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.3 Negative output signals

*Negative output signals or measured values may not be suppressed (life zero).*

## 6.2 Equipment

No additional equipment was needed to test this performance criterion.

## 6.3 Testing

It was tested, in the laboratory and in the field, whether the measuring system displays negative signals.

## 6.4 Evaluation

The measuring system also displays negative measured values.

## 6.5 Assessment

The measuring system also displays negative measured values.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.4 Failure in the mains voltage

*In case of malfunction of the measuring system or failure in the mains voltage for a period of up to 72 h, uncontrolled emission of operation and calibration gas shall be avoided. The instrument parameters shall be secured by buffering against loss caused by failure in the mains voltage. When mains voltage returns, the instrument shall automatically reach the operation mode and start the measurement according to the operating instructions.*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

A failure in the mains voltage was simulated in order to check whether the instrument remains intact and is ready to measure when mains voltage returns.

## 6.4 Evaluation

The measuring system does not require any operation or calibration gases. Thus, there is no uncontrolled emission of gases in the case of failure in the mains voltage.

In the event of power failure the measuring system will switch to warm-up mode when the power supply is re-established. It will remain in this mode until an appropriate and stable temperature for operation is reached. The time required for warm-up depends on the surrounding conditions at the installation site and on the thermal condition of the instrument itself when switched on again. After warm-up the instrument automatically switches back to the same mode that was active when the power failure occurred. The warm-up phase is indicated by a number of temperature alarms.

## 6.5 Assessment

When mains voltage returns the measuring system goes back to a failure-free operational status and automatically resumes measuring.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.5 Operating states

*The measuring system shall allow control of important operating states by telemetrically transmitted status signals.*

## 6.2 Equipment

PC for data recording.

## 6.3 Testing

The measuring system is equipped with various interfaces such as RS232, USB, digital and analogue in and outputs, TCP/IP. The analyser can be connected with an external PC via Modbus or the communication software APICOM. Telematrical data transfer is made possible with the software, configurational settings can be performed and the analysator's display can be pictured on the PC. Using this modus information and functions of the analyser's display can be requested and operated on the PC.

## 6.4 Evaluation

The measuring system allows for extensive telemetrical monitoring and control via various connectivity options. The "APICOM" software is a helpful tool for data transfer and remote control of the measuring system.

## 6.5 Assessment

By means of various connectivity options and the "APICOM" software the measuring system can be monitored and controlled from an external PC.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.6 Switch-over

*Switch-over between measurement and functional check and /or calibration shall be possible telemetrically by computer control or manual intervention.*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

The measuring system may be monitored or controlled via the control panel of the analyser or telemetrically via remote control.

## 6.4 Evaluation

All control functions which do not require direct on-site intervention may be performed by operating staff on-site or telemetrically via remote control.

## 6.5 Assessment

In general, all necessary tasks related to functional checks may be performed directly on-site or monitored telemetrically using the remote control functions.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.7 Maintenance interval

*The maintenance interval of the measuring system shall be determined during the field test and specified. The maintenance interval should be three months, if possible, but at least two weeks.*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

In testing this performance criterion, the types of maintenance work and the corresponding maintenance intervals needed to ensure proper functioning of the measuring system were determined. Moreover, drift behaviour of zero and reference point according to 7.1 8.5.4 Long term drift was taken into consideration in determining the maintenance interval.

## 6.4 Evaluation

During the entire field test period, no excessive drift behaviour was observed in the measuring systems. The maintenance interval is therefore determined by the necessary maintenance tasks.

During operation, maintenance tasks are generally limited to contamination and plausibility checks as well as checking for potential status signals and error warnings.

Akk necessary maintenance work is listed in chapter 8 “recommendation for use”.

## 6.5 Assessment

As determined by the necessary maintenance tasks the maintenance interval is 4 weeks.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.2.8 Availability

*The availability of the measuring system shall be determined during the field test and shall be at least 95 %.*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

The start and end time of the availability test are determined by the start and end time at the field test site. To this effect any interruptions of the test, for instance due to malfunctions or maintenance work, are recorded.

## 6.4 Evaluation

The field test was carried out in the period from 20 June 2014 to 22 September 2014. Thus, the measuring systems were tested in the field for 94 days. Table 4 lists periods of operation, maintenance and malfunction.

No malfunction was observed.

## 6.5 Assessment

Availability for both systems was 100 % incl. maintenance times during testing.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

*Table 4: Determination of availability*

| | | System 1 | System 2 |
|---|---|---|---|
| Operating time | h | 2274 | 2274 |
| Down time | h | 0 | 0 |
| Maintenance time | h | 8 | 8 |
| Effective operating time | h | 2266 | 2266 |
| Effective operating time incl. maintenance | h | 2274 | 2274 |
| Availability | % | 100 | 100 |

## 6.1 5.2.9 Instrument software

*The version of the instrument software to be tested shall be displayed during switch-on of the measuring system. The test institute shall be informed on changes in the instrument software, which have influence on the performance of the measuring system.*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

It was verified whether the instrument displays its software version upon switch-on. The instrument manufacturer was advised to inform the test institute on any changes to the instrument software.

## 6.4 Evaluation

Die aktuelle Software wird beim Einschalten des Systemes im Display angezeigt. Sie kann zudem jederzeit im Menü „Konfiguration“ eingesehen werden.

Die Prüfung wurde mit der Softwareversion Rev 1.0.2 bld 22 durchgeführt.

## 6.5 Assessment

The instrument software version is indicated in the display. Changes to the software will be communicated to the test institute.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results


*Figure 6: Display of the software version (Rev 1.0.2 bld 22) on the start screen*

## 6.1 5.3.1 General

*The test shall be performed on the basis of the minimum requirements as stipulated in VDI 4202 Sheet 1 (September 2010).*

## 6.2 Equipment

Not required for this criterion.

## 6.3 Testing

The test is performed on the basis of the minimum requirements as stipulated in VDI 4202, Sheet 1 (September 2010) and Standard EN 14211 (August 2012).

## 6.4 Evaluation

VDI Guideline 4202 Sheet 1 and VDI Guideline 4203 Sheet 3 were revised extensively and republished in an amended version in September 2010. Minimum requirements as listed in Table 2 a/b of said guideline were used for evaluation.

## 6.5 Assessment

The tests were performed on the basis of the minimum requirements as stipulated in VDI 4202 Sheet 1 (September 2010) as well as Standard EN 14211 (2012).

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.2 Repeatability standard deviation at zero point

*The repeatability standard deviation at zero at point shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010) in the certification range according to Table 1 of VDI 4202 Sheet 1 (September 2010).*

*In case of deviating certification ranges, the repeatability standard deviation at zero point shall not exceed 2 % of the upper limit of this certification range.*

*The repeatability standard deviation at zero point shall not exceed 1.0 nnmol/mol (i.e. 1.25 µg/m³).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the repeatability standard deviation at zero point are in line with the requirements stipulated in Standard EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.5 Repeatability standard deviation.

## 6.4 Evaluation

Please refer to section 7.1 8.4.5 Repeatability standard deviation.

## 6.5 Assessment

Please refer to section 7.1 8.4.5 Repeatability standard deviation.
Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.3 Repeatability standard deviation at reference point

*The repeatability standard deviation at reference point shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010) in the certification range according to Table 1 of VDI 4202 Sheet 1 (September 2010). The limit value or the alert threshold shall be used as reference point.*

*In case of deviating certification ranges, the repeatability standard deviation at reference point shall not exceed 2 % of the upper limit of this certification range. In this case a value $c_t$ at 70 % to 80 % of the upper limit of this certification range shall be used as reference point.*

*The repeatability standard deviation at reference point shall not exceed 3 nmol/mol (= 5,76 µg/m³).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the repeatability standard deviation at reference point are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.5 Repeatability standard deviation.

## 6.4 Evaluation

Please refer to section 7.1 8.4.5 Repeatability standard deviation.

## 6.5 Assessment

Please refer to section 7.1 8.4.5 Repeatability standard deviation.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.4 Linearität (Lack-of-fit)

*The analytical function describing the relationship between the output signal and the value of the air quality characteristic shall be linear.*

*Reliable linearity is given, if deviations of the group averages of measured values about the calibration function meet the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010) in the certification range according to Table 1 of VDI 4202 Sheet 1 (September 2010).*

*For all other certification ranges the group averages of measured values about the calibration function shall not exceed 5 % of the upper limit of the corresponding certification range.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the lack of fit are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to 7.1 8.4.6 Lack of fit of linearity of the calibration function.

## 6.4 Evaluation

Please refer to section 7.1 8.4.6 Lack of fit of linearity of the calibration function.

## 6.5 Assessment

Please refer to section 7.1 8.4.6 Lack of fit of linearity of the calibration function.
Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.5 Sensitivity coefficient of sample gas pressure

*The sensitivity coefficient of sample gas pressure at reference point shall not exceed the requirements of Table 2 of VDI 4202, Sheet 1 (September 2010). A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used at reference point.*
*The sensitivity coefficient of sample gas pressure shall not exceed 8 (nmol/mol)/kPa (=15,36 µg/m³)/kPa).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the sensitivity coefficient of sample gas pressure are in line with the requirements stipulated in EN 14211 (2012). The reader is referred to section 7.1 8.4.7 Sensitivity coefficient to sample gas pressure.

## 6.4 Evaluation

Please refer to section 7.1 8.4.7 Sensitivity coefficient to sample gas pressure.

## 6.5 Assessment

Please refer to section 7.1 8.4.7 Sensitivity coefficient to sample gas pressure.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.6 Sensitivity coefficient of sample gas temperature

*The sensitivity coefficient of sample gas temperature at reference point shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010). A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.*
*The sensitivity coefficient of sample gas temperature shall not exceed 3 (nmol/mol)/K (= 5,76 µg/m³)/K).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the sensitivity coefficient of sample gas temperature are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.8 Sensitivity coefficient to sample gas temperature.

## 6.4 Evaluation

Please refer to section 7.1 8.4.8 Sensitivity coefficient to sample gas temperature.

## 6.5 Assessment

Please refer to section 7.1 8.4.8 Sensitivity coefficient to sample gas temperature.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.7 Sensitivity coefficient of surrounding temperature

*The sensitivity coefficient of surrounding temperature at zero and reference point shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010). A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.*

*The sensitivity coefficient of surrounding temperature shall not exceed 3 (nmol/mol)/K (= 5,76 µg/m³)/K).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the sensitivity coefficient of surrounding temperature are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.9 Sensitivity coefficient to the surrounding temperature.

## 6.4 Evaluation

Please refer to section 7.1 8.4.9 Sensitivity coefficient to the surrounding temperature.

## 6.5 Assessment

Please refer to section 7.1 8.4.9 Sensitivity coefficient to the surrounding temperature.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.8 Sensitivity coefficient of supply voltage

*The sensitivity coefficient of supply voltage shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010). A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point..*

*The sensitivity coefficient of supply voltage shall not exceed 0.3 (nmol/mol)/V (= 0,57 µg/m³)/V).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the sensitivity coefficient of supply voltage are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.10 Sensitivity coefficient to electrical voltage.

## 6.4 Evaluation

Please refer to section 7.1 8.4.10 Sensitivity coefficient to electrical voltage.

## 6.5 Assessment

Please refer to section 7.1 8.4.10 Sensitivity coefficient to electrical voltage.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.9 Cross-sensitivity

*The change in the measured value caused by interfering components in the sample gas shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010) at zero and reference point. The limit value (1 h limit value for $NO_2$ = 200 µg/m³ = 104,1 nmol/mol) shall be used as reference point.*
*For measuring principles deviating from EN standards the absolute values of the sum of the positive and the sum of negative deviations caused by interfering components in the sample gas shall not exceed 3 % of the upper limit of the certification range at zero and reference point. A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.*

## 6.2 Equipment

Zero and test gases, vaporation system

## 6.3 Testing

The measuring system does not operate according to the reference method of chemiluminescence, instead it measures $NO_2$ directly. Testing and evaluation to determine cross-sensitivity according to EN 14211 (2012) is matched to the reference method regarding the cross-sensitivity components. In addition to the three interferents mentioned in EN 14211, all interferents mentioned in VDI 4202-1 were tested.

## 6.4 Evaluation

Differences with and without interferent for the zero and reference point for both systems are shown in the following. Positive and negative deviations are collected in the tables below.

*Table 5: Cross-sensitivity according to VDI 4202 sheet 1 for $NO_2$, system 1*

| Component | Zero gas [nmol/mol] | | Deviation | Span gas [nmol/mol]* | | Deviation |
|---|---|---|---|---|---|---|
| | without | with | [nmol/mol] | without | with | [nmol/mol] |
| $H_2O$ | 0,03 | 0,15 | **-0,13** | 103,86 | 102,03 | **-1,83** |
| $H_2S$ | 0,04 | -0,22 | **-0,26** | 105,59 | 105,49 | **-0,10** |
| $NH_3$ | -0,44 | -0,48 | **-0,03** | 104,11 | 104,40 | **0,29** |
| $N_2O$ | 0,13 | 0,21 | **0,08** | 105,27 | 105,35 | **0,08** |
| $SO_2$ | 0,06 | 0,33 | **0,27** | 105,18 | 105,43 | **0,25** |
| $O_3$ | 0,15 | 0,45 | **0,30** | 104,63 | 104,20 | **-0,43** |
| CO | 0,17 | -0,14 | **-0,31** | 105,31 | 105,44 | **0,13** |
| $CO_2$ | -0,07 | 0,37 | **0,44** | 103,95 | 105,29 | **1,33** |
| NO | 0,09 | 1,11 | **1,01** | 105,22 | 106,62 | **1,40** |
| Benzol | 0,02 | 0,07 | **0,05** | 105,46 | 105,31 | **-0,16** |
| Sum of positive deviations | | | **-0,73** | | | **-2,52** |
| Sum of negative deviations | | | **2,15** | | | **3,48** |
| Max. allowed deviation | | | **7,81** | | | **7,81** |
| Fullfilled ? | | | **yes** | | | **yes** |

*Span gas level according to EN 14211

*Table 6: Cross-sensitivity according to VDI 4202 sheet 1 for $NO_2$, system 2*

| Component | Zero gas [nmol/mol] | | Deviation | Span gas [nmol/mol]* | | Deviation |
|---|---|---|---|---|---|---|
| | without | with | [nmol/mol] | without | with | [nmol/mol] |
| $H_2O$ | 0,03 | 0,25 | **0,22** | 103,42 | 101,79 | **-1,63** |
| $H_2S$ | -0,05 | -0,10 | **-0,06** | 104,36 | 104,64 | **0,28** |
| $NH_3$ | -0,28 | -0,25 | **0,03** | 103,09 | 103,26 | **0,17** |
| $N_2O$ | 0,13 | 0,17 | **0,04** | 105,68 | 105,49 | **-0,19** |
| $SO_2$ | 0,03 | 0,24 | **0,21** | 105,02 | 105,33 | **0,31** |
| $O_3$ | 0,14 | 0,18 | **0,05** | 105,18 | 104,91 | **-0,26** |
| CO | 0,03 | 0,02 | **-0,01** | 105,53 | 105,39 | **-0,15** |
| $CO_2$ | -0,02 | 0,21 | **0,23** | 102,95 | 104,04 | **1,09** |
| NO | 0,21 | 1,19 | **0,98** | 104,97 | 106,09 | **1,13** |
| Benzol | 0,12 | 0,21 | **0,09** | 105,60 | 105,79 | **0,19** |
| Sum of positive deviations | | | **-0,07** | | | **-2,23** |
| Sum of negative deviations | | | **1,84** | | | **3,17** |
| Max. allowed deviation | | | **7,81** | | | **7,81** |
| Fullfilled ? | | | **yes** | | | **yes** |

*Span gas level according to EN 14211

## 6.5 Assessment

The influence of cross-sensitivity also complies with the requirements of VDI 4202-1 for measuring principles that do not comply with the EN Standards.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Individual results of the cross-sensitivity tests are listed in Table 7 and Table 8.

*Table 7: Individual results of cross-sensitivity, part 1*

| Date | Time | Device 1 (63) | Device 2 (65) | Date | Time | Device 1 (63) | Device 2 (65) |
|---|---|---|---|---|---|---|---|
| | | [nmol/mol] | [nmol/mol] | | | [nmol/mol] | [nmol/mol] |
| **Zero Gas** | | | | **Zero Gas** | | | |
| 04.06.2014 | 16:00 | 0,02 | 0,03 | 22.09.2014 | 09:05 | 0,03 | -0,02 |
| 04.06.2014 | 16:01 | 0,03 | 0,03 | 22.09.2014 | 09:06 | 0,05 | -0,06 |
| 04.06.2014 | 16:02 | 0,03 | 0,04 | 22.09.2014 | 09:07 | 0,04 | -0,06 |
| **Average** | | **0,03** | **0,03** | **Average** | | **0,04** | **-0,05** |
| **Zero gas + H2O (19 mmol/mol)** | | | | **Zero gas + H2S (30 µg/m$^3$)** | | | |
| 04.06.2014 | 16:10 | 0,14 | 0,23 | 22.09.2014 | 09:15 | -0,50 | -0,07 |
| 04.06.2014 | 16:11 | 0,15 | 0,25 | 22.09.2014 | 09:16 | -0,09 | -0,12 |
| 04.06.2014 | 16:12 | 0,17 | 0,27 | 22.09.2014 | 09:17 | -0,07 | -0,12 |
| **Average** | | **0,15** | **0,25** | **Average** | | **-0,22** | **-0,10** |
| **Span Gas** | | | | **Span Gas** | | | |
| 04.06.2014 | 16:25 | 103,83 | 103,27 | 22.09.2014 | 09:30 | 105,63 | 104,56 |
| 04.06.2014 | 16:26 | 103,89 | 103,52 | 22.09.2014 | 09:31 | 105,68 | 104,23 |
| 04.06.2014 | 16:27 | 103,85 | 103,48 | 22.09.2014 | 09:32 | 105,47 | 104,28 |
| **Average** | | **103,86** | **103,42** | **Average** | | **105,59** | **104,36** |
| **Span gas + H2O (16 mmol/mol)** | | | | **Span gas + H2S (30 µg/m$^3$)** | | | |
| 04.06.2014 | 16:40 | 101,97 | 101,81 | 22.09.2014 | 09:40 | 105,42 | 104,59 |
| 04.06.2014 | 16:41 | 102,03 | 101,77 | 22.09.2014 | 09:41 | 105,42 | 104,68 |
| 04.06.2014 | 16:42 | 102,08 | 101,79 | 22.09.2014 | 09:42 | 105,63 | 104,65 |
| **Average** | | **102,03** | **101,79** | **Average** | | **105,49** | **104,64** |
| **Zero Gas** | | | | **Zero Gas** | | | |
| 04.06.2014 | 14:45 | -0,43 | -0,28 | 22.09.2014 | 12:50 | 0,09 | 0,12 |
| 04.06.2014 | 14:46 | -0,44 | -0,28 | 22.09.2014 | 12:51 | 0,12 | 0,11 |
| 04.06.2014 | 14:47 | -0,46 | -0,28 | 22.09.2014 | 12:52 | 0,17 | 0,16 |
| **Average** | | **-0,44** | **-0,28** | **Average** | | **0,13** | **0,13** |
| **Zero gas + NH3 (200 nmol/mol$^3$)** | | | | **Zero gas + N2O (500 µg/m$^3$)** | | | |
| 04.06.2014 | 14:55 | -0,47 | -0,25 | 22.09.2014 | 13:01 | 0,23 | 0,15 |
| 04.06.2014 | 14:56 | -0,49 | -0,25 | 22.09.2014 | 13:02 | 0,22 | 0,19 |
| 04.06.2014 | 14:47 | -0,47 | -0,25 | 22.09.2014 | 13:03 | 0,18 | 0,17 |
| **Average** | | **-0,48** | **-0,25** | **Average** | | **0,21** | **0,17** |
| **Span Gas** | | | | **Span Gas** | | | |
| 04.06.2014 | 15:15 | 104,27 | 103,10 | 22.09.2014 | 13:10 | 105,22 | 105,69 |
| 04.06.2014 | 15:16 | 103,77 | 103,10 | 22.09.2014 | 13:11 | 105,24 | 105,72 |
| 04.06.2014 | 15:17 | 104,30 | 103,06 | 22.09.2014 | 13:12 | 105,34 | 105,62 |
| **Average** | | **104,11** | **103,09** | **Average** | | **105,27** | **105,68** |
| **Span gas + NH3 (200 nmol/mol)** | | | | **Span gas + N2O (500 µg/m$^3$)** | | | |
| 04.06.2014 | 15:30 | 104,42 | 103,27 | 22.09.2014 | 13:20 | 105,34 | 105,47 |
| 04.06.2014 | 15:31 | 104,39 | 103,25 | 22.09.2014 | 13:21 | 105,32 | 105,52 |
| 04.06.2014 | 15:32 | 104,40 | 103,25 | 22.09.2014 | 13:22 | 105,39 | 105,47 |
| **Average** | | **104,40** | **103,26** | **Average** | | **105,35** | **105,49** |
| **Zero Gas** | | | | **Zero Gas** | | | |
| 22.09.2014 | 09:50 | 0,11 | 0,06 | 22.09.2014 | 13:40 | 0,19 | 0,10 |
| 22.09.2014 | 09:51 | 0,02 | 0,02 | 22.09.2014 | 13:41 | 0,16 | 0,03 |
| 22.09.2014 | 09:52 | 0,06 | 0,02 | 22.09.2014 | 13:42 | 0,10 | 0,29 |
| **Average** | | **0,06** | **0,03** | **Average** | | **0,15** | **0,14** |
| **Zero gas + SO2 (700 µg/m$^3$)** | | | | **Zero gas + O3 (360 µg/m$^3$)** | | | |
| 22.09.2014 | 10:00 | 0,31 | 0,22 | 22.09.2014 | 13:50 | 0,42 | 0,23 |
| 22.09.2014 | 10:01 | 0,35 | 0,23 | 22.09.2014 | 13:51 | 0,48 | 0,10 |
| 22.09.2014 | 10:02 | 0,34 | 0,29 | 22.09.2014 | 13:52 | 0,44 | 0,23 |
| **Average** | | **0,33** | **0,24** | **Average** | | **0,45** | **0,18** |
| **Span Gas** | | | | **Span Gas** | | | |
| 22.09.2014 | 10:10 | 105,22 | 104,98 | 22.09.2014 | 14:01 | 104,56 | 105,23 |
| 22.09.2014 | 10:11 | 105,14 | 105,03 | 22.09.2014 | 14:02 | 104,66 | 105,20 |
| 22.09.2014 | 10:12 | 105,19 | 105,04 | 22.09.2014 | 14:03 | 104,68 | 105,10 |
| **Average** | | **105,18** | **105,02** | **Average** | | **104,63** | **105,18** |
| **Span gas + SO2 (700 µg/m$^3$)** | | | | **Span gas + O3 (360 µg/m$^3$)** | | | |
| 22.09.2014 | 10:20 | 105,36 | 105,32 | 22.09.2014 | 14:11 | 104,21 | 104,89 |
| 22.09.2014 | 10:21 | 105,47 | 105,33 | 22.09.2014 | 14:12 | 104,21 | 104,92 |
| 22.09.2014 | 10:22 | 105,46 | 105,33 | 22.09.2014 | 14:13 | 104,18 | 104,93 |
| **Average** | | **105,43** | **105,33** | **Average** | | **104,20** | **104,91** |

*Table 8: Individual results of cross-sensitivity, part 2*

| Date | Time | Device 1 (63) | Device 2 (65) | Date | Time | Device 1 (63) | Device 2 (65) |
|---|---|---|---|---|---|---|---|
| | | [nmol/mol] | [nmol/mol] | | | [nmol/mol] | [nmol/mol] |
| **Zero Gas** | | | | **Zero Gas** | | | |
| 22.09.2014 | 11:10 | 0,19 | 0,00 | 04.06.2014 | 13:30 | -0,06 | -0,01 |
| 22.09.2014 | 11:11 | 0,18 | 0,06 | 04.06.2014 | 13:31 | -0,07 | -0,01 |
| 22.09.2014 | 11:12 | 0,14 | 0,03 | 04.06.2014 | 13:32 | -0,08 | -0,03 |
| **Average** | | **0,17** | **0,03** | **Average** | | **-0,07** | **-0,02** |
| **Zero gas + CO (60 mg/m³)** | | | | **Zero gas + CO2 (500 µmol/mol)** | | | |
| 22.09.2014 | 11:13 | -0,22 | 0,00 | 04.06.2014 | 13:45 | 0,37 | 0,47 |
| 22.09.2014 | 11:14 | -0,09 | 0,00 | 04.06.2014 | 13:46 | 0,37 | 0,45 |
| 22.09.2014 | 11:15 | -0,12 | 0,06 | 04.06.2014 | 13:47 | 0,36 | 0,43 |
| **Average** | | **-0,14** | **0,02** | **Average** | | **0,37** | **0,45** |
| **Span Gas** | | | | **Span Gas** | | | |
| 22.09.2014 | 11:20 | 105,23 | 105,63 | 04.06.2014 | 14:00 | 103,88 | 102,93 |
| 22.09.2014 | 11:21 | 105,34 | 105,45 | 04.06.2014 | 14:01 | 103,98 | 102,94 |
| 22.09.2014 | 11:22 | 105,36 | 105,52 | 04.06.2014 | 14:02 | 104,00 | 102,98 |
| **Average** | | **105,31** | **105,53** | **Average** | | **103,95** | **102,95** |
| **Span gas + CO (60 mg/m³)** | | | | **Span gas + CO2 (500 µmol/mol)** | | | |
| 22.09.2014 | 11:31 | 105,48 | 105,36 | 04.06.2014 | 14:15 | 105,28 | 104,02 |
| 22.09.2014 | 11:32 | 105,42 | 105,39 | 04.06.2014 | 14:16 | 105,29 | 104,04 |
| 22.09.2014 | 11:33 | 105,42 | 105,41 | 04.06.2014 | 14:17 | 105,29 | 104,05 |
| **Average** | | **105,44** | **105,39** | **Average** | | **105,29** | **104,04** |
| **Zero Gas** | | | | **Zero Gas** | | | |
| 22.09.2014 | 12:10 | 0,06 | 0,22 | 22.09.2014 | 10:30 | 0,00 | 0,11 |
| 22.09.2014 | 12:11 | 0,08 | 0,21 | 22.09.2014 | 10:31 | 0,02 | 0,11 |
| 22.09.2014 | 12:12 | 0,14 | 0,21 | 22.09.2014 | 10:32 | 0,05 | 0,14 |
| **Average** | | **0,09** | **0,21** | **Average** | | **0,02** | **0,12** |
| **Zero gas + NO (1 mg/m³)** | | | | **Zero gas + Benzene (1 mg/m³)** | | | |
| 22.09.2014 | 12:21 | 1,06 | 1,22 | 22.09.2014 | 10:40 | 0,08 | 0,19 |
| 22.09.2014 | 12:22 | 1,14 | 1,21 | 22.09.2014 | 10:41 | 0,07 | 0,22 |
| 22.09.2014 | 12:23 | 1,12 | 1,14 | 22.09.2014 | 10:42 | 0,06 | 0,23 |
| **Average** | | **1,11** | **1,19** | **Average** | | **0,07** | **0,21** |
| **Span Gas** | | | | **Span gas** | | | |
| 22.09.2014 | 12:30 | 105,22 | 104,99 | 22.09.2014 | 10:50 | 105,36 | 105,49 |
| 22.09.2014 | 12:31 | 105,23 | 104,95 | 22.09.2014 | 10:51 | 105,42 | 105,63 |
| 22.09.2014 | 12:32 | 105,22 | 104,96 | 22.09.2014 | 10:52 | 105,61 | 105,67 |
| **Average** | | **105,22** | **104,97** | **Average** | | **105,46** | **105,60** |
| **Span gas + NO (1 mg/m³)** | | | | **Span gas + Benzene (1 mg/m³)** | | | |
| 22.09.2014 | 12:40 | 106,52 | 106,02 | 22.09.2014 | 11:00 | 105,24 | 105,89 |
| 22.09.2014 | 12:41 | 106,76 | 106,14 | 22.09.2014 | 11:01 | 105,36 | 105,75 |
| 22.09.2014 | 12:42 | 106,59 | 106,12 | 22.09.2014 | 11:02 | 105,32 | 105,72 |
| **Average** | | **106,62** | **106,09** | **Average** | | **105,31** | **105,79** |

## 6.1 5.3.10 Averaging effect

*For gaseous components the measuring system shall allow the formation of hourly averages.*

*The averaging effect shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010).*
*The averaging effect shall not exceed 7 % of the measured value.*

## 6.2 Equipment

Not applicable in this instance.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the averaging effect are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.12 Averaging test.

## 6.4 Evaluation

Please refer to section 7.1 8.4.12 Averaging test.

## 6.5 Assessment

Please refer to section 7.1 8.4.12 Averaging test.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.11 Standard deviation from paired measurements

*The standard deviation from paired measurements under field conditions shall be determined with two identical measuring systems by paired measurements in the field test. It shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010).*
*The standard deviation under field conditions shall not exceed 5 % of the average over a period of 3 months.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the standard deviation from paired measurements are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.5.5 Reproducibility standard deviation for NO2 under field conditions.

## 6.4 Evaluation

Please refer to section 7.1 8.5.5 Reproducibility standard deviation for NO2 under field conditions.

## 6.5 Assessment

Please refer to section 7.1 8.5.5 Reproducibility standard deviation for NO2 under field conditions.
Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.12 Long-term drift

*The long-term drift at zero point and reference point shall not exceed the requirements specified in Table 2 of standard VDI 4202 part 1 (September 2010). A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.*
*The long-term drift at zero point shall not exceed 5 nmol/mol (= 9,6 µg/m³).*
*The long-term drift at span point shall not exceed 5% of the upper limit of the certification range.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the long-term drift are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.5.4 Long term drift.

## 6.4 Evaluation

Please refer to section 7.1 8.5.4 Long term drift.

## 6.5 Assessment

Please refer to section 7.1 8.5.4 Long term drift.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.13 Short-term drift

*The short-term drift at zero point and reference point shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010) within 12 h (for benzene 24 h) in the laboratory test and within 24 h in the field test. A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.*
*The short-term drift at zero point shall not exceed 2 nmol/mol (i.e. 3.84 µg/m³).*
*The short-term drift at span point shall not exceed 6 nmol/mol (i.e. 11.52 µg/m³).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the short-term drift are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.4 Short-term drift .

## 6.4 Evaluation

Please refer to section 7.1 8.4.4 Short-term drift

## 6.5 Assessment

Please refer to section 7.1 8.4.4 Short-term drift
Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.14 Response time

*The response time (rise) of the measuring system shall not exceed 180 s.*

*The response time (fall) of the measuring system shall not exceed 180 s.*

*The difference between the response time (rise) and response time (fall) of the measuring system shall not exceed 10 % of response time (rise) or 10 s, whatever value is larger.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the response time are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.3 Response time.

## 6.4 Evaluation

Please refer to section 7.1 8.4.3 Response time.

## 6.5 Assessment

Please refer to section 7.1 8.4.3 Response time.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.15 Difference between sample and calibration port

*The difference between the measured values obtained by feeding gas at the sample and calibration port shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010). A value $c_t$ at 70 % to 80 % of the upper limit of the certification range shall be used as reference point.*
*The difference between sample and calibration port shall not exceed 1 %.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the difference between sample and calibration port are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.13 Difference sample/calibration port.

## 6.4 Evaluation

Please refer to section 7.1 8.4.13 Difference sample/calibration port.

## 6.5 Assessment

Please refer to section 7.1 8.4.13 Difference sample/calibration port.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.16 Converter efficiency

*In case of measuring systems with a converter, the converter efficiency shall be at least 98 %.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the converter efficiency are in line with the requirements stipulated in EN 14211 (2012). The reader is therefore referred to section 7.1 8.4.14 Converter efficiency.

## 6.4 Evaluation

Please refer to section 7.1 8.4.14 Converter efficiency.

## 6.5 Assessment

Please refer to section 7.1 8.4.14 Converter efficiency.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.17 Increase of $NO_2$ concentration due to residence in the measuring system

*In case of $NO_X$ measuring systems the increase of $NO_2$ concentration due to residence in the measuring system shall not exceed the requirements of Table 2 of VDI 4202 Sheet 1 (September 2010).*

*The requirements of Table 2 of VDI 4202 Sheet 1 (September 2010) apply to certification ranges according to Table 1 of VDI 4202 Sheet 1 (September 2010). For deviating certification ranges the requirements shall be proportionally converted.*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

Performance and evaluation of the steps taken to determine the increase of $NO_2$ due to residence time in the measuring system are in line with the test criterion for the determination of the increase of $NO_2$ due to residence time in the measuring system in accordance with EN 14211 (2012). The reader is therefore referred to 7.1 8.4.15 Residence time in the analyser.

## 6.4 Evaluation

Please refer to section 7.1 8.4.15 Residence time in the analyser.

## 6.5 Assessment

Please refer to section 7.1 8.4.15 Residence time in the analyser.

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

## 6.1 5.3.18 Overall uncertainty

*The expanded uncertainty of the measuring system shall be determined. The value determined shall not exceed the corresponding data quality objectives in the applicable EU Directives on air quality listed in Annex A, Table 1 of VDI 4202 Sheet 1 (September 2010).*

## 6.2 Equipment

Not applicable here.

## 6.3 Testing

The determination of uncertainty was performed in accordance with EN 14211 (2012) and is detailed in section 7.1 8.6 Total uncertainty in accordance with Annex E of EN 14211 (2012).

## 6.4 Evaluation

The determination of uncertainty was performed in accordance with EN 14211 (2012) and is detailed in section 7.1 8.6 Total uncertainty in accordance with Annex E of EN 14211 (2012).

## 6.5 Assessment

The determination of uncertainty was performed in accordance with EN 14211 (2012) and is detailed in section 7.1 8.6 Total uncertainty in accordance with Annex E of EN 14211 (2012).

Does this comply with the performance criterion? yes

## 6.6 Detailed presentation of test results

Not applicable in this instance.

# 7. Test results in accordance with EN 14211 (2012)

## 7.1 8.4.3 Response time

*Neither the response time (rise) nor the response time (fall) shall exceed 180 s. The difference between rise and fall response time shall not exceed 10 s.*

## 7.2 Test procedure

The determination of the response time shall be carried out by applying to the analyser a step function in the concentration from less than 20 % to about 80 % of the maximum of the certification range and vice versa.

The change from zero gas to span gas and vice versa needs to be made almost instantaneously, with the use of a suitable valve. The valve outlet shall be mounted direct to the inlet of the analyser, and both zero gas and span gas shall have the same amount of gas in excess, which is vented by the use of a tee. The gas flows of both zero gas and span gas shall be chosen in such a way that the dead time in the valve and tee can be neglected compared to the lag time of the analyser system. The step change is made by switching the valve from zero gas to span gas. This event needs to be timed and is the start ($t$ = 0) of the (rise) lag time according to Figure 7. As soon as the reading is stable to 98 % of the concentration applied, the valve can be switched back to zero gas. This point is the start ($t$ = 0) of the (fall) lag time. Once the reading is stable to 2 % of the concentration applied, the whole cycle as shown in Figure 7 is complete.

The elapsed time (response time) between the start of the step change and reaching 90 % of the analyser final stable reading of the applied concentration shall be measured. The whole cycle shall be repeated four times. The average of the four response times (rise) and the average of the four response times (fall) shall be calculated.

The test shall then be repeated with $NO_2$ at levels from less than 20 % to about 80 % of the maximum of the certification range of $NO_2$ and vice versa.

The difference in response times shall be calculated according to:

$$t_d = \bar{t}_r - \bar{t}_f$$

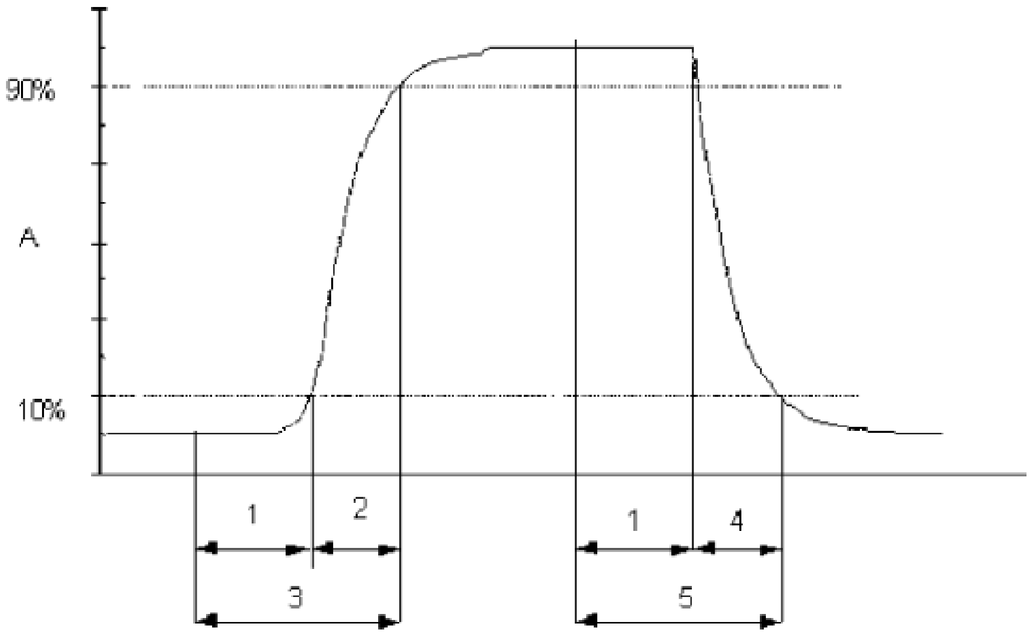
where

$t_d$ is the difference between response time (rise) and response time (fall), in s;

$t_r$ is the response time (rise) (average of the four response times - rise), in s;

$t_f$ is the response time (fall (average of the four response times - fall), in s.

$t_r$, $t_f$ and $t_d$ shall meet the performance criteria as specified above.




**Key**
A analyser response
1 lag time
2 rise time
3 response time (rise)
4 fall time
5 response time (fall)

Figure 7: Diagram illustrating the response time

### 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211. Data were recorded using a Yokogawa DX112-2-2 data logger with its averaging time set to 1 s.

## 7.4 Evaluation

*Table 9: Response times of the two T500U measuring systems for $NO_2$*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| average rise $t_r$ [s] | ≤ 180 s | 21 | ✓ | 22 | ✓ |
| average fall $t_f$ [s] | ≤ 180 s | 22 | ✓ | 21 | ✓ |
| difference $t_d$ [s] | ≤ 10 s | -1 | ✓ | 1 | ✓ |

For system 1 this results in a maximum $t_r$ of 21 s for $NO_2$, a maximum $t_f$ of 22 s and a $t_d$ of -1 s.

For system 2 this results in a maximum $t_r$ of 22 s for $NO_2$, a maximum $t_f$ of 21 s and a $t_d$ of 1 s.

## 7.5 Assessment

The maximum permissible response time of 180 s is exceeded at no time. The maximum response time determined for system 1 at $NO_2$ 22 s and for system 2 at $NO_2$ 22 s.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

*Table 10: Individual readings for the response times for the component $NO_2$*

| | | device 1 rise | | | fall | | |
|---|---|---|---|---|---|---|---|
| | 80% | | | | | | |
| measuring range | 209,21 | 0,0<br>0,00 | 0,9<br>188,28 | 1,0<br>209,21 | 1,0<br>209,21 | 0,1<br>20,92 | 0,0<br>0,00 |
| cycles 1 | t = 0 | 09:00:00 | 09:00:21 | 09:01:00 | 09:04:00 | 09:04:21 | 09:05:00 |
| | delta t | | 00:00:21 | | | 00:00:21 | |
| | delta t [s] | | 21 | | | 21 | |
| cycles 2 | t = 0 | 09:10:00 | 09:10:21 | 09:11:00 | 09:16:00 | 09:16:23 | 09:17:00 |
| | delta t | | 00:00:21 | | | 00:00:23 | |
| | delta t [s] | | 21 | | | 23 | |
| cycles 3 | t = 0 | 09:22:00 | 09:22:21 | 09:23:00 | 09:28:00 | 09:28:22 | 09:29:00 |
| | delta t | | 00:00:21 | | | 00:00:22 | |
| | delta t [s] | | 21 | | | 22 | |
| cycles 4 | t = 0 | 09:34:00 | 09:34:21 | 09:35:00 | 09:40:00 | 09:40:22 | 08:51:00 |
| | delta t | | 00:00:21 | | | 00:00:22 | |
| | delta t [s] | | 21 | | | 22 | |

| | | device 2 rise | | | fall | | |
|---|---|---|---|---|---|---|---|
| | 80% | | | | | | |
| measuring range | 209,21 | 0,0<br>0,00 | 0,9<br>188,28 | 1,0<br>209,21 | 1,0<br>209,21 | 0,1<br>20,92 | 0,0<br>0,00 |
| cycles 1 | t = 0 | 09:00:00 | 09:00:22 | 09:01:00 | 09:04:00 | 09:04:21 | 09:05:00 |
| | delta t | | 00:00:22 | | | 00:00:21 | |
| | delta t [s] | | 22 | | | 21 | |
| cycles 2 | t = 0 | 09:10:00 | 09:10:22 | 09:11:00 | 09:16:00 | 09:16:22 | 09:17:00 |
| | delta t | | 00:00:22 | | | 00:00:22 | |
| | delta t [s] | | 22 | | | 22 | |
| cycles 3 | t = 0 | 09:22:00 | 09:22:23 | 09:23:00 | 09:28:00 | 09:28:21 | 09:29:00 |
| | delta t | | 00:00:23 | | | 00:00:21 | |
| | delta t [s] | | 23 | | | 21 | |
| cycles 4 | t = 0 | 09:34:00 | 09:34:21 | 09:35:00 | 09:40:00 | 09:40:22 | 08:51:00 |
| | delta t | | 00:00:21 | | | 00:00:22 | |
| | delta t [s] | | 21 | | | 22 | |

## 7.1 8.4.4 Short-term drift

*The short-term drift at zero shall not exceed nmol/mol/12h (i.e. 3.84 µg/m³/12 h).*

*The short-term drift at span level shall not exceed 6.0 nmol/mol/12h (i.e. 11.52 µg/m³/12 h).*

## 7.2 Test procedure

After the required stabilisation period, the analyser shall be adjusted at zero and span level (around 70 % to 80 % of the maximum of the certification range of NO). After waiting the time equivalent to one independent reading, 20 individual measurements are recorded, first at zero and then at span concentration. From these 20 measurements, the average is calculated for zero and span level.

The analyser shall be kept running under the laboratory conditions while analysing ambient air. After a period of 12 h, zero and span gas is fed to the analyser. After waiting the time equivalent to one independent reading, 20 individual measurements are recorded, first at zero and then at span concentration. The averages for zero and span level shall be calculated.

The short-term drift at zero and span level shall be calculated as follows:

$$D_{S,Z} = (C_{Z,2} - C_{Z,1})$$

where

$D_{S,Z}$ is the 12-hour-drift

$C_{Z,1}$ is the average concentration of the measurements at zero at the beginning of the drift period

$C_{Z,2}$ is the average concentration of the measurements at zero at the end of the drift period

$D_{S,Z}$ shall meet the performance criterion as specified above.

$$D_{S,S} = (C_{S,2} - C_{S,1}) - D_{S,Z}$$

where

$D_{S,S}$ is the 12-hour drift at span

$C_{S,1}$ is the average concentration of the measurements at span level at the beginning of the drift period

$C_{S,2}$ is the average concentration of the measurements at span level at the end of the drift period

$D_{S,S}$ shall meet the performance criterion as specified above.

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211. According to this standard, the test shall be performed using NO at a level of 70 % to 80 % of the certification range for NO.

## 7.4 Evaluation

*Table* lists the readings obtained for the short-term drift.

*Table 11: Results for the short-term drift*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| averange at zero at the beginning [nmol/mol] | - | -0,17 | | -0,30 | |
| averange at zero at the end [nmol/mol] | - | -0,05 | | -0,10 | |
| averange at span at the beginning [nmol/mol] | - | 201,17 | | 202,25 | |
| averange at span at the end [nmol/mol] | - | 201,22 | | 201,13 | |
| 12-hour drift at zero $D_{s,z}$ [nmol/mol] | - | 0,12 | ✓ | 0,20 | ✓ |
| 12-hour drift at span $D_{s,s}$ [nmol/mol] | - | -0,07 | ✓ | -1,33 | ✓ |

## 7.5 Assessment

Short-term drift at zero point is 0,12 nmol/mol for system 1 and 0,20 nmol/mol for system 2.

Short-term drift at the reference point is -0,07 nmol/mol for system 1 and -1,33 nmol/mol for system 2.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

*Individual results of the tests are detailed in Table 11 and Table 12.*

*Table 11: Individual test results for the short term drift*

| at beginning | | |
|---|---|---|
| zero level | | |
| | device 1 | device 2 |
| time | [nmol/mol] | [nmol/mol] |
| 19:30:00 | -0,2 | -0,3 |
| 19:31:00 | -0,2 | -0,3 |
| 19:32:00 | -0,1 | -0,2 |
| 19:33:00 | -0,2 | -0,3 |
| 19:34:00 | -0,2 | -0,3 |
| 19:35:00 | -0,2 | -0,3 |
| 19:36:00 | 0,0 | -0,4 |
| 19:37:00 | -0,3 | -0,3 |
| 19:38:00 | -0,2 | -0,3 |
| 19:39:00 | -0,2 | -0,4 |
| 19:40:00 | -0,3 | -0,4 |
| 19:41:00 | -0,1 | -0,4 |
| 19:42:00 | -0,2 | -0,3 |
| 19:43:00 | -0,2 | -0,4 |
| 19:44:00 | -0,2 | -0,3 |
| 19:45:00 | -0,3 | -0,4 |
| 19:46:00 | 0,4 | 0,2 |
| 19:47:00 | -0,2 | -0,3 |
| 19:48:00 | -0,3 | -0,2 |
| 19:49:00 | -0,3 | -0,3 |
| **average** | **-0,2** | **-0,3** |

| at beginning | | |
|---|---|---|
| span level | | |
| | device 1 | device 2 |
| time | [nmol/mol] | [nmol/mol] |
| 20:05:00 | 200,1 | 200,5 |
| 20:06:00 | 200,4 | 200,6 |
| 20:07:00 | 200,4 | 200,7 |
| 20:08:00 | 200,5 | 200,8 |
| 20:09:00 | 200,9 | 201,0 |
| 20:10:00 | 200,8 | 201,0 |
| 20:11:00 | 201,0 | 201,1 |
| 20:12:00 | 201,6 | 202,9 |
| 20:13:00 | 201,7 | 202,8 |
| 20:14:00 | 201,7 | 202,8 |
| 20:15:00 | 201,7 | 202,9 |
| 20:16:00 | 201,9 | 203,0 |
| 20:17:00 | 201,0 | 203,0 |
| 20:18:00 | 202,0 | 203,1 |
| 20:19:00 | 202,0 | 203,1 |
| 20:20:00 | 201,0 | 203,1 |
| 20:21:00 | 201,2 | 203,1 |
| 20:22:00 | 201,2 | 203,2 |
| 20:23:00 | 201,2 | 203,1 |
| 20:24:00 | 201,2 | 203,1 |
| **average** | **201,2** | **202,3** |

*Table 12: Final test results for the short-term drift*

| after 12h | | |
|---|---|---|
| zero level | | |
| | device 1 | device 2 |
| time | [nmol/mol] | [nmol/mol] |
| 07:30:00 | 0,1 | 0,0 |
| 07:31:00 | 0,1 | 0,0 |
| 07:32:00 | 0,0 | -0,1 |
| 07:33:00 | -0,1 | -0,2 |
| 07:34:00 | -0,1 | -0,1 |
| 07:35:00 | 0,0 | -0,1 |
| 07:36:00 | -0,1 | 0,0 |
| 07:37:00 | -0,1 | -0,2 |
| 07:38:00 | 0,0 | -0,1 |
| 07:39:00 | -0,1 | -0,1 |
| 07:40:00 | -0,1 | -0,1 |
| 07:41:00 | -0,1 | -0,2 |
| 07:42:00 | -0,2 | -0,1 |
| 07:43:00 | 0,0 | -0,1 |
| 07:44:00 | -0,1 | 0,0 |
| 07:45:00 | -0,1 | -0,2 |
| 07:46:00 | 0,0 | -0,1 |
| 07:47:00 | -0,1 | -0,1 |
| 07:48:00 | -0,1 | -0,1 |
| 07:49:00 | -0,1 | -0,2 |
| **average** | **0,0** | **-0,1** |

| after 12h | | |
|---|---|---|
| span level | | |
| | device 1 | device 2 |
| time | [nmol/mol] | [nmol/mol] |
| 08:05:00 | 200,7 | 201,0 |
| 08:06:00 | 200,8 | 201,0 |
| 08:07:00 | 200,8 | 201,1 |
| 08:08:00 | 201,1 | 201,3 |
| 08:09:00 | 201,2 | 201,3 |
| 08:10:00 | 201,3 | 201,3 |
| 08:11:00 | 201,3 | 201,3 |
| 08:12:00 | 201,4 | 201,3 |
| 08:13:00 | 201,5 | 201,2 |
| 08:14:00 | 201,1 | 200,8 |
| 08:15:00 | 201,0 | 201,0 |
| 08:16:00 | 201,1 | 200,9 |
| 08:17:00 | 201,3 | 201,0 |
| 08:18:00 | 201,3 | 201,0 |
| 08:19:00 | 201,3 | 201,0 |
| 08:20:00 | 201,4 | 201,1 |
| 08:21:00 | 201,4 | 201,2 |
| 08:22:00 | 201,4 | 201,2 |
| 08:23:00 | 201,5 | 201,2 |
| 08:24:00 | 201,5 | 201,2 |
| **average** | **201,2** | **201,1** |

## 7.1 8.4.5 Repeatability standard deviation

*The repeatability standard deviation shall neither exceed the performance criterion 1,0 nmol/mol (=1,82 µg/m³) at zero nor shall it exceed 3 nmol/mol (=5,76 µg/m³) of the test gas concentration at reference point.*

## 7.2 Test procedure

After waiting the time equivalent of one independent reading, 20 individual measurements both at zero concentration and at an $NO_2$ test gas concentration ($c_t$) similar to the 1-hour limit value…

From these measurements, the repeatability standard deviation at zero concentration and at concentration $c_t$ shall be calculated according to:

$$s_r = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

where

| | |
|---|---|
| $s_r$ | is the repeatability standard deviation |
| $x_i$ | the *i*th measurement |
| $\bar{x}$ | is the average of the 20 measurements |
| $n$ | is the number of measurements |

The repeatability standard deviation shall be calculated separately for both series of measurements (zero gas and concentration $c_t$).

$s_r$ shall comply the performance criterion stated above at concentration zero as well as NO-test gas concentration $c_t$ of (500 ± 50) nmol/mol. The measuring system does not operate according to the reference method chemiliminescence, instead it measures $NO_2$ directly via UV absorption. Therefore, a level at the hourly limit value of $NO_2$ (104 nmol/mol) was taken as span concentration.

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211. In accordance with these requirements, the test needs to be performed using the component NO. EN 14211 specifies that the test shall be performed at a concentration level of 500 nmol/mol NO. According to VDI 4202 sheet 1 the test of the repeatability standard deviation at the reference point shall be performed using the limit value.

The analyser uses UV absorption to measure $NO_2$ directly instead of “chemiluminescence” as reference method. Therefore, a level at the hourly limit-value of $NO_2$ (104 nmol/mol) was used as span concentration.

## 7.4 Evaluation

*Table 13* details the test results for the repeatability standard deviation.

*Table 13: Repeatability standard deviation at zero and reference point*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| repeatability standard deviation $s_{r,z}$ at zero [nmol/mol] | - | 0,07 | ✓ | 0,05 | ✓ |
| repeatability standard deviation $s_{r,ct}$ at $c_t$ [nmol/mol] | - | 0,25 | ✓ | 0,15 | ✓ |
| detection limit [nmol/mol] | | 0,23 | | 0,18 | |

## 7.5 Assessment

Repeatability standard deviation at zero point is 0,07 nmol/mol for system 1 and 0,05 nmol/mol for system 2. Repeatability standard deviation at reference point is 0,25 nmol/mol for system 1 and 0,15 nmol/mol for system 2.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Table 14 lists the results of the individual measurements.

*Table 14: Individual test results for the repeatability standard deviation*

| cero level | | |
|---|---|---|
| | device 1 | device 2 |
| time | [nmol/mol] | [nmol/mol] |
| 10:05:00 | -0,4 | -0,1 |
| 10:06:00 | -0,2 | -0,2 |
| 10:07:00 | -0,4 | -0,1 |
| 10:08:00 | -0,4 | -0,1 |
| 10:09:00 | -0,4 | -0,2 |
| 10:10:00 | -0,4 | -0,2 |
| 10:11:00 | -0,3 | -0,1 |
| 10:12:00 | -0,3 | -0,2 |
| 10:13:00 | -0,4 | -0,1 |
| 10:14:00 | -0,4 | -0,1 |
| 10:15:00 | -0,4 | -0,1 |
| 10:16:00 | -0,4 | -0,2 |
| 10:17:00 | -0,5 | -0,1 |
| 10:18:00 | -0,4 | -0,2 |
| 10:19:00 | -0,4 | -0,2 |
| 10:20:00 | -0,5 | -0,2 |
| 10:21:00 | -0,5 | -0,2 |
| 10:22:00 | -0,5 | -0,2 |
| 10:23:00 | -0,5 | -0,1 |
| 10:24:00 | -0,5 | -0,2 |
| average | -0,4 | -0,1 |

| $c_t$ level | | |
|---|---|---|
| | device 1 | device 2 |
| time | [nmol/mol] | [nmol/mol] |
| 10:48:00 | 104,1 | 105,7 |
| 10:49:00 | 104,2 | 105,8 |
| 10:50:00 | 104,3 | 105,8 |
| 10:51:00 | 104,4 | 105,8 |
| 10:52:00 | 104,4 | 105,8 |
| 10:53:00 | 104,5 | 105,9 |
| 10:54:00 | 104,5 | 105,9 |
| 10:55:00 | 104,6 | 105,9 |
| 10:56:00 | 104,5 | 106,1 |
| 10:57:00 | 104,6 | 106,0 |
| 10:58:00 | 104,8 | 106,0 |
| 10:59:00 | 104,7 | 106,0 |
| 11:00:00 | 104,8 | 106,0 |
| 11:01:00 | 104,8 | 106,1 |
| 11:02:00 | 104,9 | 106,1 |
| 11:03:00 | 104,8 | 106,2 |
| 11:04:00 | 104,8 | 106,1 |
| 11:05:00 | 104,9 | 106,1 |
| 11:06:00 | 104,9 | 106,1 |
| 11:07:00 | 105,0 | 106,2 |
| average | 104,6 | 106,0 |

## 7.1 8.4.6 Lack of fit of linearity of the calibration function

*The lack of fit of linearity of the calibration function shall not exceed 5 nmol/mol (=9,6 µg/m³) at zero point and 4 % of the measured value at concentrations above zero.*

## 7.2 Test procedure

The lack of fit of linearity of the calibration function of the analyser shall be tested over the range of 0 % to 95 % of the maximum of the certification range, using at least six concentrations (including the zero point). The analyser shall be adjusted at a concentration of about 80 % of the maximum of the certification range. At each concentration (including zero) at least five individual measurements shall be performed.

The concentrations shall be applied in the following sequence: 80 %, 40 %, 0 %, 60 %, 20 % and 95 %. After each change in concentration, at least a time equivalent to four response times shall be elapse before the next measurement is performed.

For each change in concentration, at least four response times shall be taken into account before the next measurement is performed.

The linear regression function is established on in accordance with Annex A of standard EN 14211. Deviations from the linear regression function need to comply with the performance characteristics stated above.

Establishing the regression line:

A regression line in the form of $Y_i = A + B * X_i$ is established through calculation of the function

$$Y_i = a + B(X_i - X_z)$$

To calculate the regression, all measuring points (including zero) are taken into account. The total number of measuring points *n* is equal to the number of concentration levels (at least six including zero) multiplied by the number of repetitions (at least five) at each concentration level.

The coefficient *a* is obtained from

$$a = \sum Y_i / n$$

where

- a is the average of the Y-values;
- $Y_i$ is the individual Y-value;
- n is the number of measuring points

The coefficient *B* is obtained from

$$B = \left(\sum Y_i (X_i - X_z)\right) / \sum (X_i - X_z)^2$$

where

$X_z$ is the average of the X-values $\left(= \sum (X_i / n)\right)$

$X_i$ is the individual X-value

The function $Y_i = a + B (X_i – X_z)$ is converted to $Y_i = A + B * X_i$ through the calculation of *A*

$A = a – B * X_z$

The dev iation of the averages of the calibration points (including the zero point) are calculated as follows.
The average value of each calibration point (including the zero point) at one and the same concentration c is calculated according to:

$$(Y_a)_c = \sum (Y_i)_c / m$$

where

$(Y_a)_c$ is the average y-value at concentration level c;
$(Y_i)_c$ is the individual y-value at concentration level c;
M is the number of repetitions at concentration level c

The deviation of each average ($r_c$) at each concentration level is calculated according to:

$$r_c = (Y_a)_c - (A + B \times c)$$

Each residual to a value relative to its own concentration level c is expressed in % as:

$$r_{c,rel} = \frac{r_c}{c} \times 100\%$$

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211.

## 7.4 Evaluation

The following linear regressions are obtained:

*Figure 8* and *Figure 9* graphically summarise the results of the determination of the group averages for $NO_2$.

*Table 15: Deviation of the analytical function for $NO_2$*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| largest value of the relative residuals $r_{max}$ [%] | ≤ 4,0 | 0,77 | ✓ | 0,69 | ✓ |
| residual at zero $r_z$ [nmol/mol] | ≤ 5,0 | -0,39 | ✓ | -0,16 | ✓ |

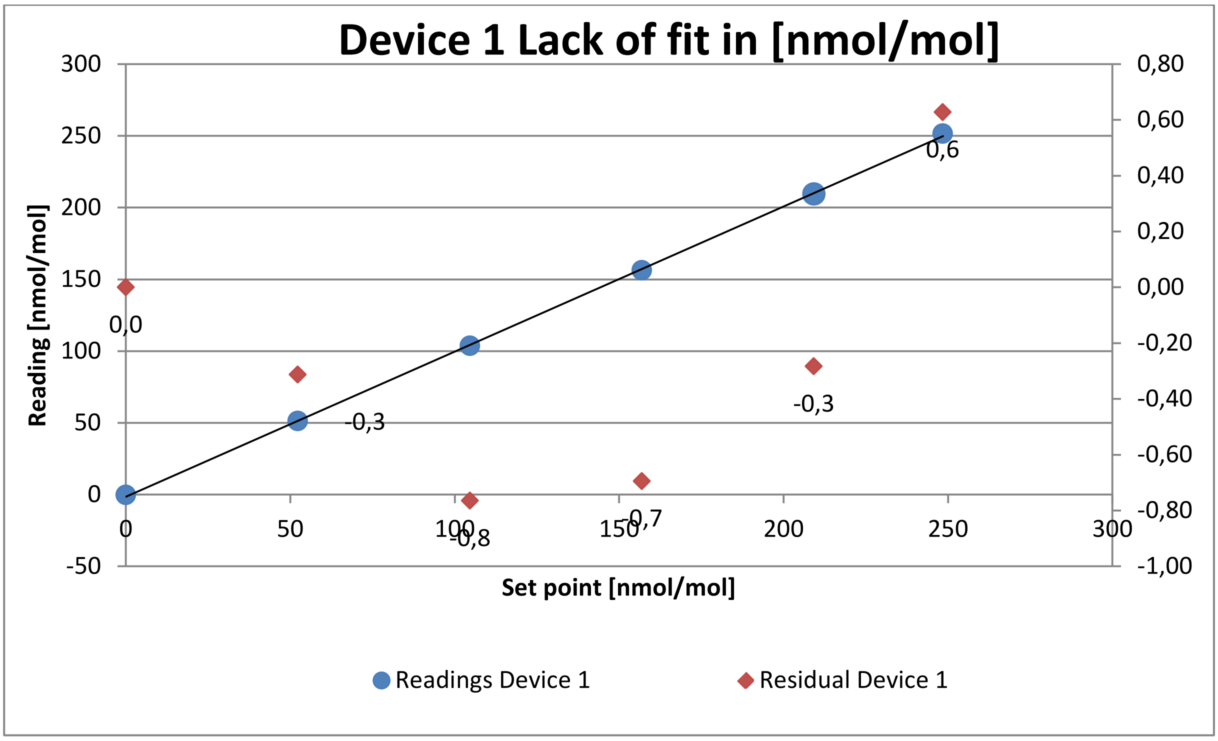



*Figure 8: Function established from group averages for system 1, component $NO_2$*

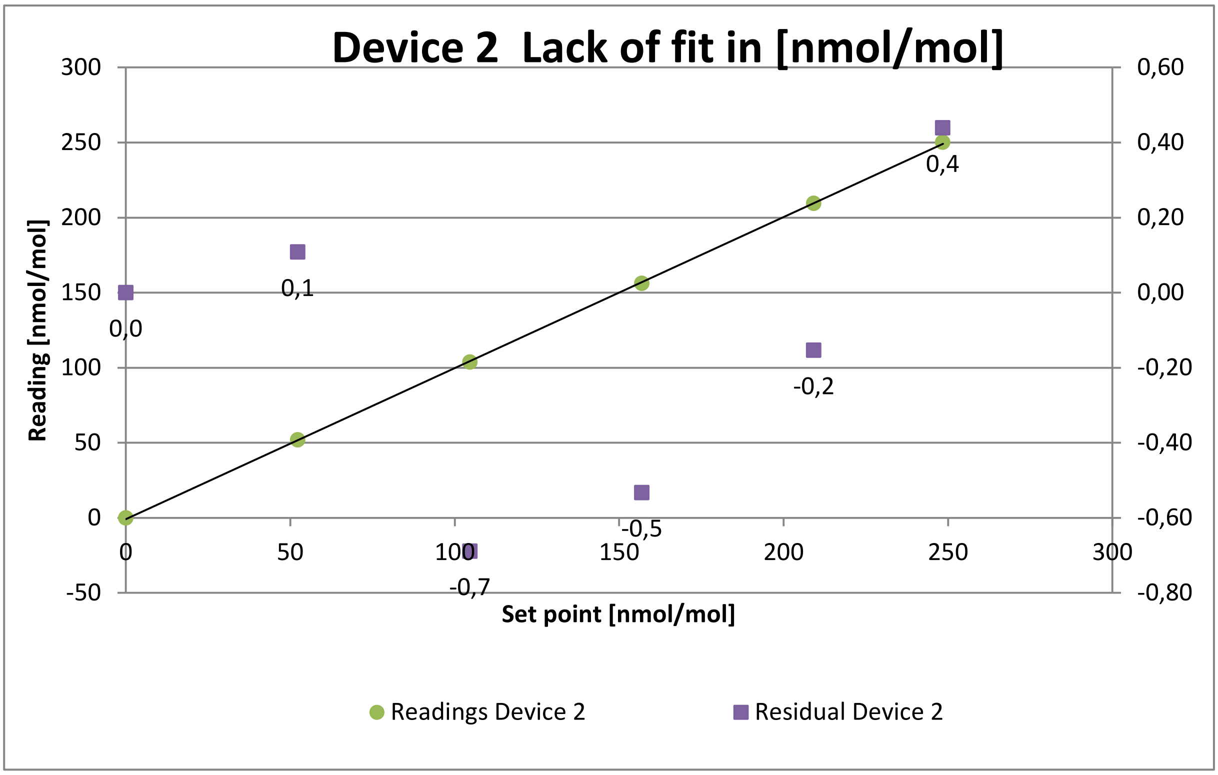



*Figure 9: Function established from group averages for system 2, component $NO_2$*

## 7.5 Assessment

For system 1 there is a deviation of -0,39 nmol/mol from the regression line at zero point and maximum 0,77 % from the set value at concentrations greater than zero. For system 2 there is a deviation of -0,16 nmol/mol from the regression line at zero and maximum 0,69 % from from the set value at concentrations greater than zero.

Deviations from the ideal regression line do not exceed the limit values stipulated in Standard EN 14211.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Individual results of the tests are detailed in Table 16.

*Table 16: Individual results of the "lack of fit" test*

| | | device 1 [nmol/mol] | | device 2 [nmol/mol] | |
|---|---|---|---|---|---|
| time | level [%] | actual value $y_i$ | set value $x_i$ | actual value $y_i$ | set value $x_i$ |
| 08:00:00 | 80 | 208,82 | 209,21 | 208,95 | 209,21 |
| 08:01:00 | 80 | 209,23 | 209,21 | 209,23 | 209,21 |
| 08:02:00 | 80 | 209,70 | 209,21 | 209,40 | 209,21 |
| 08:03:00 | 80 | 210,02 | 209,21 | 209,56 | 209,21 |
| 08:04:00 | 80 | 210,17 | 209,21 | 209,46 | 209,21 |
| average | | 209,59 | | 209,32 | |
| $r_{c,rel}$ | | -0,28 | | -0,15 | |
| 08:08:00 | 40 | 103,53 | 104,60 | 103,60 | 104,60 |
| 08:09:00 | 40 | 103,59 | 104,60 | 103,65 | 104,60 |
| 08:10:00 | 40 | 103,52 | 104,60 | 103,66 | 104,60 |
| 08:11:00 | 40 | 103,54 | 104,60 | 103,67 | 104,60 |
| 08:12:00 | 40 | 103,57 | 104,60 | 103,69 | 104,60 |
| average | | 103,55 | | 103,65 | |
| $r_{c,rel}$ | | -0,77 | | -0,69 | |
| 08:16:00 | 0 | -0,30 | 0,00 | -0,12 | 0,00 |
| 08:17:00 | 0 | -0,37 | 0,00 | -0,16 | 0,00 |
| 08:18:00 | 0 | -0,41 | 0,00 | -0,17 | 0,00 |
| 08:19:00 | 0 | -0,41 | 0,00 | -0,16 | 0,00 |
| 08:20:00 | 0 | -0,44 | 0,00 | -0,21 | 0,00 |
| average | | -0,39 | | -0,16 | |
| $r_z$ | | | | | |
| 08:24:00 | 60 | 156,02 | 156,90 | 156,11 | 156,90 |
| 08:25:00 | 60 | 156,05 | 156,90 | 156,09 | 156,90 |
| 08:26:00 | 60 | 156,06 | 156,90 | 156,16 | 156,90 |
| 08:27:00 | 60 | 156,29 | 156,90 | 156,12 | 156,90 |
| 08:28:00 | 60 | 156,46 | 156,90 | 156,36 | 156,90 |
| average | | 156,18 | | 156,17 | |
| $r_{c,rel}$ | | -0,69 | | -0,53 | |
| 08:32:00 | 20 | 51,37 | 52,30 | 51,81 | 52,30 |
| 08:33:00 | 20 | 51,29 | 52,30 | 51,79 | 52,30 |
| 08:34:00 | 20 | 51,26 | 52,30 | 51,80 | 52,30 |
| 08:35:00 | 20 | 51,24 | 52,30 | 51,78 | 52,30 |
| 08:36:00 | 20 | 51,22 | 52,30 | 51,79 | 52,30 |
| average | | 51,28 | | 51,80 | |
| $r_{c,rel}$ | | -0,31 | | 0,11 | |
| 08:40:00 | 95 | 251,18 | 248,43 | 250,05 | 248,43 |
| 08:41:00 | 95 | 251,33 | 248,43 | 250,12 | 248,43 |
| 08:42:00 | 95 | 251,46 | 248,43 | 250,21 | 248,43 |
| 08:43:00 | 95 | 251,54 | 248,43 | 250,32 | 248,43 |
| 08:44:00 | 95 | 251,61 | 248,43 | 250,33 | 248,43 |
| average | | 251,42 | | 250,21 | |
| $r_{c,rel}$ | | 0,63 | | 0,44 | |

## 7.1 8.4.7 Sensitivity coefficient to sample gas pressure

*The sensitivity coefficient to sample gas pressure shall not exceed 8,0 nmol/mol/kPa (= 15,36 µg/m³/kPa).*

## 7.2 Test procedure

Measurements are taken at a concentration of about 70 % to 80 % of the maximum of the certification range at an absolute pressure of about (80 ± 0,2) kPa and at an absolute pressure of about (110 ± 0,2) kPa. At each pressure after waiting the time equivalent to one independent reading, three individual measurements are recorded. From these three measurements, the averages at each pressure are calculated.

Measurements at different pressures shall be separated by at least four response times.

The sample gas pressure influence is calculated by:

$$b_{gp} = \left| \frac{(C_{P2} - C_{P1})}{(P_2 - P_1)} \right|$$

Dabei ist:

$b_{gp}$ is the sample gas pressure sensitivity coefficient,

$C_{P1}$ is the average concentration of the measurements at sampling gas pressure $P_1$

$C_{P2}$ is the average concentration of the measurements at sampling gas pressure $P_2$

$P_1$ sampling gas pressure $P_1$

$P_2$ sampling gas pressure $P_2$

$b_{gp}$ shall satisfy the performance characteristics stated above.

## 7.3 Testing

The test was not performed in accordance with the test procedures specified in standard EN 14211.

Reducing the applied gas volume through restriction of the test gas line, a vacuum could be generated. During the pressure test the analyser was connected to a test gas source. The generated amount of test gas was set higher than the amount drawn in by the analyser. Gas in surplus is conducted via a T-piece. Pressure was generated by restricting the bypass line. The test gas pressure was determined by a pressure transducer in the gas path.

Independent measurements are taken at concentrations of about 70 % to 80 % of the maximum certification range and at pressures of 80 kPa and 101 kPa.

## 7.4 Evaluation

The following sensitivity coefficients were determined for the influence of sample gas pressure.

*Table 17: Sensitivity coefficient to sample gas pressure*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| sensitivity coeff. sample gas pressure $b_{gp}$ [nmol/mol/kPa] | - | 0,08 | ✓ | 0,16 | ✓ |

## 7.5 Assessment

For system 1, the sensitivity coefficient to the sample gas pressure is 0,08 nmol/mol/kPa.

For system 2 (002), the sensitivity coefficient to the sample gas pressure is 0,16 nmol/mol/kPa.

**Does this comply with the performance criterion? yes**

## 7.6 Detailed presentation of test results

*Table 18: Individual results of the influence of the sample gas pressure*

| time | pressure [kPa] | concentration | device 1 [nmol/mol] | device 2 [nmol/mol] |
|---|---|---|---|---|
| 08:42:00 | 80 | 187,50 | 188,27 | 187,10 |
| 08:43:00 | 80 | 187,50 | 188,35 | 187,10 |
| 08:44:00 | 80 | 187,50 | 188,51 | 187,22 |
| average $C_{P1}$ | | | 188,38 | 187,14 |
| 09:25:00 | 110 | 187,50 | 185,95 | 182,50 |
| 09:26:00 | 110 | 187,50 | 186,22 | 182,48 |
| 09:27:00 | 110 | 187,50 | 186,15 | 182,44 |
| average $C_{P2}$ | | | 186,11 | 182,47 |

## 7.1 8.4.8 Sensitivity coefficient to sample gas temperature

*The sensitivity coefficient to sample gas temperature shall not exceed 3.0 nmol/mol/K (i.e. 5.76 µg/m³/K).*

## 7.2 Test procedure

Measurements shall be performed at sample gas temperatures of $T_1$ = 0 °C and $T_2$ = 30 °C. A concentration around 70 % to 80 % of the maximum of the certification range shall be applied. After waiting the time equivalent to one independent measurement, three individual measurements at each temperature are recorded.

The sample gas temperature, measured at the inlet of the analyser, is held constant for at least 30 min.

The influence of sample gas temperature is calculated from:

$$b_{gt} = \frac{(C_{GT,2} - C_{GT,1})}{(T_{G,2} - T_{G,1})}$$

where

| | |
|---|---|
| $b_{gt}$ | is the sample gas temperature sensitivity coefficient |
| $C_{GT,1}$ | is the average concentration of the measurements at sample gas temperature $T_1$ |
| $C_{GT,2}$ | is the average concentration of the measurements at sample gas temperature$T_2$ |
| $T_{G,1}$ | is the sample gas temperature $T_1$ |
| $T_{G,2}$ | is the sample gas temperature $T_2$ |
| $b_{gt}$ | shall meet the performance criterion specified above. |

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211.

For the purpose of the test, the sample gas mixture was conducted through a bundle of tubes of 20 m length, which was placed in a climate chamber. The measuring systems were set up directly in front of this chamber. The end of the hose bundle has been taken out of the climate chamber and connected to the analysers. The feed line outside the climate chamber has been insulated and the test gas temperature was monitored directly in front of the measuring systems by means of a thermocuple. The temperature of the climate chamber has been regulated, so that the gas temperature at the analysers was 0 °C. To check the 30 °C gas temperature the gas was transmitted to the analyser through a tempered heating cable instead of the hose bundle.

## 7.4 Evaluation

*Table 19: Sensitivity coefficient to sample gas temperature*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| sensitivity coeff. sample gas temperature $b_{gt}$ [nmol/mol/K] | - | 0,01 | ✓ | 0,01 | ✓ |

## 7.5 Assessment

For system 1, the sensitivity coefficient to sample gas temperature von 0,01 nmol/mol/K).
For system 2, the sensitivity coefficient to sample gas temperature is 0,01 nmol/mol/K).
Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

*Table 20: Individual values obtained from the determination of the influence of sample gas temperature for $NO_2$*

| time | temp [ºC] | concentration | device 1 [nmol/mol] | device 2 [nmol/mol] |
|---|---|---|---|---|
| 16:15:00 | 0 | 196,13 | 188,85 | 190,05 |
| 16:16:00 | 0 | 196,13 | 188,96 | 190,65 |
| 16:17:00 | 0 | 196,13 | 188,76 | 190,68 |
| average $C_{GT,1}$ | | | 188,86 | 190,46 |
| 18:10:00 | 30 | 196,13 | 188,69 | 190,75 |
| 18:11:00 | 30 | 196,13 | 189,23 | 190,65 |
| 18:12:00 | 30 | 196,13 | 189,54 | 190,69 |
| average $C_{GT,2}$ | | | 189,15 | 190,70 |

## 7.1 8.4.9 Sensitivity coefficient to the surrounding temperature

The sensitivity coefficient to the surrounding temperature must be≤ 3,0 nmol/mol/K (= 5,76 µg/m³/K).

## 7.2 Test procedure

The sensitivity of the analyser readings to the surrounding temperature shall be determined by performing measurements at the following temperatures (within the specifications of the manufacturer):

1) at the minimum temperature $T_{min}$ = 0 °C;
2) at the temperature within the laboratory $T_l$ = 20 °C;
3) at the maximum temperature $T_{max}$ = 30 °C;

For these tests, a climatic chamber is necessary.

A concentration around 70 % to 80 % of the maximum of the certification range of NO shall be applied. At each temperature setting after waiting the time equivalent to one independent measurement, three individual measurements at zero and at span shall be recorded.

The sequence of test temperatures is as follows:

$T_l$, $T_{min}$, $T_l$ and $T_l$, $T_{max}$, $T_l$

At the first temperature ($T_l$), the analyser shall be adjusted at zero and at span level (70 % to 80 % of the maximum of the certification range).Then three individual measurements are recorded after waiting the time equivalent to one independent reading at $T_l$, at $T_{min}$ and again at $T_l$. This measurement procedure shall be repeated at the temperature sequence of $T_l$, $T_{max}$ and $T_l$.

In order to exclude any possible drift due to factors other than temperature, the measurements at $T_l$ are averaged, which is taken into account in the following formula for calculation of the sensitivity coefficient for temperature dependence:

$$b_{st} = \left| \frac{x_T - \frac{x_1 + x_2}{2}}{T_S - T_{S,0}} \right|$$

where

$b_{st}$ is the surrounding temperature sensitivity coefficient

$x_T$ is the average of the measurements at $T_{min}$ or $T_{max,}$

$x_1$ is the first average of the measurements at $T_{1,}$

$x_2$ is the second average of the measurements at $T_{1,}$

$T_S$ is the extreme surrounding temperature at which the test is performed in the laboratory

$T_{S,0}$ is the average of the surrounding temperatures at set point

For reporting the surrounding temperature dependence the higher value is taken of the two calculations of the temperature dependence at $T_{S,1}$ oder $T_{S,2}$.

$b_{st}$ shall meet the performance criterion specified above.

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211.

## 7.4 Evaluation

The following sensitivity coefficients to the surrounding temperature resulted from the tests:

*Table 21: Sensitivity coefficient to the surrounding temperature at zero point and at reference point, systems 1 and 2*

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| sensitivity coefficient at 0 ºC for zero level [nmol/mol/K] | ≤ 3,0 | 0,001 | ✓ | 0,003 | ✓ |
| sensitivity coefficient at 30 ºC for zero level [nmol/mol/K] | ≤ 3,0 | 0,016 | ✓ | 0,021 | ✓ |
| sensitivity coefficient at 0 ºC for span level [nmol/mol/K] | ≤ 3,0 | 0,097 | ✓ | 0,136 | ✓ |
| sensitivity coefficient at 30 ºC for span level [nmol/mol/K] | ≤ 3,0 | 0,088 | ✓ | 0,143 | ✓ |

As illustrated in Table 21 the sensitivity coefficient to the surrounding temperature at zero point and at span point complies with the performance criteria.

## 7.5 Assessment

The sensitivity coefficient to the surrounding temperature does not exceed the performance criteria of max. 3.0 nmol/mol/K. For both systems, the highest value $b_{st}$ is used for the purpose of evaluating uncertainty. For system 1 it is 0,097 nmol/mol/K and for system 2 0,143 nmol/mol/K.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Individual results of the tests are detailed in Table 22.

*Table 22: Individual results of the test of the sensitivity coefficient to the surrounding temperature for $NO_2$*

| | zero level | | | | span level | | | |
|---|---|---|---|---|---|---|---|---|
| | | | device 1 | device 2 | | | device 1 | device 2 |
| date | time | temp [ºC] | [nmol/mol] | [nmol/mol] | time | temp [ºC] | [nmol/mol] | [nmol/mol] |
| 05.06.2014 | 07:30:00 | 20 | 0,1 | 0,1 | 07:45:00 | 20 | 188,0 | 185,8 |
| 05.06.2014 | 07:31:00 | 20 | 0,1 | 0,1 | 07:46:00 | 20 | 188,1 | 185,9 |
| 05.06.2014 | 07:32:00 | 20 | 0,0 | 0,1 | 07:47:00 | 20 | 188,4 | 186,1 |
| average ($X_{1(TS1)}$) | | | 0,1 | 0,1 | | | 188,2 | 186,0 |
| 05.06.2014 | 15:55:00 | 0 | 0,1 | 0,2 | 16:10:00 | 0 | 189,8 | 182,8 |
| 05.06.2014 | 15:56:00 | 0 | 0,1 | 0,2 | 16:11:00 | 0 | 189,8 | 182,9 |
| 05.06.2014 | 15:57:00 | 0 | 0,1 | 0,2 | 16:12:00 | 0 | 189,8 | 182,9 |
| average($X_{Ts,1}$) | | 0 | 0,1 | 0,2 | | | 189,8 | 182,9 |
| 06.06.2014 | 07:30:00 | 20 | 0,1 | 0,1 | 07:45:00 | 20 | 187,3 | 185,0 |
| 06.06.2014 | 07:31:00 | 20 | 0,1 | 0,1 | 07:46:00 | 20 | 187,6 | 185,3 |
| 06.06.2014 | 07:32:00 | 20 | 0,1 | 0,1 | 07:47:00 | 20 | 187,9 | 185,5 |
| average ($X_{2(TS1)}$) = ($X_{1(TS2)}$) | | | 0,1 | 0,1 | | | 187,6 | 185,3 |
| 06.06.2014 | 15:05:00 | 30 | 0,0 | -0,1 | 15:20:00 | 30 | 186,5 | 184,1 |
| 06.06.2014 | 15:06:00 | 30 | -0,1 | -0,1 | 15:21:00 | 30 | 186,7 | 184,3 |
| 06.06.2014 | 15:07:00 | 30 | -0,1 | -0,1 | 15:22:00 | 30 | 187,0 | 184,5 |
| average($X_{Ts,2}$) | | | -0,1 | -0,1 | | | 186,7 | 184,3 |
| 07.06.2014 | 08:45:00 | 20 | 0,1 | 0,1 | 09:00:00 | 20 | 187,6 | 186,0 |
| 07.06.2014 | 08:46:00 | 20 | 0,1 | 0,1 | 09:01:00 | 20 | 187,6 | 186,3 |
| 07.06.2014 | 08:47:00 | 20 | 0,1 | 0,1 | 09:02:00 | 20 | 187,8 | 186,4 |
| average ($X_{2(TS2)}$) | | | 0,1 | 0,1 | | | 187,7 | 186,2 |

## 7.1 8.4.10 Sensitivity coefficient to electrical voltage

*The sensitivity coefficient to electrical voltage shall not exceed 0.30 nmol/mol/V (i.e. 0.38 µg/m³/V).*

## 7.2 Test procedure

The sensitivity coefficient of electrical voltage shall be determined at both ends of the voltage range specified by the manufacturer at zero concentration and at a concentration around 70 % to 80 % of the maximum of the certification range. After waiting the time equivalent to one independent measurement, three individual measurements at each voltage and concentration level shall be recorded.

The voltage dependence in accordance with standard EN 14211 is calculated from:

$$b_v = \left| \frac{(C_{V2} - C_{V1})}{(V_2 - V_1)} \right|$$

where

$b_v$ is the voltage sensitivity coefficient

$C_{V1}$ is the average concentration reading of the measurements at voltage $V_1$

$C_{V2}$ is the average concentration reading of the measurements at voltage $V_2$

$V_1$ is the minimum voltage $V_{min}$

$V_2$ is the maximum voltage $V_{max}$

For reporting the dependence on voltage, the higher value of the result at zero and span level shall be taken.

$b_v$ shall meet the performance criterion specified above.

## 7.3 Testing

For the purpose of testing the voltage sensitivity coefficient, a transformer was interposed between the analyser and the voltage supply. Sample gas was fed at various voltages at zero and span point.

## 7.4 Evaluation

The following sensitivity coefficients to electrical voltage resulted from the tests:

*Table 23:* Sensitivity coefficient to electrical voltage at zero point and at span point

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| sensitivity coeff. of voltage $b_v$ at zero level [nmol/mol/V] | - | 0,001 | ✓ | 0,002 | ✓ |
| sensitivity coeff. of voltage $b_v$ at span level [nmol/mol/V] | - | 0,003 | ✓ | 0,004 | ✓ |

## 7.5 Assessment

The sensitivity coefficient of electrical voltage $b_v$ does not exceed the performance criteria of max. 0.30 nmol/mol/V stipulated in Standard EN 14211 at any point. For both systems, the highest value $b_v$ is used for the purpose of evaluating uncertainty. For system 1 it is 0,003 nmol/mol/V and for system 2 it is 0,004 nmol/mol/V.

Does this comply with the performance criterion? Yes

## 7.6 Detailed presentation of test results

*Table 24: Individual results of sensitivity coefficient to electrical voltage*

| time | voltage [V] | concentration | device 1 [nmol/mol] | device 2 [nmol/mol] |
|---|---|---|---|---|
| 13:41:00 | 198 | 0 | -0,08 | -0,10 |
| 13:42:00 | 198 | 0 | -0,13 | -0,16 |
| 13:43:00 | 198 | 0 | -0,18 | -0,05 |
| average $C_{V1}$ at 0 | | | -0,13 | -0,10 |
| 14:13:00 | 264 | 0 | -0,23 | -0,21 |
| 14:14:00 | 264 | 0 | -0,21 | -0,21 |
| 14:15:00 | 264 | 0 | -0,23 | -0,21 |
| average $C_{V2}$ at 0 | | | -0,23 | -0,21 |
| 13:55:00 | 198 | 196,13 | 186,56 | 185,49 |
| 13:56:00 | 198 | 196,13 | 186,56 | 185,57 |
| 13:57:00 | 198 | 196,13 | 186,64 | 185,62 |
| average $C_{V1}$ at Span | | | 186,59 | 185,56 |
| 14:29:00 | 264 | 196,13 | 186,69 | 185,78 |
| 14:30:00 | 264 | 196,13 | 186,72 | 185,75 |
| 14:31:00 | 264 | 196,13 | 186,88 | 185,86 |
| average $C_{V2}$ at Span | | | 186,76 | 185,80 |

## 7.1 8.4.11 Interferents

*Interferents at zero concentration and at an NO concentration$c_t$ (at the level of the hourly limit = 104 nmol/mol für $NO_2$). Maximum responses for the interferent components $H_2O$, $CO_2$ and $NH_3$ are ≤ 5,0 nmol/mol (= 9,6µg/m³ each).*

## 7.2 Test procedure

The analyser response to certain interferents, which are to be expected to be present in ambient air, shall be tested. The interferents can give a positive or negative response. Testing is performed at zero and at an $NO_2$ sample gas concentration ($c_t$), similar to the 1-hour limit value (104 nmol/mol).

The concentration of the mixtures of the test gases with the interferent shall have an expanded uncertainty of ≤ 5 % and shall be traceable to nationally accepted standards. The interferents to be tested and their respective concentrations are given in Table 25. The influence of each interferent shall be determined separately. A correction on the concentration of the measurand shall be made for the dilution effect due to addition of an interferent (e.g. water vapour).

After adjustment of the analyser at zero and span level, the analyser shall be fed with a mixture of zero gas and the interferent to be investigated with the concentration as given in Table 25. With this mixture, one independent measurement followed by two individual measurements shall be carried out. This procedure shall be repeated with a mixture of the measurand at concentration $c_t$ and the interferent to be investigated. The influence quantity at zero and concentration $c_t$ is calculated from:

$$X_{\text{int},z} = x_z$$

$$X_{\text{int},ct} = x_{ct} - c_t$$

where:

$X_{\text{int},z}$ is the influence quantity of the interferent at zero,

$x_z$ is the average of the measurements at zero,

$X_{\text{int},ct}$ is the influence quantity of the interferent at concentration $c_t$,

$x_{ct}$ is the average of the measurements at concentration $c_t$,

$c_t$ is the concentration of the gas applied at a level of the hourly limit,

The influence quantities of the interferents shall comply with the performance criteria as stated above, both at zero and at concentration $c_t$.

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211. The systems were adjusted to zero concentration and to the concentration (104nmol/mol). Zero and test gas with various interferents were then applied. Interferents and their respective concentrations used during testing are provided in Table 25.

*Table 25: Interferents according to EN 14211*

| Interferent | Concentration |
|---|---|
| $H_2O$ | 19 mmol/mol |
| $CO_2$ | 500 µmol/mol |
| $NH_3$ | 200 nmol/mol |

## 7.4 Evaluation

The following table lists the response levels of individual interferents.

*Table 26: Influence of the interferents tested ($c_t$ = 104 nmol/mol)*

| | requirements | **device 1** | | **device 2** | |
|---|---|---|---|---|---|
| influence quantity interferent $H_2O$ at cero [nmol/mol/V] | ≤ 5.0 nmol/mol | 0,12 | ✓ | 0,22 | ✓ |
| influence quantity interferent $H_2O$ at $c_t$ [nmol/mol/V] | ≤ 5.0 nmol/mol | -1,83 | ✓ | -1,67 | ✓ |
| influence quantity interferent $CO_2$ at cero [nmol/mol/V] | ≤ 5.0 nmol/mol | 0,44 | ✓ | 0,47 | ✓ |
| influence quantity interferent $CO_2$ at $c_t$ [nmol/mol/V] | ≤ 5.0 nmol/mol | 1,33 | ✓ | 1,09 | ✓ |
| influence quantity interferent $NH_3$ at cero [nmol/mol/V] | ≤ 5.0 nmol/mol | -0,03 | ✓ | 0,03 | ✓ |
| influence quantity interferent NH3 at $c_t$ [nmol/mol/V] | ≤ 5.0 nmol/mol | 0,29 | ✓ | 0,17 | ✓ |

## 7.5 Assessment

Cross-sensitivity at zero point 0,12 nmol/mol for system 1 and 0,22 nmol/mol for system 2 for $H_2O$, 0,40 nmol/mol for system 1 and 0,47 nmol/mol for system 2 for $CO_2$ and -0,03 nmol/mol for system 1 and 0,03 nmol/mol for system 2 for $NH_3$.

Cross-sensitivity at the limit value -1,83 nmol/mol for system 1 and -1,67 nmol/mol for system 2 for $H_2O$, 1,33 nmol/mol for system 1 and 1,09 nmol/mol for system 2 for $CO_2$ and 0,29 nmol/mol for system 1 and 0,17 nmol/mol for $NH_3$.

Does this comply with the performance criterion? Yes

## 7.6 Detailed presentation of test results

Table 27 states the individual test results.

*Table 27: Individual readings for each interferent*

| | without interferents | | | with interferents | | |
|---|---|---|---|---|---|---|
| | time | device 1 | device 2 | time | device 1 | device 2 |
| zero gas + $H_2O$ (19 mmol/mol) | 16:00:00 | 0,02 | 0,03 | 16:10:00 | 0,14 | 0,23 |
| | 16:01:00 | 0,03 | 0,03 | 16:11:00 | 0,15 | 0,25 |
| | 16:02:00 | 0,03 | 0,04 | 16:12:00 | 0,17 | 0,27 |
| | average $x_z$ | 0,03 | 0,03 | average $x_z$ | 0,15 | 0,25 |
| test gas $c_t$ + $H_2O$ (19 mmol/mol) | 16:25:00 | 103,83 | 103,37 | 16:40:00 | 101,97 | 101,81 |
| | 16:26:00 | 103,89 | 103,52 | 16:41:00 | 102,03 | 101,77 |
| | 16:27:00 | 103,85 | 103,48 | 16:42:00 | 102,08 | 101,79 |
| | average $x_{ct}$ | 103,86 | 103,46 | average $x_{ct}$ | 102,03 | 101,79 |
| zero gas + $CO_2$ (500 µmol/mol) | 13:30:00 | -0,06 | -0,01 | 13:45:00 | 0,37 | 0,47 |
| | 13:31:00 | -0,07 | -0,01 | 13:46:00 | 0,37 | 0,45 |
| | 13:32:00 | -0,08 | -0,03 | 13:47:00 | 0,36 | 0,43 |
| | average $x_z$ | -0,07 | -0,02 | average $x_z$ | 0,37 | 0,45 |
| test gas $c_t$ + $CO_2$ (500 µmol/mol) | 14:00:00 | 103,88 | 102,93 | 14:15:00 | 105,28 | 104,02 |
| | 14:01:00 | 103,98 | 102,94 | 14:16:00 | 105,29 | 104,04 |
| | 14:02:00 | 104,00 | 102,98 | 14:17:00 | 105,29 | 104,05 |
| | average $x_{ct}$ | 103,95 | 102,95 | average $x_{ct}$ | 105,29 | 104,04 |
| zero gas + $NH_3$ (200 nmol/mol) | 14:45:00 | -0,43 | -0,28 | 14:55:00 | -0,47 | -0,25 |
| | 14:46:00 | -0,44 | -0,28 | 14:56:00 | -0,49 | -0,25 |
| | 14:47:00 | -0,46 | -0,28 | 14:57:00 | -0,47 | -0,25 |
| | average $x_z$ | -0,44 | -0,28 | average $x_z$ | -0,48 | -0,25 |
| test gas $c_t$ + $NH_3$ (200 nmol/mol) | 15:15:00 | 104,27 | 103,10 | 15:30:00 | 104,42 | 103,27 |
| | 15:16:00 | 103,77 | 103,10 | 15:31:00 | 104,39 | 103,25 |
| | 15:17:00 | 104,30 | 103,06 | 15:32:00 | 104,40 | 103,25 |
| | average $x_{ct}$ | 104,40 | 103,09 | average $x_{ct}$ | 104,40 | 103,25 |

## 7.1 8.4.12 Averaging test

*The influence of averaging shall not exceed 7% of the instrument reading.*

## 7.2 Test procedure

The averaging test gives a measure of the uncertainty in the averaged values caused by short-term concentration variations in the sampled air shorter than the time scale of the measurement process in the analyser. In general, the output of an analyser is a result of the determination of a reference concentration (normally zero) and the actual concentration which takes a certain time.

For the determination of the uncertainty due to averaging, the following concentrations are applied to the analyser and readings are taken at each concentration.

- a constant concentration of $NO_2$ at a concentration $c_{t,NO\ 2}$ which is about twice the hourly limit value; and
- a stepwise varied concentration of NO between zero and 600 nmol/mol (concentration $c_{t,NO}$).

The time period ($t_c$) of the constant NO concentration shall be at least equal to a period necessary to obtain four independent readings (which is equal to at least sixteen response times). The time period ($t_v$) of the varying NO concentration shall be at least equal to a period to obtain four independent readings. The time period ($t_{NO}$) for the NO concentration shall be 45 s followed by a period ($t_{zero}$) of 45 s of zero concentration.

Further:

$c_t$ is the test concentration,

$t_v$ is a time period including a whole number of $t_{NO}$- and $t_{zero}$-pairs (a minimum of 3 such pairs)

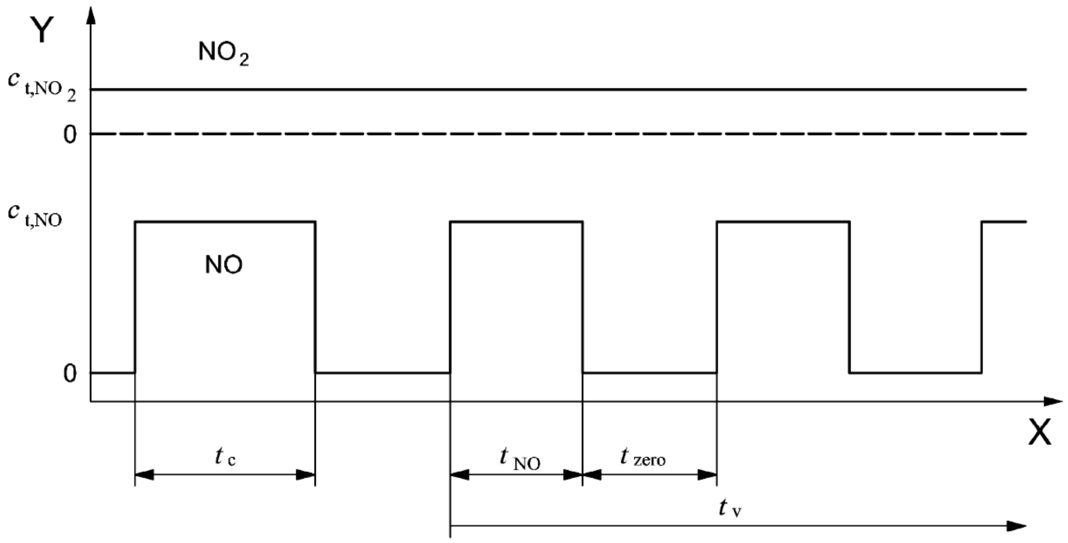
The change from $t_{NO}$ to $t_{zero}$ shall be within 0,5 s. The change from $t_C$ to $t_V$ shall be within one response time of the analyser under test.

The averaging effect ($E_{av}$) is calculated according to:

$$E_{av} = \frac{C_{const}^{av} - 2C_{var}^{av}}{C_{const}^{av}} * 100$$

Where:

| | |
|---|---|
| $E_{av}$ | is the averaging effect (in %), |
| $C_{const}^{av}$ | is the average of the at least four independent measurements during the constant concentration period |
| $C_{var}^{av}$ | is the average of the at least four independent measurements during the variable concentration period |




**Legende**
Y Konzentration (nmol/mol)
X Zeit

*Figure 10: Concentration variation for the averaging test (tNO = tzero = 45 s)*

## 7.3 Testing

The averaging test was performed in accordance with the requirements on testing as stipulated in EN 14211. Since the system under test measures $NO_2$ directly, the test was performed by means of a step change in $NO_2$ concentration between zero and a concentration of $c_t$ (104 nmol/mol). First, the average was calculated at a constant concentration of test gas. Then, an alternating change between zero and test gas every 45 s was established using a three-way valve. For the period of alternating test gas application, the average was calculated as well.

## 7.4 Evaluation

The following averages were obtained during testing:

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| averaging effect $E_{av}$ [%] | ≤ 7% | -2,31 | ✓ | -2,08 | ✓ |

This results in the following averaging effects:

System 1: -2,31 %

System 2: -2,08 %

## 7.5 Assessment

This is in complete compliance with the performance criteria stipulated in Standard EN 14211.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Table 28 provides the individual results for the averaging test.

*Table 28: Individual results of the averaging test*

| | time | device 1 [nmol/mol] | device 2 [nmol/mol] |
|---|---|---|---|
| average constant concentration $C_{av,c}$ | 09:30:00 till 09:55:00 | 103,2 | 103,0 |
| average variable concentration $C_{av,c}$ | 09:55:00 till 10:18:00 | 54,6 | 53,5 |

| | time | device 1 [nmol/mol] | device 2 [nmol/mol] |
|---|---|---|---|
| average constant concentration $C_{av,c}$ | 10:20:00 till 10:45:00 | 103,4 | 103,3 |
| average variable concentration $C_{av,c}$ | 10:45:00 till 11:05:00 | 53,3 | 54,4 |

| | time | device 1 [nmol/mol] | device 2 [nmol/mol] |
|---|---|---|---|
| average constant concentration $C_{av,c}$ | 12:50:00 till 13:10:00 | 103,4 | 103,0 |
| average variable concentration $C_{av,c}$ | 13:10:00 till 13:30:00 | 50,6 | 50,1 |

## 7.1 8.4.13 Difference sample/calibration port

*The difference between sample and calibration port must be maximum ≤ 1,0 %.*

## 7.2 Test procedure

If the analyser has different ports for feeding sample gas and calibration gas, the difference in response of the analyser to feeding through the sample or calibration port shall be tested. The test shall be carried out by feeding the analyser with a test gas with a concentration of 70 % to 80 % of the maximum of the certification range through the sample port. The test shall consist of one independent measurement followed by two individual measurements. After a period of at least four response times, the test shall be repeated using the calibration port. The difference shall be calculated according to:

$$\Delta_{SC} = \frac{x_{sam} - x_{cal}}{c_t} \times 100$$

where

| | |
|---|---|
| $\Delta_{SC}$ | is the difference sample/calibration port; |
| $x_{sam}$ | is the average of the measured concentration using the sample port; |
| $x_{cal}$ | is the average of the measured concentration using the calibration port; |
| $c_t$ | is the concentration of the test gas; |
| $\Delta_{SC}$ | shall meet the performance criterion specified above. |

## 7.3 Testing

The test was performed in accordance with the requirements on testing as stipulated in EN 14211. For test gas feeding the path was controlled by means of a three-way valve between sample and calibration gas port.

## 7.4 Evaluation

The following differences between sample and calibration gas point were determined:

| | requirements | device 1 | | device 2 | |
|---|---|---|---|---|---|
| difference sample/calibration port $\Delta x_{cs}$ [%] | ≤ 1% | -0,14 | ✓ | -0,17 | ✓ |

## 7.5 Assessment

This is in complete compliance with the performance criteria stipulated in Standard EN 14211.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Individual results are provided in Table *29*.

*Table 29: Individual results for the difference between sample and calibration port*

| | | device 1 | device 2 |
|---|---|---|---|
| | time | [nmol/mol] | [nmol/mol] |
| calibration port | 09:50:00 | 201,2 | 199,9 |
| | 09:51:00 | 201,2 | 199,8 |
| | 09:52:00 | 201,5 | 200,0 |
| sample port | 10:10:00 | 201,6 | 200,2 |
| | 10:11:00 | 201,7 | 200,2 |
| | 10:12:00 | 201,5 | 200,2 |

## 7.1 8.4.14 Converter efficiency

*Converter efficiency must be at least 98 %.*

## 7.2 Test procedure

The converter efficiency is determined by measurements with known amounts of $NO_2$. This can be achieved by means of gas-phase titration of NO to $NO_2$ with ozone.

The test shall be performed at two concentration levels: at about 50 % and about 95 % of the maximum of the certification range of $NO_2$.

The $NO_x$ measuring system shall be calibrated via the NO and $NO_x$ channel, feeding an NO concentration of about 70 % to 80 % of the maximum of the certification range of NO. Both channels have to be adjusted in such a way that they display identical values. These values shall be recorded.

A known NO concentration of about 50 % of the maximum of the certification range of NO shall be applied until a stable reading is reached. This stable period shall extend over at least four response times. Four individual measurements are taken at the NO and at the $NO_X$ channel. $O_3$ then oxidises NO to generate $NO_2$. This mixture at a constant concentration of $NO_X$ is fed to the analyser until the output signal is stable. This stable period shall extend over a minimum of four response times. The NO concentration after the gas-phase titration shall be between 10 % and 20 % of the original concentration of NO. Subsequently, four individual measurements are taken at the channels for NO and $NO_X$. The supply with O3 is then interrupted and only NO is fed to the analyser until the output signal is stable. This stable period shall be equivalent to at least four response times. It is then verified whether the average of the four individual measurements at the channels for NO and $NO_X$ are identical to the original values. Potential deviations shall not exceed 1 %.

The converter efficiency is calculated from:

$$E_{conv} = \left(1 - \frac{(NO_x)_i - (NO_x)_f}{(NO)_i - (NO)_f}\right) \times 100\%$$

where

$E_{conv}$ is the converter efficiency in %;

$(NO_x)_i$ is the average of the four individual measurements at the $NO_X$ channel at the initial $NO_X$ concentration

$(NO_x)_f$ is the average of the four individual measurements at the $NO_X$ channel at the resulting $NO_X$ concentration after applying $O_3$

$(NO)_i$ is the average of the four individual measurements at the NO channel at the resulting NO concentration at the initial NO concentration

$(NO)_f$ is the average of the four individual measurements at the NO channel at the resulting NO concentration after applying $O_3$ in nmol/mol.

The lowest value of the two converter efficiencies shall be reported.

## 7.3 Testing

The T500U does not use a converter. $NO_2$ is measured directly.

## 7.4 Evaluation

Not applicable in this instance.

## 7.5 Assessment

The T500U does not use a converter. Daher ist dieser Prüfpunkt hier nicht relevant.

Does this comply with the performance criterion? -

## 7.6 Detailed presentation of test results

Not applicable in this instance.

## 7.1 8.4.15 Residence time in the analyser

*The residence time in the analyser must be maxium ≤ 3,0 s.*

## 7.2 Test procedure

The residence time inside the analyser shall be calculated on the basis of the flow and volumes of the tubing and other relevant components inside the analyser.

## 7.3 Testing

The gas volume of the T500U analyser is 37,0 ml from sample inlet to the measuring cell. The nominal sample gas volume flow is 0,9 l/min. This results in a residence time inside the analyser of 2.5 s.

## 7.4 Evaluation

Not applicable in this instance.

## 7.5 Assessment

The residence time inside the analyser is 2.5 s.

Does this comply with the performance criterion? Yes

## 7.6 Detailed presentation of test results

Not applicable in this instance.

## 7.1 8.5.4 Long term drift

*The long term drift at zero shall not exceed 5.0 nmol/mol (i.e. 9.36 µg/m³).*
*The long term drift at span level shall not exceed 5 % of the certification range (i.e. 25 µg/m³ in a measuring range of 0 to 500 µg/m³).*

## 7.2 Test procedure

After each bi-weekly calibration, the drift of the analysers under test shall be calculated at zero and at span following the procedures as given underneath. If the drift compared to the initial calibration exceeds one of the performance criteria for drift at zero or span level the "period of unattended operation" equals the number of weeks until the observation of the infringement, minus two weeks. For further (uncertainty) calculations, the values for "long term drift" are the values for zero and span drift over the period of unattended operation.

The long term drift is calculated as follows:

$$D_{L,Z} = (C_{Z,1} - C_{Z,0})$$

where:

$D_{L,Z}$ is the drift at zero,

$C_{Z,0}$ is the average concentration of the measurements at zero at the beginning of the drift period

$C_{Z,1}$ is the average concentration of the measurements at zero at the end of the drift period

$D_{L,Z}$ shall meet the performance criterion as specified above.

$$D_{L,S} = \frac{(C_{S,1} - C_{S,0}) - D_{L,Z}}{C_{S,1}} \times 100$$

where

$D_{L,S}$ is the drift at span concentration

$C_{S,0}$ is the average concentration of the measurements at span level at the beginning of the drift period

$C_{S,1}$ is the average concentration of the measurements at span level at the end of the drift period

$D_{L,S}$ shall meet the performance criterion as specified above.

## 7.3 Testing

For the purpose of the test, test gas was applied every 2 weeks. Table 30 and Table 31 list the results of this biweekly test gas application.

## 7.4 Evaluation

*Table 30: Results for the long term drift at zero for the component $NO_2$*

| | | Device 1 (63) [nmol/mol] | Device 2 (65) [nmol/mol] |
|---|---|---|---|
| $C_{Z,0}$ | 20.06.2014 | 0,04 | -0,05 |
| | | | |
| $C_{Z,1}$ | 04.07.2014 | 0,11 | 0,02 |
| **$D_{L,Z}$** | **04.07.2014** | **0,07** | **0,07** |
| $C_{Z,1}$ | 17.07.2014 | 0,24 | 0,08 |
| **$D_{L,Z}$** | **17.07.2014** | **0,20** | **0,13** |
| $C_{Z,1}$ | 31.07.2014 | 0,21 | 0,06 |
| **$D_{L,Z}$** | **31.07.2014** | **0,17** | **0,11** |
| $C_{Z,1}$ | 14.08.2014 | 0,16 | 0,15 |
| **$D_{L,Z}$** | **14.08.2014** | **0,12** | **0,20** |
| $C_{Z,1}$ | 29.08.2014 | 0,29 | 0,19 |
| **$D_{L,Z}$** | **29.08.2014** | **0,25** | **0,24** |
| $C_{Z,1}$ | 12.09.2014 | 0,34 | 0,04 |
| **$D_{L,Z}$** | **12.09.2014** | **0,30** | **0,09** |
| $C_{Z,1}$ | 22.09.2014 | 0,22 | 0,23 |
| **$D_{L,Z}$** | **22.09.2014** | **0,18** | **0,28** |

*Table 31: Results for the long term drift at reference point for the component $NO_2$*

| | | Device 1 (63) [nmol/mol] | Device 2 (65) [nmol/mol] |
|---|---|---|---|
| $C_{S,0}$ | 20.06.2014 | 205,2 | 205,6 |
| | | | |
| $C_{S,1}$ | 04.07.2014 | 205,2 | 205,9 |
| **$D_{L,S}$** | **04.07.2014** | **0,00%** | **0,11%** |
| $C_{S,1}$ | 17.07.2014 | 204,9 | 205,6 |
| **$D_{L,S}$** | **17.07.2014** | **-0,25%** | **-0,06%** |
| $C_{S,1}$ | 31.07.2014 | 204,8 | 204,9 |
| **$D_{L,S}$** | **31.07.2014** | **-0,25%** | **-0,42%** |
| $C_{S,1}$ | 14.08.2014 | 204,5 | 204,6 |
| **$D_{L,S}$** | **14.08.2014** | **-0,38%** | **-0,62%** |
| $C_{S,1}$ | 29.08.2014 | 204,0 | 205,4 |
| **$D_{L,S}$** | **29.08.2014** | **-0,68%** | **-0,23%** |
| $C_{S,1}$ | 12.09.2014 | 203,5 | 202,7 |
| **$D_{L,S}$** | **12.09.2014** | **-0,98%** | **-1,48%** |
| $C_{S,1}$ | 22.09.2014 | 202,1 | 202,2 |
| **$D_{L,S}$** | **22.09.2014** | **-1,58%** | **-1,82%** |

## 7.5 Assessment

The maximum long term drift at zero Nullpunkt $D_{l,z}$ is 0,30 nmol/mol for system 1 and 0,28 nmol/mol for system 2. The maximum long term drift at span point $D_{l,s}$ is -1,58 % for system 1 and -1,82 % for system 2.

Does this comply with the performance criterion? Yes

## 7.6 Detailed presentation of the test results

The individual results of the determination of long term drift behaviour are provided in Table 32.

*Table 32: Individual results of drift tests*

| Date | Time | Device 1 (63) | Device 2 (65) | Time | Device 1 (63) | Device 2 (65) |
|---|---|---|---|---|---|---|
| | Zero point | | | Span point | | |
| | [hh:mm] | [nmol/mol] | [nmol/mol] | [hh:mm] | [nmol/mol] | [nmol/mol] |
| 20.06.2014 | 09:15 | 0,05 | -0,02 | 12:25 | 205,1 | 205,5 |
| 20.06.2014 | 09:20 | 0,05 | -0,05 | 12:30 | 205,2 | 205,6 |
| 20.06.2014 | 09:25 | 0,01 | -0,06 | 12:30 | 205,2 | 205,7 |
| 20.06.2014 | 09:30 | 0,01 | -0,05 | 12:25 | 205,1 | 205,7 |
| 20.06.2014 | 09:35 | 0,06 | -0,05 | 12:20 | 205,1 | 205,6 |
| **Average** | | **0,04** | **-0,05** | | **205,2** | **205,6** |
| 04.07.2014 | 13:15 | 0,11 | 0,02 | 12:45 | 205,2 | 205,9 |
| 17.07.2014 | 15:20 | 0,24 | 0,08 | 10:00 | 204,9 | 205,6 |
| 31.07.2014 | 08:55 | 0,21 | 0,06 | 16:20 | 204,8 | 204,9 |
| 14.08.2014 | 12:10 | 0,16 | 0,15 | 16:45 | 204,5 | 204,6 |
| 29.08.2014 | 10:35 | 0,29 | 0,19 | 12:25 | 204,0 | 205,4 |
| 12.09.2014 | 10:40 | 0,34 | 0,04 | 13:45 | 203,5 | 202,7 |
| 22.09.2014 | 13:15 | 0,22 | 0,23 | 11:15 | 202,1 | 202,2 |

The measured values listed are averaging one independent measurement and four individual measurements.

## 7.1 8.5.5 Reproducibility standard deviation for NO2 under field conditions

*The reproducibility standard deviation under field conditions must be maximum ≤ 5 % of the average over a period of 3 months.*

## 7.2 Test procedure

The reproducibility standard deviation under field conditions is calculated from the measured hourly averaged data during the three-month period.

The difference $\Delta x_{f,i}$ for each i*th* parallel measurement is calculated from:

$$\Delta x_{f,i} = x_{f,1,i} - x_{f,2,i}$$

where

$\Delta x_{f,i}$ is the i*th* difference in a parallel measurement

$x_{f,1,i}$ is the i*th* measurement result of analyser 1

$x_{f,2,i}$ is the i*th* measurement result of analyser 2

The reproducibility standard deviation (under field conditions) is calculated according to:

$$s_{r,f} = \frac{\left(\sqrt{\frac{\sum_{i=1}^{n} \Delta x_{f,i}^2}{2*n}}\right)}{c_f} \times 100$$

where

$s_{r,f}$ is the reproducibility standard deviation for $NO_2$ under field conditions, in %;

$n$ is the number of parallel measurements;

$c_f$ is the average concentration of nitrogen dioxide measured during the field test, in nmol/mol.

The reproducibility standard deviation for $NO_2$ under field conditions, $s_{r,f}$ , shall meet the performance criterion as specified above.

## 7.3 Testing

Using the equations given above, the reproducibility standard deviation under field conditions was calculated from the data averaged hourly during the field test.

In order to demonstrate that the measuring system operates reliably at higher concentrations as well, the sample air was enriched with $NO_2$ from time to time.

## 7.4 Evaluation

*Table 33: Determination of the reproducibility standard deviation on the basis of all data collected during the field test*

| **Reproducibility standard deviation in the field** | | | | |
|---|---|---|---|---|
| Number of measurements | n | = | 2266 | |
| Average of both analysers | | = | 21,1 | nmol/mol |
| Standard deviation from paired measurements | sd | = | 0,256 | nmol/mol |
| **Reproducibility standard deviation (%)** | **Sr,f** | **=** | **1,21** | **%** |

The reproducibility standard deviation under field conditions is 1,21 % of the average.

## 7.5 Assessment

The reproducibility standard deviation for $NO_2$ was 1,21 % related to the average over a period of three months in the field. Hereby, the requirements of EN 14211 are met.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Figure 11 illustrates the reproducibility standard deviation under field conditions.

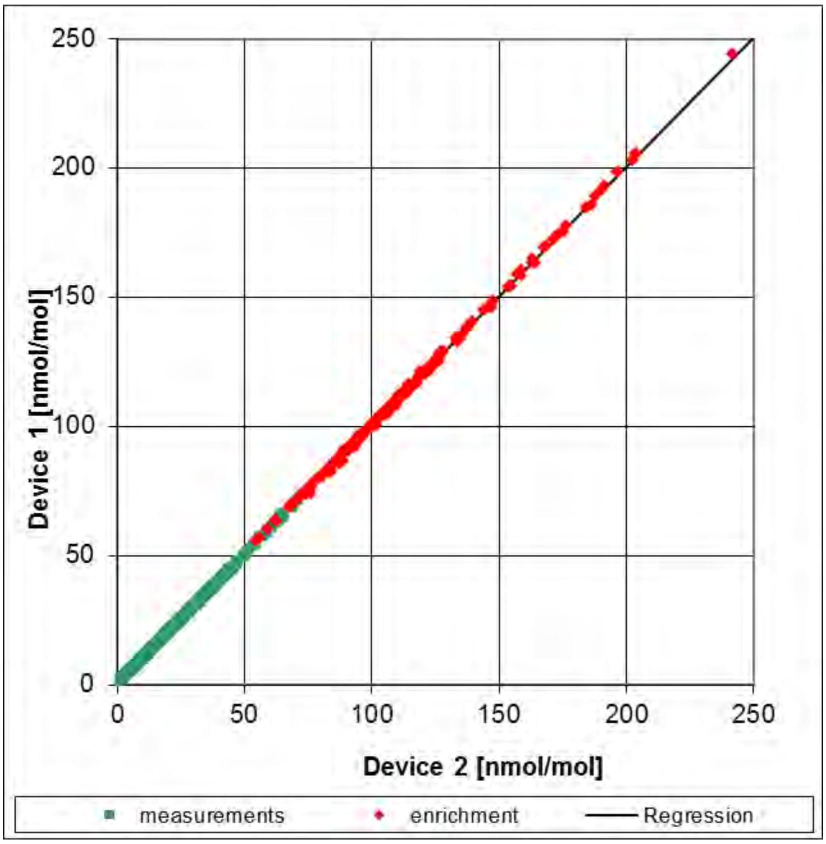



*Figure 11: Illustration of the reproducibility standard deviation under field conditions*

## 7.1 8.5.6 Period of unattended operation

*The maintenance interval shall be at least 2 weeks.*

## 7.2 Equipment

Not required for this criterion.

## 7.3 Testing

For this criterion, the tasks necessary to ensure proper functioning of the measuring system as well as the corresponding interval were identified. In determining the maintenance interval, the results of the drift tests at zero and span point according to 7.1 8.5.4 Long term drift were taken into consideration.

## 7.4 Evaluation

No excessive drift behaviour was observed during the entire period of the field test. The maintenance interval is therefore subject to the necessary maintenance tasks.

During operation, maintenance tasks may primarily be limited to contamination and plausibility checks as well as potential status signals and error warnings.

## 7.5 Assessment

The maintenance interval is subject to the necessary maintenance tasks and is 4 weeks.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Not applicable in this instance.

## 7.1 8.5.7 Availability of the analyser

*The availability oft the analyser must be at least ≥ 90 %.*

## 7.2 Test procedure

The correct operation of the analysers shall be checked at least every fourteen days. It is recommended to perform this check every day during the first fourteen days. These checks consists of plausibility checks on the measured values, as well as, when available, on status signals and other relevant parameters. Time, duration and nature of any malfunctioning shall be logged.

The total time period with useable measuring data is the period during the field test during which valid measuring data of the ambient air concentrations are obtained. In this time period, the time needed for calibrations, conditioning of sample systems and filters (6.3) and maintenance shall not be included.

Availability oft he analyser is:

$$A_a = \frac{t_u}{t_t} * 100$$

Where:

$A_a$ is the availability of the analyser (%);

$t_u$ is the total time period with validated measuring data;

$t_t$ is the time period of the field test minus the time for calibration, conditioning and maintenance;

$t_u$ and $t_t$ shall be expressed in the same units.

Availability shall satisfy the performance characteristics stated above.

## 7.3 Testing

Availability was calculated on the basis of periods for the field test and any outage times based on the equation stated above.

**Evaluation**

Table 34 lists down times during the field test.

*Tabelle 34: Availability of the T500U anaylser*

| | | System 1 | System 2 |
|---|---|---|---|
| Time in the field | h | 2274 | 2274 |
| Outage time | h | 0 | 0 |
| Maintenance | h | 8 | 8 |
| Total operating time | h | 2266 | 2266 |
| Total operating time incl. maintenance | h | 2274 | 2274 |
| Availability | % | 100 | 100 |

Maintenance times result from daily test gas feeding for the purpose of determining the drift behaviour and the maintenance interval as well as times required to change internal Teflon filters in the sample gas line.

## 7.5 Assessment

The availability is 100 %. This complies with the requirements of standard EN 14211.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Not applicable in this instance.

## 7.1 8.6 Total uncertainty in accordance with Annex E of EN 14211 (2012)

*The type approval of the analyser consists of the following steps*

1) *The value of each individual performance characteristic tested in the laboratory shall fulfil the criterion stated in Table E.1 of EN 14211.*
2) *The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory tests shall fulfil the criterion as stated in Annex I of Directive 2008/50/EC (15% for fixed measurements or 25% for indicative measurements). This criterion is the maximum uncertainty of hourly values of continuous measurements at the hourly limit value. The relevant specific performance characteristics and the calculation procedure are given inAnnex E of EN 14211.*
3) *The value of each of the individual performance characteristics tested in the field shall fulfil the criterion stated inTable E.1 of EN 14211.*
4) *The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests shall fulfil the criterion as stated in Annex I of Directive 2008/50/EC (15% for fixed measurements or 25% for indicative measurements). This criterion is the maximum uncertainty of hourly values of continuous measurements at the hourly limit value. The relevant specific performance characteristics and the calculation procedure are given in Annex E of EN 14211.*

## 7.2 Equipment

Total uncertainty calculation in accordance with Annex E of standard EN 14211 (2012).

## 7.3 Testing

At the end of the tests for type approval, total uncertainty was calculated using the values obtained from each individual test.

## 7.4 Evaluation

1) The value of each individual performance characteristic tested in the laboratory fulfils the criterion stated Table E.1 of EN 14211.
2) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained fulfils the criterion.
3) The value of each of the individual performance characteristics tested in the field fulfils the criterion stated inTable E.1 of standard EN 14211.
4) The expanded uncertainty calculated from the standard uncertainties due to the values of the specific performance characteristics obtained in the laboratory and field tests fulfils the criterion.

## 7.5 Assessment

The total uncertainty complies with the performance criteria.

Does this comply with the performance criterion? yes

## 7.6 Detailed presentation of test results

Table 35 summarises the results for items 1 and 3.

Table *36* and 38 state the results for item 2.

Table 37 and 39 list the results for item 4.

*Table 35: Performance criteria according to EN 14211*

| Performance characteristics | Criterion | Test result | Met | Page |
|---|---|---|---|---|
| 8.4.5 Repeatability standard deviation at zero | ≤ 1,0 nmol/mol | $S_r$ System 1: 0,07 nmol/mol<br>$S_r$ System 2: 0,05 nmol/mol | yes | 77 |
| 8.4.5 Repeatability standard deviationat the concentration ct | ≤ 3,0 nmol/mol | $S_r$ System 1: 0,25 nmol/mol<br>$S_r$ System 2: 0,15 nmol/mol | yes | 77 |
| 8.4.6 „lack of fit“ (deviation from the linear regression) | ≤ 4,0 % oft he measured value above zero<br>Deviation at zero point ≤ 5 nmol/mol | $X_{l,z}$ System 1: ZP -0,39 nmol/mol<br>$X_l$ System 1: RP 0,77 %<br>$X_{l,z}$ System 2: ZP -0,16 nmol/mol<br>$X_l$ System 2: RP 0,69 % | yes | 79 |
| 8.4.7 Sensitivity coefficient of the sample gas pressure | ≤ 8,0 nmol/mol/kPa | $b_{gp}$ System 1: 0,08 nmol/mol/kPa<br>$b_{gp}$ System 2: 0,16 nmol/mol/kPa | yes | 84 |
| 8.4.8 Sensitivity coefficient of the sample gas temperature | ≤ 3,0 nmol/mol/K | $b_{gt}$ System 1: 0,01 nmol/mol/K<br>$b_{gt}$ System 2: 0,01 nmol/mol/K | yes | 86 |
| 8.4.9 Sensitivity coefficient of the surrounding temperature | ≤ 3,0 nmol/mol/K | $b_{st}$ System 1: 0,097 nmol/mol/K<br>$b_{st}$ System 2: 0,143 nmol/mol/K | yes | 88 |
| 8.4.10 Sensitivity coefficient of electric voltage | ≤ 0,3 nmol/mol/V | $b_V$ System 1: RP 0,003 nmol/mol/V<br>$b_V$ System 2: RP 0,004 nmol/mol/V | yes | 93 |
| 8.4.11 Interferents at zero and concentration ct | $H_2O$<br>≤5,0 nmol/mol<br>$CO_2$<br>≤5,0 nmol/mol<br>$NH_3$<br>≤5,0 nmol/mol | $H_2O$<br>System 1: ZP 0,12 nmol/mol / RP-1,83 nmol/mol<br>System 2: ZP0,22 nmol/mol / RP -1,67 nmol/mol<br>$CO_2$<br>System 1: ZP 0,44 nmol/mol / RP1,33 nmol/mol<br>System 2: ZP 0,47 nmol/mol / RP1,09 nmol/mol<br>$NH_3$<br>System 1: ZP -0,03 nmol/mol / RP 0,29 nmol/mol<br>System 2: ZP 0,03 nmol/mol / RP 0,17 nmol/mol | yes | 93 |

| **Performance characteristic** | **Criterion** | **Test result** | **Met** | **Page** |
|---|---|---|---|---|
| 8.4.12 Averaging effect | ≤ 7,0 % oft he measurement | $E_{av}$ System 1: -2,31 %<br>$E_{av}$ System 2: -2,08 % | yes | 93 |
| 8.4.13 Difference sample/calibration port | ≤ 1,0 % | $\Delta_{SC}$ System 1: -0,14 %<br>$\Delta_{SC}$ System 2: -0,17 % | yes | 99 |
| 8.4.3 Response time (rise) | ≤ 180 s | $t_r$ System 1:21 s<br>$t_r$ System 2:22 s | yes | 69 |
| 8.4.3 Response time (fall) | ≤ 180 s | $t_f$ System 1: 22s<br>$t_f$ System 2:21 s | yes | 69 |
| 8.4.3 Difference between rise and fall | ≤ 10 % relative difference or 10s,depending on which is larger | $t_d$ System 1: -1 s<br>$t_d$ System 2: 1 s | yes | 69 |
| 8.4.14 Converter efficiency | ≥ 98 % | $E_{conv}$ System 1: ---<br>$E_{conv}$ System 2: --- | yes | 101 |
| 8.4.15 Residence in the analyser | ≤ 3,0 s | System 1: 2,5 s<br>System 2: 2,5 s | yes | 103 |
| 8.5.6 Period of unattended operation | 3 months or less acc. to manufacturer specifications, no less than 2 weeks | System 1: 4 Weeks<br>System 2: 4 Weeks | yes | 110 |
| 8.5.7 Availability of the analyser | > 90 % | $A_a$ System 1: 100 %<br>$A_a$ System 2: 100 % | yes | 111 |
| 8.5.5 Reproducibility standard deviation under field conditions | ≤ 5,0 % of the average over a period of 3 months | $S_{r,f}$ System 1: 1,21 %<br>$S_{r,f}$ System 2: 1,21 % | yes | 108 |
| 8.5.4 Long-term drift at zero | ≤ 5,0 nmol/mol | $C_{,z}$ System 1: 0,30 nmol/mol<br>$C_{,z}$ System 2: 0,28 nmol/mol | yes | 104 |
| 8.5.4 Long-term drift at span level | ≤ 5,0 % of the maximum of the certification range | $C_{,s}$ System 1: max. -1,58 %<br>$C_{,s}$ System 2: max. -1,82 % | yes | 104 |
| 8.4.4 Short-term drift at zero | ≤ 2,0 nmol/mol über 12 h | $D_{s,z}$ System 1: 0,12 nmol/mol<br>$D_{s,z}$ System 2: 0,20 nmol/mol | yes | 73 |
| 8.4.4 Short-term drift at span level | ≤ 6,0 nmol/mol über 12 h | $D_{s,s}$ System 1: -0,07nmol/mol<br>$D_{s,s}$ System 2: -1,33 nmol/mol | yes | 73 |

## *Table 36: Expanded uncertainty from the results of the laboratory test for system 1*

| | | | |
|---|---|---|---|
| Measuring device: | Teledyne T500U | Serial-No.: | SN 63 |
| Measured component: | $NO_2$ | 1h-limit value: | 104,6 nmol/mol |

| No. | Performance characteristic | Performance criterion | | Result | Partial uncertainty | | Square of partial uncertainty | |
|---|---|---|---|---|---|---|---|---|
| 1 | Repeatability standard deviation at zero | ≤ | 1.0 nmol/mol | 0,070 | $u_{r,z}$ | 0,01 | 0,0001 | |
| 2 | Repeatability standard deviation at 1h-limit value | ≤ | 3.0 nmol/mol | 0,250 | $u_{r,lh}$ | 0,04 | 0,0015 | |
| 3 | "lack of fit" at 1h-limit value | ≤ | 4.0% of measured value | 0,770 | $u_{l,lh}$ | 0,47 | 0,2162 | |
| 4 | Sensitivity coefficient of sample gas pressure at 1h-limit value | ≤ | 8.0 nmol/mol/kPa | 0,080 | $u_{gp}$ | 0,77 | 0,5944 | |
| 5 | Sensitivity coefficient of sample gas temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,010 | $u_{gt}$ | 0,10 | 0,0093 | |
| 6 | Sensitivity coefficient of surrounding temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,097 | $u_{st}$ | 0,93 | 0,8646 | |
| 7 | Sensitivity coefficient of electrical voltage at 1h-limit value | ≤ | 0.30 nmol/mol/V | 0,003 | $u_V$ | 0,03 | 0,0012 | |
| 8a | Interferent $H_20$ with 21 mmol/mol | ≤ | 10 nmol/mol (Zero) | 0,120 | $u_{H2O}$ | -1,37 | 1,8876 | |
| | | ≤ | 10 nmol/mol (Span) | -1,830 | | | | |
| 8b | Interferent $CO_2$ with 500 µmol/mol | ≤ | 5.0 nmol/mol (Zero) | 0,440 | $u_{int,pos}$ | 0,94 | 0,8824 | |
| | | ≤ | 5.0 nmol/mol (Span) | 1,330 | or | | | |
| 8c | Interferent $NH_3$ mit 200 nmol/mol | ≤ | 5.0 nmol/mol (Zero) | -0,030 | | | | |
| | | ≤ | 5.0 nmol/mol (Span) | 0,290 | $u_{int,neg}$ | | | |
| 9 | Averaging effect | ≤ | 7.0% of measured value | -2,310 | $u_{av}$ | -1,40 | 1,9461 | |
| 18 | Difference sample/calibration port | ≤ | 1.0% | -0,140 | $u_{\Delta sc}$ | -0,15 | 0,0214 | |
| 21 | Converter efficiency | ≥ | 98 | 100,00 | $u_{EC}$ | 0,00 | 0,0000 | |
| 23 | Uncertainty of test gas | ≤ | 3.0% | 2,000 | $u_{cg}$ | 1,05 | 1,0941 | |
| | | | Combined standard uncertainty | | $u_c$ | | 2,7424 | nmol/mol |
| | | | Expanded uncertainty | | U | | 5,4847 | nmol/mol |
| | | | Relative expanded uncertainty | | W | | 5,24 | % |
| | | | Maximum allowed expanded uncertainty | | $W_{req}$ | | 15 | % |

## *Table 37: Expanded uncertainty from the results of the laboratory and field tests for system 1*

| | | | |
|---|---|---|---|
| Measuring device: | Teledyne T500U | Serial-No.: | SN 63 |
| Measured component: | $NO_2$ | 1h-limit value: | 104,6 nmol/mol |

| No. | Performance characteristic | Performance criterion | | Result | Partial uncertainty | | Square of partial uncertainty | |
|---|---|---|---|---|---|---|---|---|
| 1 | Repeatability standard deviation at zero | ≤ | 1.0 nmol/mol | 0,070 | $u_{r,z}$ | 0,01 | 0,0001 | |
| 2 | Repeatability standard deviation at 1h-limit value | ≤ | 3.0 nmol/mol | 0,250 | $u_{r,lh}$ | not considered, as √2*ur,lh = 0,05 < ur,f | - | |
| 3 | "lack of fit" at 1h-limit value | ≤ | 4.0% of measured value | 0,770 | $u_{l,lh}$ | 0,47 | 0,2162 | |
| 4 | Sensitivity coefficient of sample gas pressure at 1h-limit value | ≤ | 8.0 nmol/mol/kPa | 0,080 | $u_{gp}$ | 0,77 | 0,5944 | |
| 5 | Sensitivity coefficient of sample gas temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,010 | $u_{gt}$ | 0,10 | 0,0093 | |
| 6 | Sensitivity coefficient of surrounding temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,097 | $u_{st}$ | 0,93 | 0,8646 | |
| 7 | Sensitivity coefficient of electrical voltage at 1h-limit value | ≤ | 0.30 nmol/mol/V | 0,003 | $u_V$ | 0,03 | 0,0012 | |
| 8a | Interferent $H_20$ with 21 mmol/mol | ≤ | 10 nmol/mol (Zero) | 0,120 | $u_{H2O}$ | -1,37 | 1,8876 | |
| | | ≤ | 10 nmol/mol (Span) | -1,830 | | | | |
| 8b | Interferent $CO_2$ with 500 µmol/mol | ≤ | 5.0 nmol/mol (Zero) | 0,440 | $u_{int,pos}$ | 0,94 | 0,8824 | |
| | | ≤ | 5.0 nmol/mol (Span) | 1,330 | or | | | |
| 8c | Interferent $NH_3$ mit 200 nmol/mol | ≤ | 5.0 nmol/mol (Zero) | -0,030 | | | | |
| | | ≤ | 5.0 nmol/mol (Span) | 0,290 | $u_{int,neg}$ | | | |
| 9 | Averaging effect | ≤ | 7.0% of measured value | -2,310 | $u_{av}$ | -1,40 | 1,9461 | |
| 10 | Reproducibility standard deviation under field conditions | ≤ | 5.0% of average over 3 months | 1,210 | $u_{r,f}$ | 1,27 | 1,6019 | |
| 11 | Long term drift at zero level | ≤ | 5.0 nmol/mol | 0,300 | $u_{d,l,z}$ | 0,17 | 0,0300 | |
| 12 | Long term drift at span level | ≤ | 5.0% of max. of certification range | -1,580 | $u_{d,l,lh}$ | -0,95 | 0,9105 | |
| 18 | Difference sample/calibration port | ≤ | 1.0% | -0,140 | $u_{\Delta sc}$ | -0,15 | 0,0214 | |
| 21 | Converter efficiency | ≥ | 98 | 100,000 | $u_{EC}$ | 0,00 | 0,0000 | |
| 23 | Uncertainty of test gas | ≤ | 3.0% | 2,000 | $u_{cg}$ | 1,05 | 1,0941 | |
| | | | Combined standard uncertainty | | $u_c$ | | 3,1717 | nmol/mol |
| | | | Expanded uncertainty | | U | | 6,3435 | nmol/mol |
| | | | Relative expanded uncertainty | | W | | 6,06 | % |
| | | | Maximum allowed expanded uncertainty | | $W_{req}$ | | 15 | % |

## *Table 38: Expanded uncertainty from the results of the laboratory test for system 2*

| Measuring device: | Teledyne T500U | | | | | Serial-No.: | SN 65 | |
|---|---|---|---|---|---|---|---|---|
| Measured component: | $NO_2$ | | | | | 1h-limit value: | 104,6 | nmol/mol |
| **No.** | **Performance characteristic** | **Performance criterion** | | **Result** | **Partial uncertainty** | | **Square of partial uncertainty** | |
| 1 | Repeatability standard deviation at zero | ≤ | 1.0 nmol/mol | 0,050 | $u_{r,z}$ | 0,01 | 0,0001 | |
| 2 | Repeatability standard deviation at 1h-limit value | ≤ | 3.0 nmol/mol | 0,150 | $u_{r,lh}$ | 0,02 | 0,0005 | |
| 3 | "lack of fit" at 1h-limit value | ≤ | 4.0% of measured value | 0,690 | $u_{l,lh}$ | 0,42 | 0,1736 | |
| 4 | Sensitivity coefficient of sample gas pressure at 1h-limit value | ≤ | 8.0 nmol/mol/kPa | 0,160 | $u_{gp}$ | 1,55 | 2,4029 | |
| 5 | Sensitivity coefficient of sample gas temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,010 | $u_{gt}$ | 0,10 | 0,0091 | |
| 6 | Sensitivity coefficient of surrounding temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,143 | $u_{st}$ | 1,39 | 1,9194 | |
| 7 | Sensitivity coefficient of electrical voltage at 1h-limit value | ≤ | 0.30 nmol/mol/V | 0,004 | $u_V$ | 0,05 | 0,0021 | |
| 8a | Interferent $H_20$ with 21 mmol/mol | ≤ | 10 nmol/mol (Zero) | 0,000 | $u_{H2O}$ | -1,25 | 1,5732 | |
| | | ≤ | 10 nmol/mol (Span) | 0,000 | | | | |
| 8b | Interferent $CO_2$ with 500 µmol/mol | ≤ | 5.0 nmol/mol (Zero) | 0,470 | $u_{int,pos}$ | 0,73 | 0,5329 | |
| | | ≤ | 5.0 nmol/mol (Span) | 1,090 | or | | | |
| 8c | Interferent $NH_3$ mit 200 nmol/mol | ≤ | 5.0 nmol/mol (Zero) | 0,030 | | | | |
| | | ≤ | 5.0 nmol/mol (Span) | 0,170 | $u_{int,neg}$ | | | |
| 9 | Averaging effect | ≤ | 7.0% of measured value | -2,080 | $u_{av}$ | -1,26 | 1,5779 | |
| 18 | Difference sample/calibration port | ≤ | 1.0% | -0,170 | $u_{\Delta sc}$ | -0,18 | 0,0316 | |
| 21 | Converter efficiency | ≥ | 98 | 100,00 | $u_{EC}$ | 0,00 | 0,0000 | |
| 23 | Uncertainty of test gas | ≤ | 3.0% | 2,000 | $u_{cg}$ | 1,05 | 1,0941 | |
| | | | | Combined standard uncertainty | $u_c$ | | 3,0525 | nmol/mol |
| | | | | Expanded uncertainty | U | | 6,1051 | nmol/mol |
| | | | | Relative expanded uncertainty | W | | 5,84 | % |
| | | | | Maximum allowed expanded uncertainty | $W_{req}$ | | 15 | % |

## *Table 39: Expanded uncertainty from the results of the laboratory and field tests for system 2*

| Measuring device: | Teledyne T500U | | | | | Serial-No.: | SN 65 | |
|---|---|---|---|---|---|---|---|---|
| Measured component: | $NO_2$ | | | | | 1h-limit value: | 104,6 | nmol/mol |
| **No.** | **Performance characteristic** | **Performance criterion** | | **Result** | **Partial uncertainty** | | **Square of partial uncertainty** | |
| 1 | Repeatability standard deviation at zero | ≤ | 1.0 nmol/mol | 0,050 | $u_{r,z}$ | 0,01 | 0,0001 | |
| 2 | Repeatability standard deviation at 1h-limit value | ≤ | 3.0 nmol/mol | 0,150 | $u_{r,lh}$ | not considered, as √2*ur,lh = 0,03 < ur,f | - | |
| 3 | "lack of fit" at 1h-limit value | ≤ | 4.0% of measured value | 0,690 | $u_{l,lh}$ | 0,42 | 0,1736 | |
| 4 | Sensitivity coefficient of sample gas pressure at 1h-limit value | ≤ | 8.0 nmol/mol/kPa | 0,160 | $u_{gp}$ | 1,55 | 2,4029 | |
| 5 | Sensitivity coefficient of sample gas temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,010 | $u_{gt}$ | 0,10 | 0,0091 | |
| 6 | Sensitivity coefficient of surrounding temperature at 1h-limit value | ≤ | 3.0 nmol/mol/K | 0,143 | $u_{st}$ | 1,39 | 1,9194 | |
| 7 | Sensitivity coefficient of electrical voltage at 1h-limit value | ≤ | 0.30 nmol/mol/V | 0,004 | $u_V$ | 0,05 | 0,0021 | |
| 8a | Interferent $H_20$ with 21 mmol/mol | ≤ | 10 nmol/mol (Zero) | 0,220 | $u_{H2O}$ | -1,25 | 1,5732 | |
| | | ≤ | 10 nmol/mol (Span) | -1,670 | | | | |
| 8b | Interferent $CO_2$ with 500 µmol/mol | ≤ | 5.0 nmol/mol (Zero) | 0,470 | $u_{int,pos}$ | 0,73 | 0,5329 | |
| | | ≤ | 5.0 nmol/mol (Span) | 1,090 | or | | | |
| 8c | Interferent $NH_3$ mit 200 nmol/mol | ≤ | 5.0 nmol/mol (Zero) | 0,030 | | | | |
| | | ≤ | 5.0 nmol/mol (Span) | 0,170 | $u_{int,neg}$ | | | |
| 9 | Averaging effect | ≤ | 7.0% of measured value | -2,080 | $u_{av}$ | -1,26 | 1,5779 | |
| 10 | Reproducibility standard deviation under field conditions | ≤ | 5.0% of average over 3 months | 1,210 | $u_{r,f}$ | 1,27 | 1,6019 | |
| 11 | Long term drift at zero level | ≤ | 5.0 nmol/mol | 0,280 | $u_{d,l,z}$ | 0,16 | 0,0261 | |
| 12 | Long term drift at span level | ≤ | 5.0% of max. of certification range | -1,820 | $u_{d,l,lh}$ | -1,10 | 1,2080 | |
| 18 | Difference sample/calibration port | ≤ | 1.0% | -0,170 | $u_{\Delta sc}$ | -0,18 | 0,0316 | |
| 21 | Converter efficiency | ≥ | 98 | 100,000 | $u_{EC}$ | 0,00 | 0,0000 | |
| 23 | Uncertainty of test gas | ≤ | 3.0% | 2,000 | $u_{cg}$ | 1,05 | 1,0941 | |
| | | | | Combined standard uncertainty | $u_c$ | | 3,4861 | nmol/mol |
| | | | | Expanded uncertainty | U | | 6,9722 | nmol/mol |
| | | | | Relative expanded uncertainty | W | | 6,67 | % |
| | | | | Maximum allowed expanded uncertainty | $W_{req}$ | | 15 | % |

# 8. Recommendation for use

## Tasks during the period of unattended operation (4 weeks)

The following checks are required on a regular basis:

- Regular visual inspections / telemetric monitoring
- Analyser status O.K.
- No error warnings
- Replacement of theTeflon filter in the sample gas inlet
- Zero and span point checks with suitable test gas

For all intents and purposes consider the manufacturer’s instructions.

Further details are specified in the manual.

Immissionsschutz/Luftreinhaltung

Dipl.-Ing. Guido Baum | Dipl.-Ing. Martin Schneider

Cologne, March 03, 2015
TÜV Report: 936/21224798/B

# 9. Bibliography

[1] VDI guideline 4202 part 1: „Performance criteria for performance tests of automated ambient air measuring systems – Point-related measurement methods for gaseous and particulate air pollutants“, September 2010

[2] VDI guideline 4203 part 3: „Testing of automated measuring systems - Test procedures for point-related ambient air measuring systems for gaseous and particulate air pollutants“, September 2010

[3] European Standard EN 14211Ambient air - Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, August 2012

[4] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe

# 10. Annex

# Annex 1

## Further performance criteria in accordance with guideline “Demonstration of Equivalence of Ambient Air Monitoring Methods“

The field test evaluation according to VDI 4202 and DIN EN 14211 was conducted from June 20, 2014 to September 22, 2014.

The entire field installation was installed from June 2014 till January 2015. During the entire period parallel measurements between the two T500U analyzers and a certified reference analyzer type Horiba APNA 370 (SN 43286610022) have been conducted.

The reference analyzer was connected to the same sampling system as the two specimens. The length of the test gas line was 2 meter for all systems.

Additional investigations according to the guideline “Demonstration of Equivalence of Ambient Air Monitoring Methods” have been carried out.

Four measurements with the duration of one month each were carried out within half a year in order to compare the T500U measuring systems with the already tested systems.

Four comparisons with the duration of one month each (July 2014, August 2014, November 2014 and January 2015) were carried out within half a year in order to compare the T500U measuring systems with the already tested systems. Different month have been chosen to cover different environmental conditions (temperature, pressure, humidity, $NO_2$-concentrations) during the tests.

Prior to each comparison month the adjustment of the tested analyzers as well as the reference system has been checked. The converter efficiency of the Horiba analyzer was also checked.

During the January comparison the sample gas has been enriched with a higher $NO_2$ concentration from test gas bottles. During 10 days the concentration has been enriched to get a concentration level higher than 200 µg/m³, to show that the equivalence is also given at higher gas levels. For this enrichment a small flow (approx. 50 ml/minute) $NO_2$ test gas from gas bottles has been added to the sample gas flow with the help of a gas mixing device.

## 7.1 Between instrument uncertainty determination $u_{bs}$ [8.5.3.2]

*The relative between-instrument uncertainty $w_{bs}$ shall be determined according to parameter 8.5.3.2 of the guide „Demonstration of Equivalence of Ambient Air Monitoring Methods".*

## 7.2 Equipment

Not required for this minimum requirement.

## 7.3 Carrying out the test

The test has been carried out in four different months (**July, August, November and January**) at the field test site in Cologne. Here, different seasons and different concentrations of sample gas have been considered.

## 7.4 Evaluation

According to parameter **8.5.3.2** of guideline „Demonstration of Equivalence of Ambient Air Monitoring Methods" the following is required:

The between-instrument uncertainty $w_{bs}$ shall be equal or less than 5 %. Since no further reference value is specified, 200 µg/m³ (2008/50/EG) as the hourly limit value for $NO_2$ were used as reference value. Thus, the maximum allowed between-instrument uncertainty shall not exceed 10 µg/m³ for $NO_2$.

The uncertainty was determined for each month.

The between-instrument uncertainty $u_{bs}$ is calculated from the differences of all daily averages (24 h values) of the candidate instruments operated in parallel as:

$$w_{bs}^2 = \frac{\sum_{i=1}^{n}(y_{i,1} - y_{i,2})^2}{2ny}$$

where $y_{i,1}$ and $y_{i,2}$ are the results of parallel measurements for a single 1-hour period i
$n$ is the number of hourly averages

## 7.5 Assessment

With a maximum of 1.097µg/m³, the between-instrument uncertainty $w_{bs}$ for component $NO_2$ is below the required value of not more than 10 µg/m³.

Minimum requirement fulfilled? yes

## 7.6 Detailed representation of test results

Table 36 shows the calculated values of the between-instrument uncertainty $u_{bs}$. See Figure 13 to 16 for a graphical representation.

*Table 40: Between-instrument uncertainty $w_{bs}$ for candidate SN 63 and SN 65*

| Candidates | Month | No. of values | Uncertainty $w_{bs}$ |
|---|---|---|---|
| Component $NO_2$ | | | |
| SN 63 / SN 65 | July | 744 | 0,309 |
| SN 63 / SN 65 | August | 744 | 0,218 |
| SN 63 / SN 65 | November | 720 | 0,224 |
| SN 63 / SN 65 | January | 744 | 1,097 |

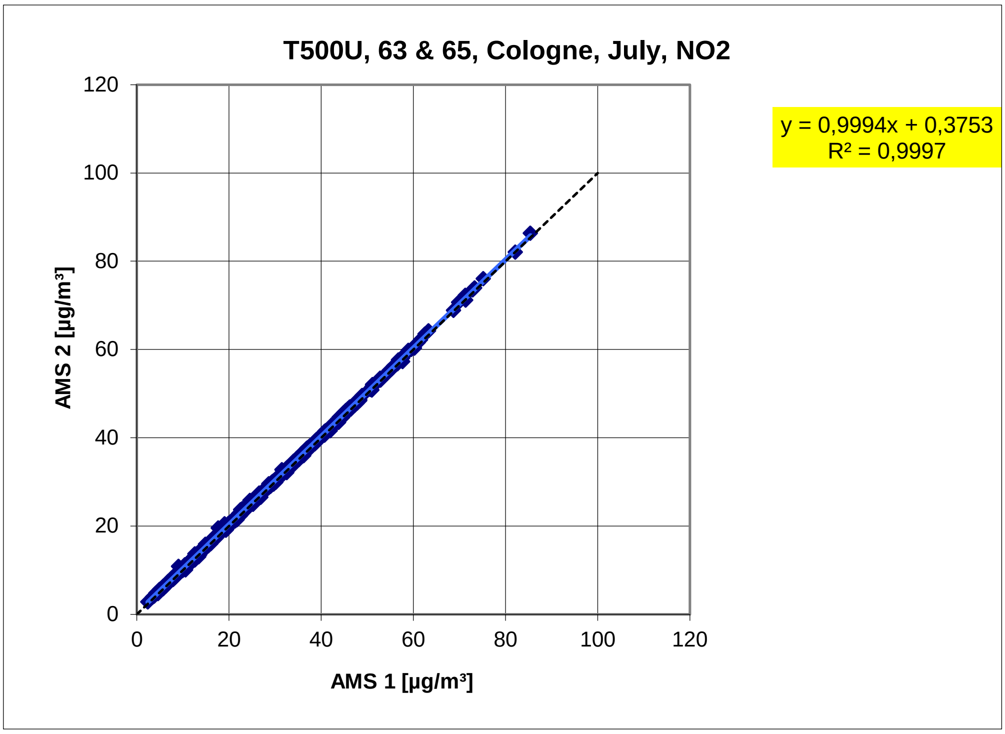



*Figure 12: Result of the parallel measurements of device SN 63 and SN 65, July, component $NO_2$*

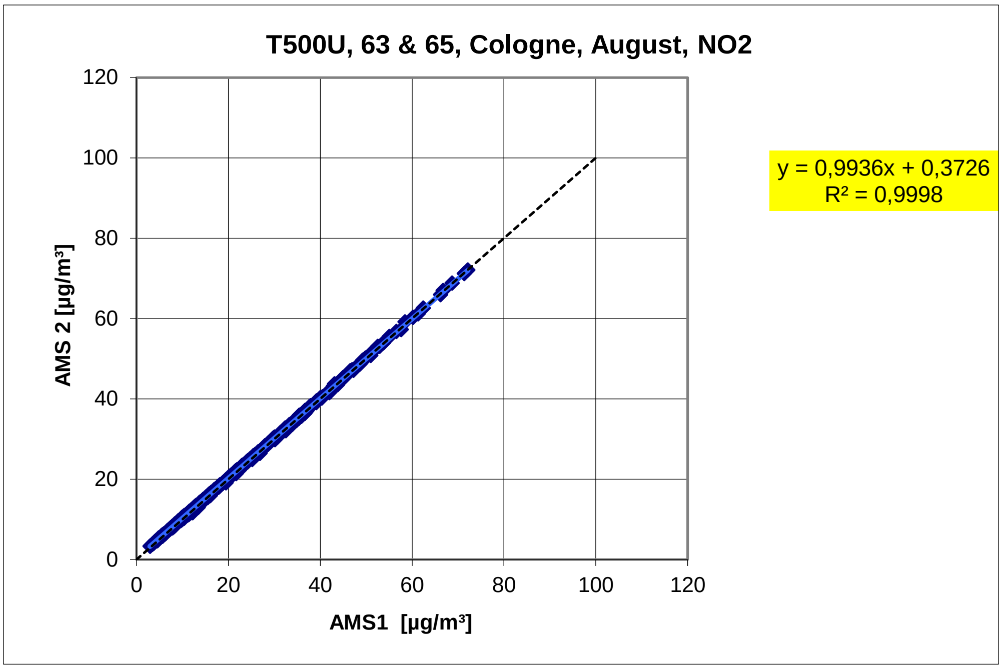



*Figure 13: Result of the parallel measurements of device SN 63 and SN 65, August, component $NO_2$*

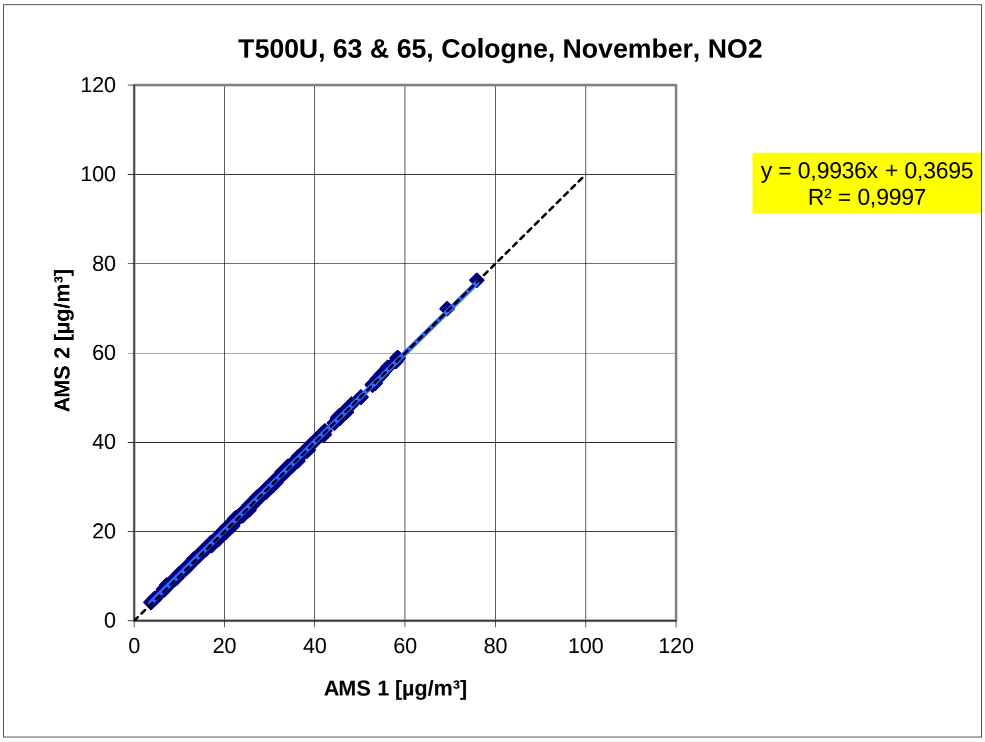



*Figure 14: Result of the parallel measurements of device SN 63 and SN 65, November, component $NO_2$*

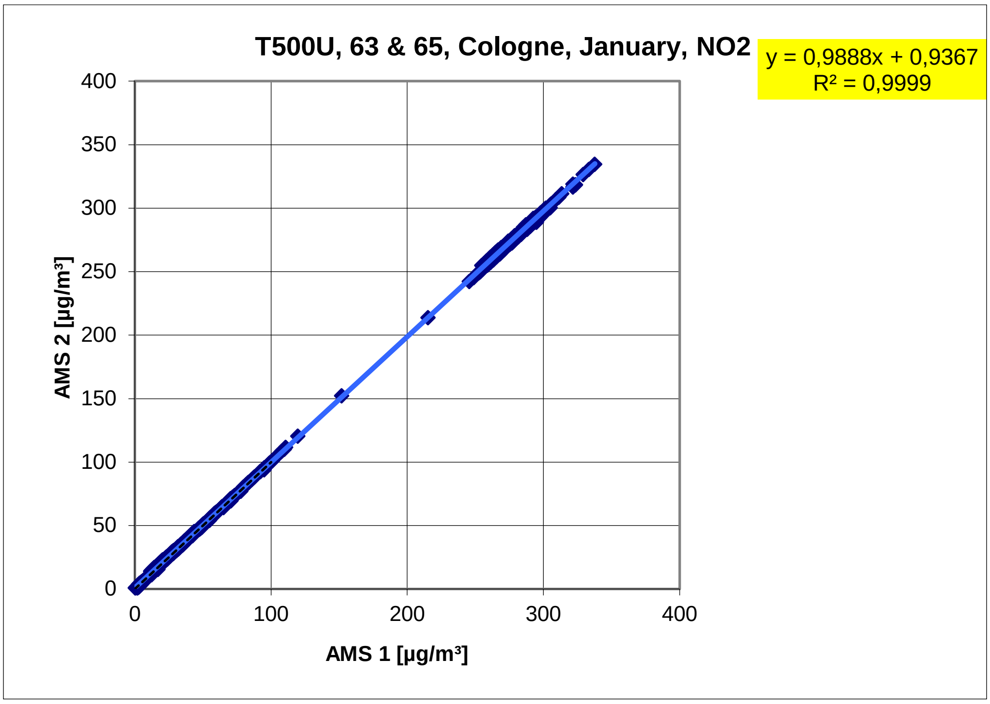



*Figure 15: Result of the parallel measurements of device SN 63 and SN 65, January, component $NO_2$*

## 7.1 Comparison with standard reference methods [8.5.3.3]

*The candidate instruments shall be tested on equivalence with the standard reference method according to the parameters 8.5.2.2 to 8.5.4 of guideline „Demonstration of Equivalence of Ambient Air Monitoring Methods“. The highest expanded uncertainty that has been calculated for the candidates shall be compared with the requirements on data quality of ambient air measurements according to EC Directive.*

## 7.2 Equipment

The devices listed in section 4 of the present report were additionally operated for this test parameter.

## 7.3 Carrying out the test

The test has been carried out in four different months (**July, August, November and January**) at the field test site in Cologne. Here, different seasons and different concentrations of sample gas have been considered.

Four measurements were made, and each measurement was carried out over a month. The measurements were arranged over a six-month period. The measured concentrations were related to ambient conditions.

## 7.4 Evaluation

A linear relation $y_i = a + bx_i$ between the results of the measurements of both methods is assumed in order to evaluate the comparability of the candidates with reference method x. The relation between the averages of the reference devices and the averages of the candidates is established by orthogonal regression.

The uncertainty of the results $w_{c\_s}$ of the candidates in comparison with the reference methods is calculated according to the following equation, which describes $w_{c\_s}$ as a function of the sample gas concentration $x_i$:

$$w_{c\_s}^2(y_i) = \frac{RSS}{(n-2)} - u^2(x_i) + [a + (b-1)x_i]^2$$

where RSS is the sum of the relative residuals from orthogonal regression

$u(x_i)$ is the random uncertainty of the standard method

Algorithms for the calculation of the axis intercept a and the slope b and their variances by orthogonal regression are described in detail in Annex B of [4].

The sum of the (relative) residuals RSS is calculated from the following equation:

$$RSS = \sum_{i=1}^{n} (y_i - a - bx_i)^2$$

[Parameter 8.5.3] The combined uncertainty of the candidates $w_{c,CM}$ is calculated by combining the results from 8.5.3.1 and 8.5.3.2 according to the following equation:

$$w_{c,CM}^2(y_i) = \frac{u_{c\_s}^2(y_i)}{y_i^2}$$

The uncertainty $w_{c,CM}$ is calculated at the hourly limit value (here 200 µg/m³) for each data set. $y_i$ is considered as the concentration at the hourly limit value.

[Parameter 8.5.3.4] The expanded relative uncertainty of the candidate results is calculated by multiplying $w_{c,CM}$ with a corrective factor k for each data set:

$$W_{CM} = k \cdot w_{CM}$$

In practice, k=2 is used for high n.

The highest resulting uncertainty $W_{CM}$ is compared and evaluated with the requirements on data quality of ambient air measurements according to EC directive.

The defined expanded relative uncertainty $W_{cm}$ is 15 % for $NO_2$

## 7.5 Assessment

The determined uncertainties $W_{CM}$ are below the defined expanded relative uncertainties $W_{cm}$ of 15 % without using corrective factors for all considered data sets

Minimum requirement fulfilled? yes

## 7.6 Detailed representation of test results

A summarized representation and assessment of the expanded measurement uncertainties $W_{CM}$ from results of the field test. Table 38 to Table 41 show the results of the evaluations of the single data sets.

*Table 41: Summary and Assessment of the expanded measurement uncertainties $W_{CM}$ from the field test, raw data*

| **Monat** | **Component** µg/m³ | **Limit value** µg/m³ | **Slope b** (µg/m³)/(µg/m³) | **Axis intercept a** µg/m³ | **$u_{c\_s}$ at the limit** µg/m³ | **$w_{CM}$** % | **$W_{CM}$** % | **$W_{CM}$ ≤ $W_{dqo}$** ($W_{dqo}$ = 15 %) |
|---|---|---|---|---|---|---|---|---|
| July | $NO_2$ | 200 | 1,02 | -0,14 | 4,08 | 2,04 | 4,08 | yes |
| August | $NO_2$ | 200 | 1,02 | 0,40 | 4,17 | 2,08 | 4,17 | yes |
| November | $NO_2$ | 200 | 1,04 | 0,07 | 7,13 | 3,56 | 7,13 | yes |
| January | $NO_2$ | 200 | 1,00 | -0,54 | 1,39 | 0,69 | 1,39 | yes |

*Table 42: Comparison between the candidate and the reference device, July, component $NO_2$*

| Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods" | | | | |
|---|---|---|---|---|
| Device | T500U | SN | 63 & 65 | |
| Testside / month | Cologne, July | Limit value | 200 | µg/m³ |
| Component | NO2 | allowed uncertainty | 15 | % |
| Results of the regression analysis | | | | |
| Slope b | **1,02** | **significant** | | |
| Uncertainty of b | **0,00** | | | |
| Ordinate intercept a | **-0,14** | **significant** | | |
| Uncertainty of a | **0,04** | | | |
| Results of the equivalence test | | | | |
| Deviation at limit value | **4,03** | **µg/m³** | | |
| Uncertainty $u_{c\_s}$ at limit value | **4,08** | **µg/m³** | | |
| Combined measurement uncertainty $w_{CM}$ | **2,04** | **%** | | |
| Expanded uncertainty $W_{CM}$ | **4,08** | **%** | | |
| Status equivalence test | **passed** | | | |

*Table 43: Comparison between the candidate and the reference device, August, component $NO_2$*

| Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods" | | | | |
|---|---|---|---|---|
| Device | T500U | SN | 63 & 65 | |
| Testside / month | Cologne, August | Limit value | 200 | µg/m³ |
| Component | NO2 | allowed uncertainty | 15 | % |
| Results of the regression analysis | | | | |
| Slope b | **1,02** | **significant** | | |
| Uncertainty of b | **0,00** | | | |
| Ordinate intercept a | **0,40** | **significant** | | |
| Uncertainty of a | **0,05** | | | |
| Results of the equivalence test | | | | |
| Deviation at limit value | **4,11** | **µg/m³** | | |
| Uncertainty $u_{c\_s}$ at limit value | **4,17** | **µg/m³** | | |
| Combined measurement uncertainty $w_{CM}$ | **2,08** | **%** | | |
| Expanded uncertainty $W_{CM}$ | **4,17** | **%** | | |
| Status equivalence test | **passed** | | | |

*Table 44: Comparison between the candidate and the reference device, November, component $NO_2$*

| **Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"** | | | | |
|---|---|---|---|---|
| Device | T500U | SN | 63 & 65 | |
| Testside / month | Cologne, November | Limit value | 200 | µg/m³ |
| Component | NO2 | allowed uncertainty | 15 | % |
| Results of the regression analysis | | | | |
| Slope b | **1,04** | **significant** | | |
| Uncertainty of b | **0,00** | | | |
| Ordinate intercept a | **0,07** | **not significant** | | |
| Uncertainty of a | **0,04** | | | |
| Results of the equivalence test | | | | |
| Deviation at limit value | **7,11** | **µg/m³** | | |
| Uncertainty uc_s at limit value | **7,13** | **µg/m³** | | |
| Combined measurement uncertainty wCM | **3,56** | **%** | | |
| Expanded uncertainty WCM | **7,13** | **%** | | |
| Status equivalence test | **passed** | | | |

*Table 45: Comparison between the candidate and the reference device, January, component $NO_2$*

| **Comparison candidate with refernce according to guidance "Demonstration of Equivalence Of Ambient Air Monitoring Methods"** | | | | |
|---|---|---|---|---|
| Device | T500U | SN | 63 & 65 | |
| Testside / month | Cologne, January | Limit value | 200 | µg/m³ |
| Component | NO2 | allowed uncertainty | 15 | % |
| Results of the regression analysis | | | | |
| Slope b | **1,00** | **significant** | | |
| Uncertainty of b | **0,00** | | | |
| Ordinate intercept a | **-0,54** | **significant** | | |
| Uncertainty of a | **0,06** | | | |
| Results of the equivalence test | | | | |
| Deviation at limit value | **0,23** | **µg/m³** | | |
| Uncertainty $u_{c\_s}$ at limit value | **1,39** | **µg/m³** | | |
| Combined measurement uncertainty $w_{CM}$ | **0,69** | **%** | | |
| Expanded uncertainty $W_{CM}$ | **1,39** | **%** | | |
| Status equivalence test | **passed** | | | |

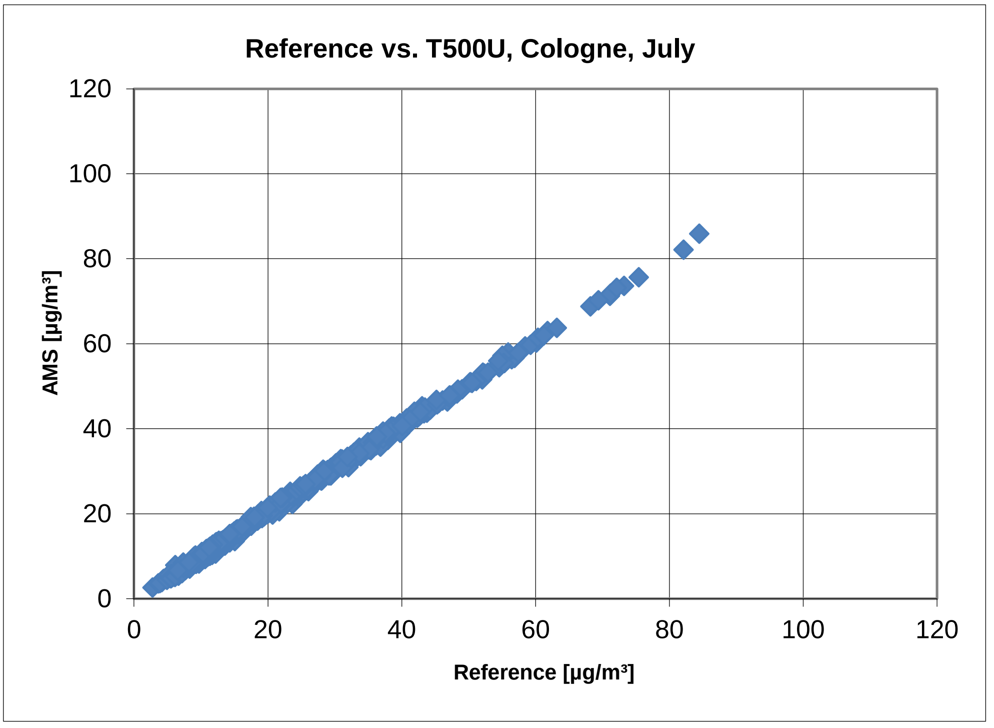



*Figure 16: Reference device vs. candidate, July, component $NO_2$*

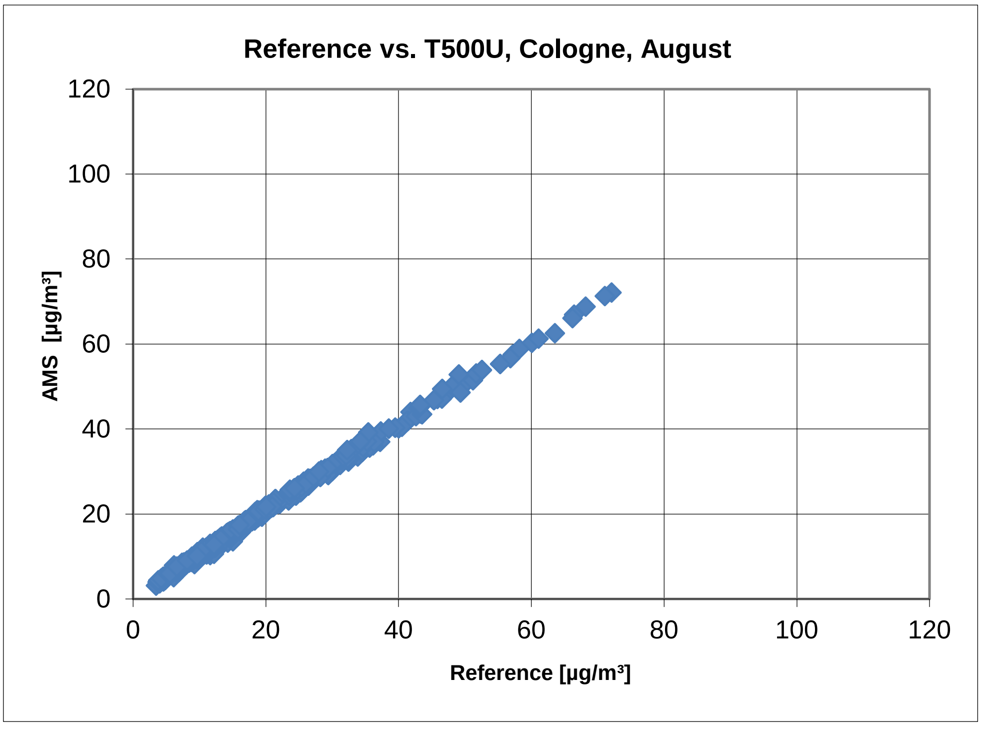



*Figure 17: Reference device vs. candidate, August, component $NO_2$*

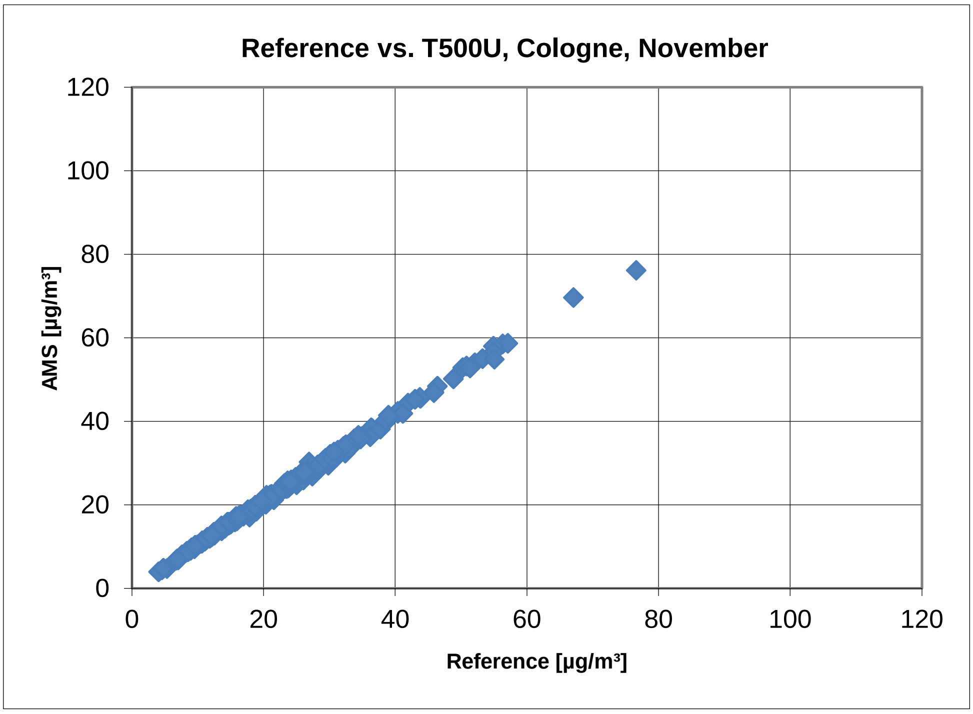



*Figure 18: Reference device vs. candidate, November, component $NO_2$*

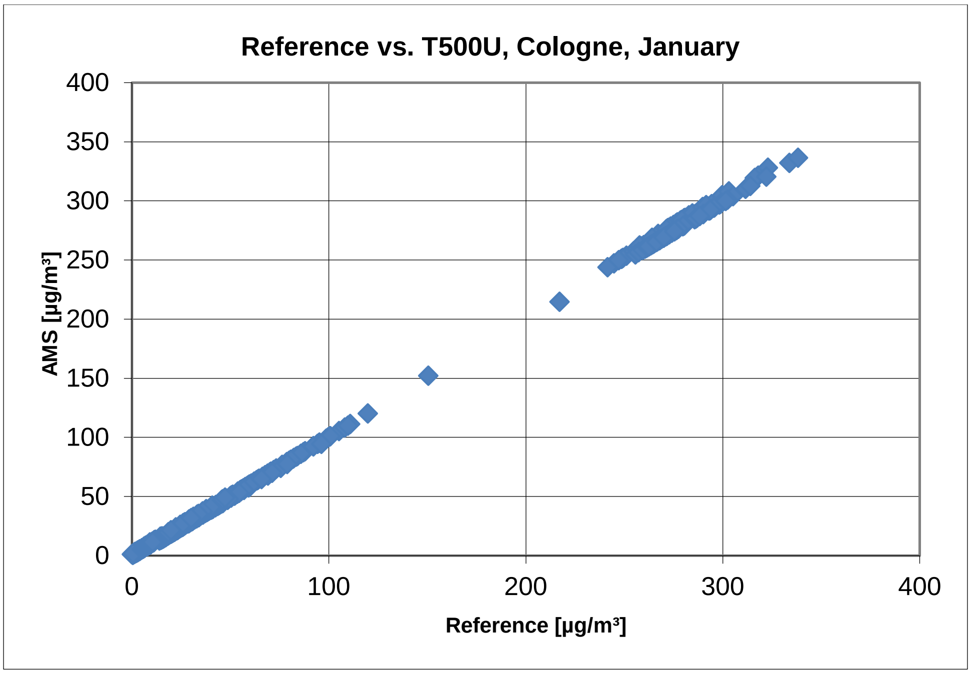



*Figure 19: Reference device vs. candidate, January, component $NO_2$*

## Annex 2 Accreditation certificate according to EN ISO/IEC 17025:2005

DAkkS
Deutsche
Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

**Beliehene gemäß § 8 Absatz 1 AkkStelleG i.V.m. § 1 Absatz 1 AkkStelleGBV**
Unterzeichnerin der Multilateralen Abkommen
von EA, ILAC und IAF zur gegenseitigen Anerkennung

# Akkreditierung

Die Deutsche Akkreditierungsstelle GmbH bestätigt hiermit, dass das Prüflaboratorium

**TÜV Rheinland Energie und Umwelt GmbH**

mit seinen in der Urkundenanlage aufgeführten Messstellen

die Kompetenz nach DIN EN ISO/IEC 17025:2005 und CEN/TS 15675:2007 besitzt, Prüfungen in folgenden Bereichen durchzuführen:

**Bestimmung (Probenahme und Analytik) von anorganischen und organischen gas- oder partikelförmigen Luftinhaltsstoffen im Rahmen von Emissions- und Immissionsmessungen; Probenahme von luftgetragenen polyhalogenierten Dibenzo-p-Dioxinen und Dibenzofuranen bei Emissionen und Immissionen; Probenahme von faserförmigen Partikeln bei Emissionen und Immissionen; Ermittlung von gas- oder partikelförmigen Luftinhaltsstoffen mit kontinuierlich arbeitenden Messgeräten; Bestimmung von Geruchsstoffen in Luft; Kalibrierungen und Funktionsprüfungen kontinuierlich arbeitender Messgeräte für Luftinhaltsstoffe einschließlich Systemen zur Datenauswertung und Emissionsfernüberwachung; Eignungsprüfungen von automatisch arbeitenden Emissions- und Immissionsmesseinrichtungen einschließlich Systemen zur Datenauswertung und Emissionsfernüberwachung; Feuerraummessungen; Ermittlung der Emissionen und Immissionen von Geräuschen; Ermittlung von Geräuschen und Vibrationen am Arbeitsplatz; Akustische und schwingungstechnische Messungen im Eisenbahnwesen; Bestimmung von Schallleistungspegeln von zur Verwendung im Freien vorgesehenen Geräten und Maschinen nach Richtlinie 2000/14/EG und Konformitätsbewertungsverfahren; Schallmessungen an Windenergieanlagen (Geräuschemission, Geräuschimmission); Immissionsprognose auf der Grundlage der Technischen Anleitung zur Reinhaltung der Luft und der Geruchsimmissions-Richtlinie und der VDI 3783 Blatt 13; physikalische, physikalisch-chemische und mikrobiologische Untersuchungen von Wasser, Schwimm- und Badebeckenwasser, Abwasser; Probenahme von Abwasser, Schwimm- und Badebeckenwasser; mikrobiologische und sensorische Untersuchungen gemäß Trinkwasserverordnung; Probenahme von Roh- und Trinkwasser; ausgewählte mikrobiologische Untersuchungen von Bedarfsgegenständen und kosmetischen Mitteln; Probenahme anorganischer faserförmiger Partikel sowie von partikel- und gasförmigen luftverunreinigenden Stoffen in der Innenraumluft; ausgewählte mikrobiologische Untersuchungen in Innenräumen; Probenahme von Asbestfasern und anderen anorganischen Fasern bei Arbeitsplatzmessungen; Ermittlung von Aerosolen, anorganischen und organischen Gasen und Dämpfen sowie ausgewählten Parametern und/oder in ausgewählten Gebieten bei Arbeitsplatzmessungen gemäß Gefahrstoffverordnung §7, Abs. 10;**
**Modul Immissionsschutz**

Die Akkreditierungsurkunde gilt nur in Verbindung mit dem Bescheid vom 09.07.2014 mit der Akkreditierungsnummer D-PL-11120-02 und ist gültig bis 22.01.2018. Sie besteht aus diesem Deckblatt, der Rückseite des Deckblatts und der folgenden Anlage mit insgesamt 54 Seiten.

Registrierungsnummer der Urkunde: **D-PL-11120-02-00**

Im Auftrag

Berlin, 09.07.2014
Siehe Hinweise auf der Rückseite

Andrea Valbuena
Abteilungsleiterin

*Figure 20: Accreditation certificate according to DIN EN ISO/IEC 17025:2005*

# Deutsche Akkreditierungsstelle GmbH

Standort Berlin
Spittelmarkt 10
10117 Berlin

Standort Frankfurt am Main
Gartenstraße 6
60594 Frankfurt am Main

Standort Braunschweig
Bundesallee 100
38116 Braunschweig

Die auszugsweise Veröffentlichung der Akkreditierungsurkunde bedarf der vorherigen schriftlichen Zustimmung der Deutsche Akkreditierungsstelle GmbH (DAkkS). Ausgenommen davon ist die separate Weiterverbreitung des Deckblattes durch die umseitig genannte Konformitätsbewertungsstelle in unveränderter Form.

Es darf nicht der Anschein erweckt werden, dass sich die Akkreditierung auch auf Bereiche erstreckt, die über den durch die DAkkS bestätigten Akkreditierungsbereich hinausgehen.

Die Akkreditierung erfolgte gemäß des Gesetzes über die Akkreditierungsstelle (AkkStelleG) vom 31. Juli 2009 (BGBl. I S. 2625) sowie der Verordnung (EG) Nr. 765/2008 des Europäischen Parlaments und des Rates vom 9. Juli 2008 über die Vorschriften für die Akkreditierung und Marktüberwachung im Zusammenhang mit der Vermarktung von Produkten (Abl. L 218 vom 9. Juli 2008, S. 30).
Die DAkkS ist Unterzeichnerin der Multilateralen Abkommen zur gegenseitigen Anerkennung der European co-operation for Accreditation (EA), des International Accreditation Forum (IAF) und der International Laboratory Accreditation Cooperation (ILAC). Die Unterzeichner dieser Abkommen erkennen ihre Akkreditierungen gegenseitig an.

Der aktuelle Stand der Mitgliedschaft kann folgenden Webseiten entnommen werden:
EA: www.european-accreditation.org
ILAC: www.ilac.org
IAF: www.iaf.nu

# Annex 3

## Manual

TELEDYNE
ADVANCED POLLUTION INSTRUMENTATION
Everywhereyoulook™

# MODEL T500U
# CAPS $NO_2$ ANALYZER
## Operation Manual

© Teledyne Advanced Pollution Instrumentation (TAPI)
9480 Carroll Park Drive
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USA

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Copyright 2013-2014
Teledyne Advanced Pollution Instrumentation

07834A DCN5543
21 April 2014

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## TRADEMARKS

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## SAFETY MESSAGES

Important safety messages are provided throughout this manual for the purpose of avoiding personal injury or instrument damage. Please read these messages carefully. Each safety message is associated with a safety alert symbol, and are placed throughout this manual; the safety symbols are also located inside the instrument. It is imperative that you pay close attention to these messages, the descriptions of which are as follows:

WARNING: Electrical Shock Hazard

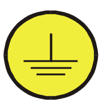
HAZARD: Strong oxidizer

GENERAL WARNING/CAUTION: Read the accompanying message for specific information.

CAUTION: Hot Surface Warning

Do Not Touch: Touching some parts of the instrument without protection or proper tools could result in damage to the part(s) and/or the instrument.

Technician Symbol: All operations marked with this symbol are to be performed by qualified maintenance personnel only.



Electrical Ground: This symbol inside the instrument marks the central safety grounding point for the instrument.

**CAUTION**

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

NEVER use any gas analyzer to sample combustible gas(es)!

For Technical Assistance regarding the use and maintenance of this instrument or any other Teledyne API product, contact Teledyne API's Technical Support Department:

Telephone: 800-324-5190
Email: sda_techsupport@teledyne.com
or access any of the service options on our website at http://www.teledyne-api.com/

## CONSIGNES DE SÉCURITÉ

Des consignes de sécurité importantes sont fournies tout au long du présent manuel dans le but d'éviter des blessures corporelles ou d'endommager les instruments. Veuillez lire attentivement ces consignes. Chaque consigne de sécurité est représentée par un pictogramme d'alerte de sécurité; ces pictogrammes se retrouvent dans ce manuel et à l'intérieur des instruments. Les symboles correspondent aux consignes suivantes :

AVERTISSEMENT : Risque de choc électrique

DANGER : Oxydant puissant

AVERTISSEMENT GÉNÉRAL / MISE EN GARDE : Lire la consigne complémentaire pour des renseignements spécifiques

MISE EN GARDE : Surface chaude

Ne pas toucher : Toucher à certaines parties de l'instrument sans protection ou sans les outils appropriés pourrait entraîner des dommages aux pièces ou à l'instrument.

Pictogramme « technicien » : Toutes les opérations portant ce symbole doivent être effectuées uniquement par du personnel de maintenance qualifié.

Mise à la terre : Ce symbole à l'intérieur de l'instrument détermine le point central de la mise à la terre sécuritaire de l'instrument.

**MISE EN GARDE**

Cet instrument doit être utilisé aux fins décrites et de la manière décrite dans ce manuel. Si vous utilisez cet instrument d'une autre manière que celle pour laquelle il a été prévu, l'instrument pourrait se comporter de façon imprévisible et entraîner des conséquences dangereuses.

NE JAMAIS utiliser un analyseur de gaz pour échantillonner des gaz combustibles!

# WARRANTY

## Warranty Policy (02024 G)

Teledyne Advanced Pollution Instrumentation (TAPI), a business unit of Teledyne Instruments, Inc., provides that:

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

## Coverage

After the warranty period and throughout the equipment lifetime, TAPI 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 are to be performed by the customer.

## Non-TAPI Manufactured Equipment

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

## Product Return

All units or components returned to Teledyne API 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.

The complete Terms and Conditions of Sale can be reviewed at http://www.teledyne-api.com/terms_and_conditions.asp

**CAUTION – Avoid Warranty Invalidation**

Failure to comply with proper anti-Electro-Static Discharge (ESD) handling and packing instructions and Return Merchandise Authorization (RMA) procedures when returning parts for repair or calibration may void your warranty. For anti-ESD handling and packing instructions please refer to the manual, Fundamentals of ESD, PN 04786, in its "Packing Components for Return to Teledyne API's Customer Service" section. The manual can be downloaded from our website at http://www.teledyne-api.com under Help Center > Product Manuals in the Special Manuals section; RMA procedures are under Help Center > Return Authorization.

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## ABOUT THIS MANUAL

This manual is comprised of multiple documents, in PDF format, as listed below.

| Part No. | Rev | Name/Description |
|---|---|---|
| 078340000 | A | T500U Operation Manual (this manual) |
| 080610000 | A | Software Menu Trees, Appendix A |
| 080670000 | A | T500U Spare Parts List, Appendix B |
| 080620000 | A | T500U Repair Questionnaire, Appendix C |
| 078480000 | A | T500U Interconnect Diagram, Appendix D |

Support information such as electrostatic discharge (ESD) prevention and various communications is presented in our manuals, which are available on the TAPI website http://www.teledyne-api.com in Help Center>Product Manuals, under Special Manuals.

**Note** **We recommend that all users read this manual in its entirety before operating the instrument.**

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## REVISION HISTORY

This section provides information regarding changes to this manual.

### T500U CAPS $NO_2$ Analyzer Manual PN 07834

| Date | Rev | DCN | Change Summary |
|---|---|---|---|
| 2014 April 21 | A | 5543 | Initial Release |

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# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

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# 1. INTRODUCTION

Teledyne API's Model T500U CAPS $NO_2$ Analyzer uses Cavity-Attenuated Phase-Shift (CAPS) spectroscopy to render true measurement of nitrogen dioxide ($NO_2$). The T500U operates as an optical absorption spectrometer, wherein the absorbance (lost light) is directly proportional to both the path-length and the concentration of the absorbing gas (Beer-Lambert law), providing direct measurement of $NO_2$.

The T500U uses few components: an optical cell, a pair of highly reflective spherical mirrors centered at 450nm (strong $NO_2$ absorbance band), a light emitting diode (LED), and a vacuum photodiode detector. The LED is located behind a mirror at one end of the cell, and the detector behind the other mirror at the opposite end of the cell. The LED emits ultraviolet light (UV) into the cell; the light reflects back and forth between the two mirrors, building intensity and running a very long path length. The long path length extends the "time" or "life" of the photon, thus providing ample time to measure absorbance when $NO_2$ is present. Through the use of precisely timed data acquisition coupled with a proprietary algorithm the measured absorption is translated into a phase shift, from which the $NO_2$ concentration is calculated. The phase shift decreases as the $NO_2$ signal increases.

The CAPS method is faster than the traditional chemiluminescence method since the sample does not require cycling through a catalytic converter, in order to calculate a difference measurement. Its speed also makes measurement more precise due to the ability to capture samples closer to "real time" before ventilation vortices (e.g., urban canyons and other traffic-related forces) can scatter the concentration.

Economically, the CAPS method is less costly to operate than traditional analyzers in that it uses less power (~70W) and fewer components.

The section on Principles of Operation provides more detail on the behavior and technique of the CAPS method for $NO_2$ measurement.

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# 2. SPECIFICATIONS, APPROVALS & COMPLIANCE

## 2.1. SPECIFICATIONS

Table 2-1 below presents the T500U specifications.

**Table 2-1: Specifications**

| Parameter | Description |
|---|---|
| Range | Min: 0-5 ppb Max: 0-1 ppm $NO_2$ (User-selectable) |
| Measurement Units | ppb, ppm, µg/$m^3$, mg/$m^3$ (User-selectable) |
| Zero Noise | <0.020 ppb |
| Span Noise | <0.2% of reading + 0.020 ppb |
| Zero Drift | <0.1 ppb / 24 hours |
| Span Drift | <0.5% of reading / 24 hours |
| Lower Detectable Limit | 0.04 ppb |
| Lag Time | ~8 seconds (limited by volumetric flow rate) |
| Rise/ Fall Time | <30 Seconds to 95% |
| Linearity | < 1% Full Scale |
| Precision | 0.5% of reading above 5 ppb |
| Sample Flow Rate | 900 $cm^3$/min ±10% |
| AC Power | Rating / Typical Power Consumption<br>110 - 120 V~ 60 Hz 3.0 A / 80 W<br>220 - 240 V~ 50 Hz 3.0 A / 80 W |
| Analog Output Ranges | 10V, 5V, 1V, 0.1V (selectable) |
| Analog Output Resolution | 1 part in 4096 of selected full-scale voltage |
| Communications | |
| Standard I/O | 1 Ethernet: 10/100Base-T<br>2 RS-232 (300 – 115,200 baud)<br>2 USB device ports<br>8 opto-isolated digital outputs<br>6 opto-isolated digital inputs (3 defined, 3 spare)<br>4 analog outputs |
| Optional I/O | 1 USB com port<br>1 RS485<br>8 analog inputs (0-10V, 12-bit)<br>4 digital alarm outputs<br>Multidrop RS232<br>3 4-20mA current outputs |
| Operating Temperature | 5-40 $^{o}$C |
| Humidity Range | 0-95% RH, Non-Condensing |
| Dimensions HxWxD | 7” x 17” x 23.5” (178 x 432 x 597 mm)<br>(19” rack mount, 5U, 24” deep) |
| Weight | 33 lbs (15 kg) |
| Environmental Conditions | • Installation Category (Over Voltage Category ) II Pollution Degree 2<br>• Intended for Indoor Use Only at Altitudes ≤ 2000m |

# 2.2. EPA EQUIVALENCY DESIGNATION

Teledyne Advanced Pollution Instrumentation's Model T500U cavity attenuated phase shift spectroscopy nitrogen dioxide analyzer has received preliminary approval for designation as an equivalent method for $NO_2$ measurement as defined in 40 CFR Part 53, pending official publication in the Federal Register; this designation applies when the T500U is operated under the following conditions:

- on any full scale range between 0-50 ppb and 0-1000 ppb
- with any range mode (Single, Dual, or Auto Range)
- at any operating temperature from 5°C to 40°C
- with the software setting Temperature and Pressure compensation ON
- with or without any of the following options:
  - Zero/Span (Z/S) valves
  - internal Zero/Span (IZS) permeation oven
  - external communication and data monitoring interfaces

This analyzer is approved for use, with proper factory configuration (if applicable), on either 50 or 60 Hertz line frequency and nominal power line voltages of 115 VAC and 230 VAC, or similar voltages as specified in this manual.

# 2.3. APPROVALS AND CERTIFICATIONS

The Teledyne-API Model T500U was designed, tested and certified for Safety and Electromagnetic Compatibility (EMC). This section presents the compliance statements for those requirements and directives. For additional certifications, please contact Technical Support by telephone at 1-800-324-5190 or by email at sda_techsupport@teledyne.com.

## 1.1.1 SAFETY

IEC/EN 61010-1:2010 (3rd Edition), Safety requirements for electrical equipment for the measurement, control and laboratory use.

CE: 2006/95/EC, Low-Voltage Directive

## 1.1.2 EMC

IEC/EN 61326-1, Class A Emissions/Industrial Immunity

EN55011 (CISPR 11), Group 1, Class A Emissions

FCC 47 CFR Part 15B, Class A Emissions

CE: 2004/108/EC, Electromagnetic Compatibility Directive

# 3. GETTING STARTED

This section discusses unpacking, connecting, and initializing the instrument.

## 3.1. UNPACKING

The shipping crate contains:

- instrument
- power cord
- CD-ROM of manuals

Verify that there is no apparent external shipping damage to the unit. If damage has occurred, please advise the shipper first, then Teledyne API.

Included with your analyzer is a printed record of the final performance characterization performed on your instrument at the factory, titled *Final Test and Validation Data Sheet* (*P/N 07853*). It is an important quality assurance and calibration record and should be placed in the quality records file for this instrument.

With no power to the unit, carefully open the analyzer and check for internal shipping damage:

1. Remove the two screws on either side of the chassis toward the back.
2. Slide the cover backward until it clears the analyzer's front bezel.
3. Lift the cover straight up.
4. Check that all circuit boards and other components are in good shape and properly seated.
5. Ensure that the connectors of the various internal wiring harnesses and pneumatic hoses are firmly and properly seated.
6. Verify that all optional hardware ordered with the unit has been installed (listed on the paperwork accompanying the analyzer).

**WARNING**
**ELECTRICAL SHOCK HAZARD**

**Never disconnect any electronic assemblies or subassemblies while the instrument is under power.**

### 3.1.1. INSTALLATION REQUIREMENTS

Whether the analyzer is set up on a bench or installed into an instrument rack, be sure to leave sufficient ventilation clearance.

**Table 3-1: Ventilation Clearance Requirements**

| AREA | MINIMUM CLEARANCE |
|---|---|
| Back of the instrument | **4 in (10 cm)** |
| Top, Bottom, Sides of the instrument | **1 in (2.5 cm)** |

**Note** **Ensure accessibility to rear panel for disconnecting power.**

## 3.2. INSTRUMENT LAYOUT

This section illustrates front panel and display, rear panel connectors, and internal chassis layout.

### 3.2.1. FRONT PANEL

Figure 3-1 shows the analyzer's front panel layout, followed by a close-up of the display screen in Figure 3-2 which is described in Table 3-2. The two USB ports on the front panel are provided for the connection of peripheral devices:

- plug-in mouse (not included) to be used as an alternative to the touchscreen interface
- thumb (or flash) drive (not included) to download updates to software (contact TAPI Technical Support for information).

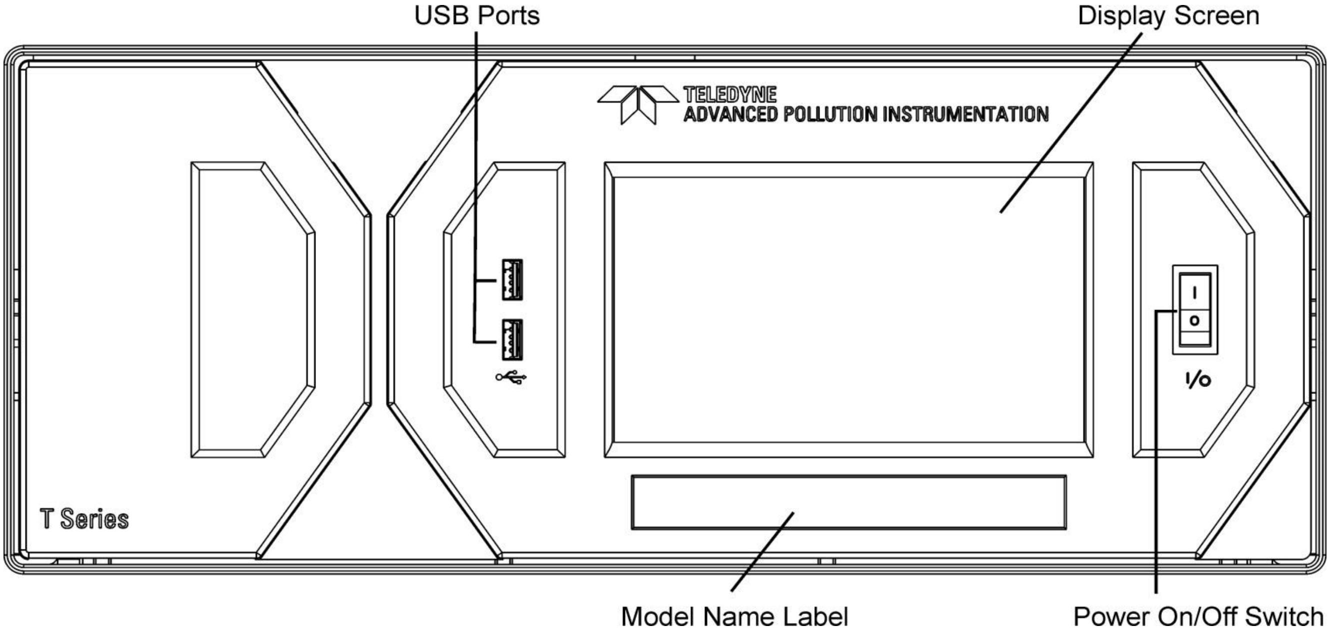


**Figure 3-1: Front Panel Layout**


**Figure 3-2: Display Screen and Touch Control**

**Table 3-2: Display Screen and Touch Control Description**

| Field | Description/Function | | | |
|---|---|---|---|---|
| Status | LEDs indicating the states of Sample, Calibration and Fault, as follows: | | | |
| | Name | Color | State | Definition |
| | SAMPLE | Green | Off | Unit is not operating in sample mode, DAS is disabled. |
| | | | On | Sample Mode active; Front Panel Display being updated; DAS data being stored. |
| | | | Blinking | Unit is operating in sample mode, front panel display being updated, DAS hold-off mode is ON, DAS disabled |
| | CAL | Yellow | Off | Auto Cal disabled |
| | | | On | Auto Cal enabled |
| | | | Blinking | Unit is in calibration mode |
| | FAULT | Red | Off | No warnings exist |
| | | | Blinking | Warnings exist |
| Conc | Displays the actual concentration of the sample gas currently being measured by the analyzer in the currently selected units of measure. | | | |
| Mode | Displays the name of the analyzer's current operating mode | | | |
| Param | Displays a variety of informational messages such as warning messages, operational data, test function values and response messages during interactive tasks. | | | |
| Control Buttons | Displays dynamic, context sensitive labels on each button, which is blank when inactive until applicable. | | | |

## 3.2.2. **REAR PANEL**

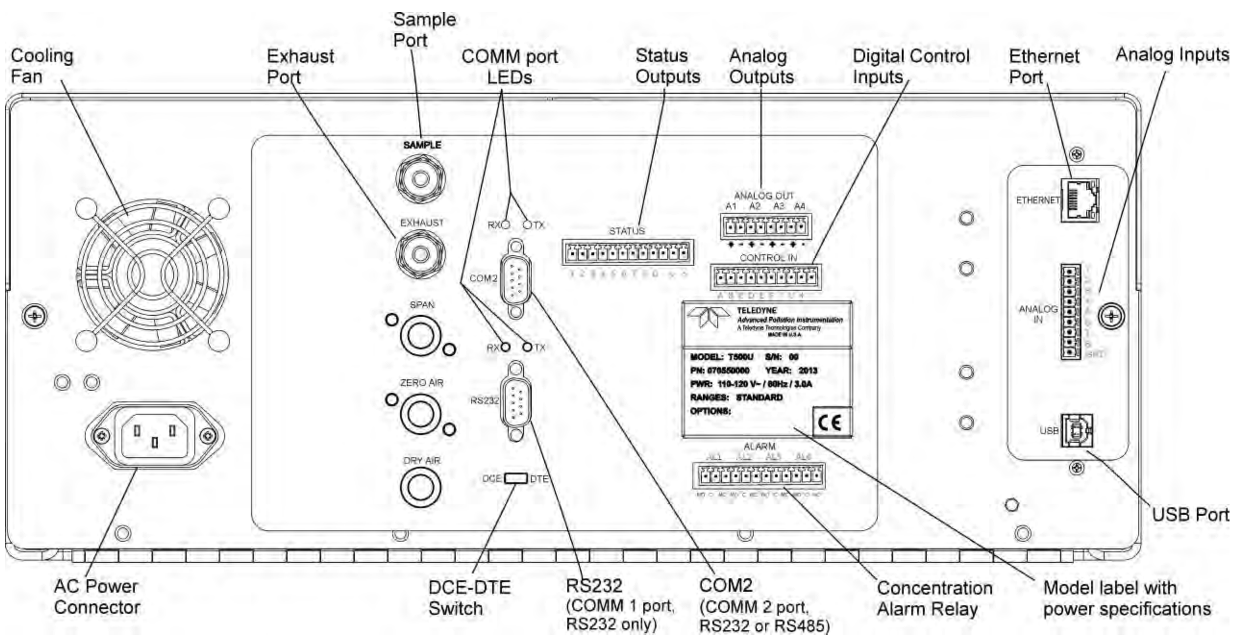


**Figure 3-3: T500U Rear Panel**

Table 3-3 provides a description of the rear panel components.

**Table 3-3: Rear Panel Description**

| Component | Function |
|---|---|
| **cooling fan** | Pulls ambient air into chassis through side vents and exhausts through rear. |
| **AC power connector** | Connector for three-prong cord to apply AC power to the analyzer.<br>**CAUTION! The cord's power specifications (specs) MUST comply with the power specs on the analyzer's rear panel Model label** |
| **Model/specs label** | Identifies the analyzer model number and provides power specs |
| **SAMPLE** | Connect a gas line from the source of sample gas here.<br>Calibration gases can also enter here on units without zero/span/shutoff valve options installed. |
| **EXHAUST** | Connect an exhaust gas line of not more than 10 meters long here that leads outside the shelter or immediate area surrounding the instrument. The line must be ¼" tubing or greater. |
| **SPAN** | On units with zero/span valve option installed, connect a gas line to the source of calibrated span gas here. |
| **ZERO AIR** | On units with zero/span valve option installed, but no zero air scrubber, attach a gas line to the source of zero air here. If a permeation oven, also known as internal zero/span valve (IZS), option is installed attach the zero air scrubber here. |
| **DRY AIR** | Not Used |
| **RX TX** | LEDs indicate receive (RX) and transmit (TX) activity when blinking. |
| **COM 2** | Serial communications port for RS-232 or RS-485 (RS-485. |
| **RS-232** | Serial communications port for RS-232 only. |
| **DCE DTE** | Switch to select either data terminal equipment or data communication equipment during RS-232 communication. |
| **STATUS** | For outputs to devices such as Programmable Logic Controllers (PLCs). |
| **ANALOG OUT** | (AOUT) For voltage or current loop outputs to a strip chart recorder and/or a data logger. |
| **CONTROL IN** | For remotely activating the zero and span calibration modes. |
| **ALARM** | Option for concentration alarms and system warnings. |
| **ETHERNET** | Connector for network or Internet remote communication, using Ethernet cable |
| **ANALOG IN** | (AIN) Option for receiving and logging voltage signals from other instrumentation. |
| **USB** | Connector for direct connection to laptop computer, using USB cable. |
| **Model Label** | Includes voltage and frequency specifications |

## 3.2.3. **INTERNAL CHASSIS LAYOUT**

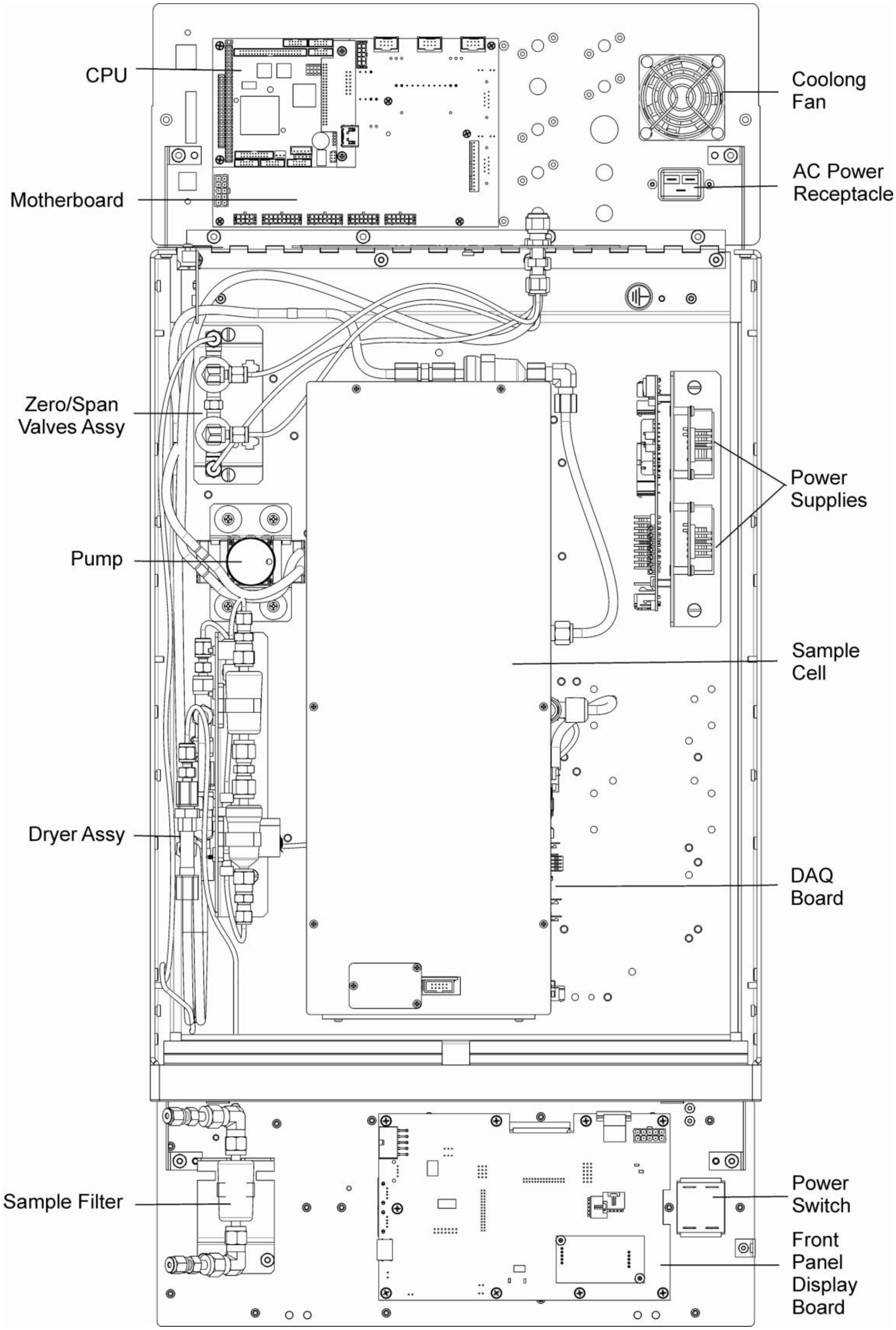


**Figure 3-4: Internal Layout**

# 3.3. CONNECTIONS AND SETUP

This section presents the electrical (Section 3.3.1) and pneumatic (Section 3.3.2) connections for setting up and preparing the instrument for operation.

## 3.3.1. ELECTRICAL CONNECTIONS

**Note** **To maintain compliance with EMC standards, it is required that the cable length be no greater than 3 meters for all I/O connections, which include Analog In, Analog Out, Status Out, Control In, Ethernet/LAN, USB, RS-232, and RS-485.**

**WARNING**
**ELECTRICAL SHOCK HAZARD**

**High Voltages are present inside the analyzer's case.**

**Power connection must have functioning ground connection.**

**Do not defeat the ground wire on power plug.**

**Turn off analyzer power before disconnecting or connecting electrical subassemblies.**

**Do not operate with cover off.**

**CAUTION**
**GENERAL SAFETY HAZARD**

**To avoid damage to your analyzer, ensure that the AC power voltage matches the voltage indicated on the analyzer's model/specs label located on the rear panel before plugging the T500U into line power.**

### 3.3.1.1. CONNECTING POWER

Adhering to all safety and cautionary messages, attach the power cord between the analyzer's AC power connector and a power outlet capable of carrying at least the rated current at your AC voltage range; also ensure that it is equipped with a functioning earth ground.

#### 3.3.1.2. **CONNECTING ANALOG INPUTS (AIN) OPTION**

The Analog In connector is used for connecting external voltage signals from other instrumentation (such as meteorological instruments) and for logging these signals in the analyzer's internal data acquisition system (DAS). The input voltage range for each analog input is 0-10 VDC, and input impedance is nominally 20kΩ in parallel with 0.1µF.

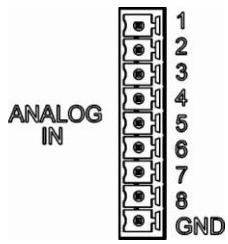


**Figure 3-5: Analog In Connector**

**Table 3-4: Analog Input Pin Assignments**

| PIN | DESCRIPTION | DAS PARAMETER[1] |
|---|---|---|
| 1 | Analog input # 1 | AIN 1 |
| 2 | Analog input # 2 | AIN 2 |
| 3 | Analog input # 3 | AIN 3 |
| 4 | Analog input # 4 | AIN 4 |
| 5 | Analog input # 5 | AIN 5 |
| 6 | Analog input # 6 | AIN 6 |
| 7 | Analog input # 7 | AIN 7 |
| 8 | Analog input # 8 | AIN 8 |
| GND | Analog input Ground | N/A |

[1] See Section 8 for details on setting up the DAS.

#### 3.3.1.3. **CONNECTING ANALOG OUTPUTS**

The T500U is equipped with analog output channels (see rear panel ANALOG OUT connector, Figure 3-3).

Channels **A1** and **A2** output a signal proportional to the $NO_2$ concentration of the sample gas. Both the voltage and concentration range are configurable.

- The default analog output voltage setting of these channels is 0 to 5 VDC with a reporting range of 0 to 500 ppb.
- An optional Current Loop output is available (Section 3.3.1.4).

Channel **A3** is not used.

Channel **A4** can be set by the user to output any one of a variety of diagnostic test functions (see Section **6.8.4**).

- The default analog output voltage setting of this channel is 0 to 5 VDC.
- See Section **6.8.4** for a list of available functions and their associated reporting range.
- There is no optional Current Loop output available for Channel A4.

To access these signals attach a strip chart recorder and/or data-logger to the appropriate analog output connections on the rear panel of the analyzer. Pin-outs for the analog output connector are:

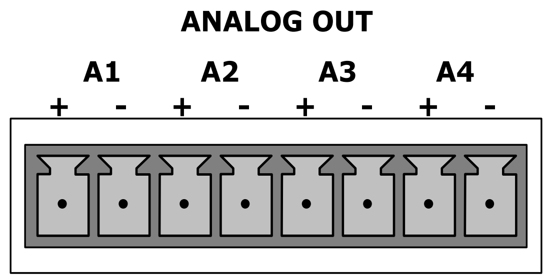


**Figure 3-6: Analog Output Connector**

**Table 3-5: Analog Output Pin Assignments**

| PIN | ANALOG OUTPUT | SIGNAL | STANDARD VOLTAGE OUTPUT | CURRENT LOOP OPTION |
|---|---|---|---|---|
| 1 | A1 | $NO_2$ Concentration* | V Out | I Out + |
| 2 | | | Ground | I Out - |
| 3 | A2 | $NO_2$ Concentration* | V Out | I Out + |
| 4 | | | Ground | I Out - |
| 3 | A3 | (Not Used) | V Out | I Out + |
| 4 | | | Ground | I Out - |
| 7 | A4 | TEST CHANNEL | V Out | Not Available |
| 8 | | | Ground | Not Available |
| * See Section 6.8.3 for analog I/O functions and configuration. | | | | |

To change the settings for the analog output channels, see Section 6.8.2.

### 3.3.1.4. CURRENT LOOP ANALOG OUTPUTS (OPTION 41) SETUP

This option converts the DC voltage analog output to a current signal with 0-20 mA output current. If your analyzer had this option installed at the factory, there are no further connections to be made. Otherwise, it can be installed as a retrofit for each of the analog outputs of the analyzer. 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.

Figure 3-7 provides installation instructions and illustrates a sample combination of one current output and two voltage outputs configuration.

To calibrate or adjust these outputs, see Section 6.8.3.7.

**CAUTION – AVOID INVALIDATING WARRANTY**

**Servicing or handling of circuit components requires electrostatic discharge (ESD) protection, i.e. ESD grounding straps, mats and containers. Failure to use ESD protection when working with electronic assemblies will void the instrument warranty. Please learn more about preventing ESD damage in our manual, *Fundamentals of ESD*, PN 04786, available on our website at http://www.teledyne-api.com in Help Center>Product Manuals, under Special Manuals.**

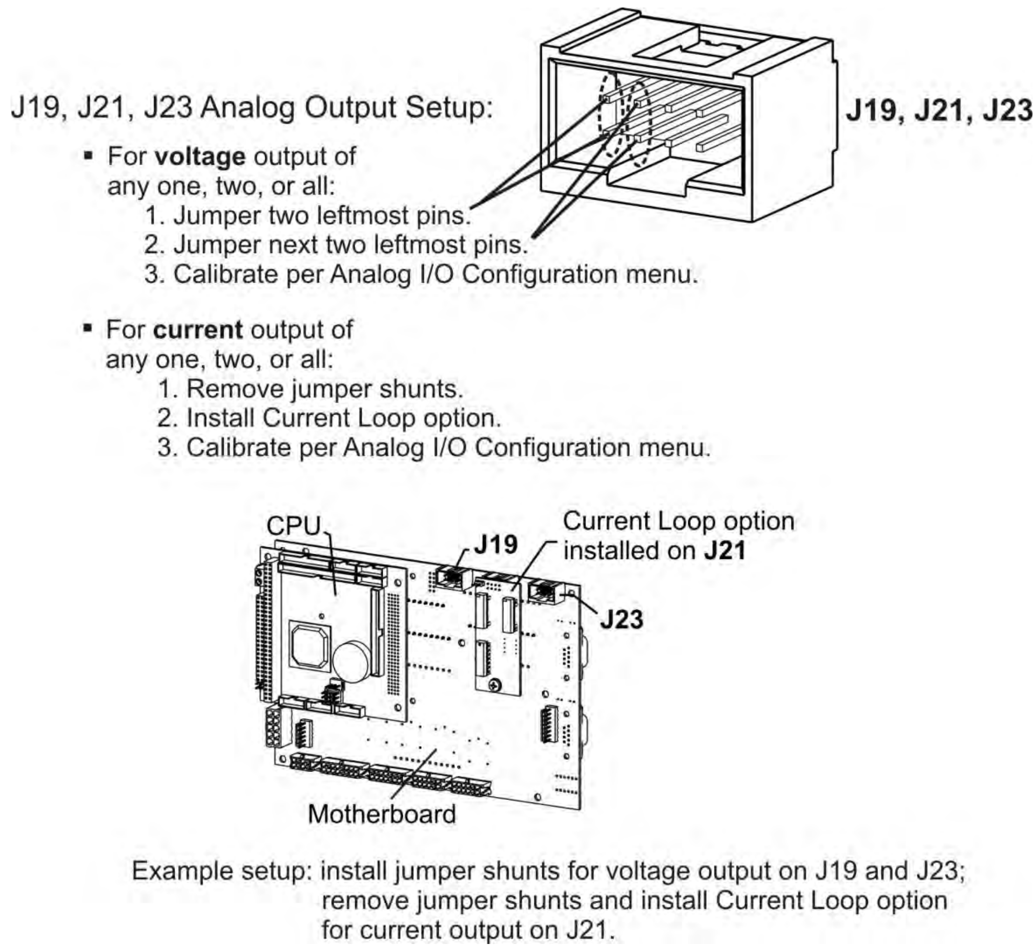


**Figure 3-7: Current Loop Option Installed on the Motherboard**

## *Converting Current Loop Analog Outputs to Standard Voltage Outputs*

This section provides instructions for converting current loop analog outputs to standard 0-to-5 VDC outputs. To convert an output configured for current loop operation to the standard 0 to 5 VDC output operation:

Turn off power to the analyzer.

1. If a recording device was connected to the output being modified, disconnect it.
2. Remove the top cover.

- Remove the set screw located in the top, center of the rear panel.
- Remove the screws fastening the top cover to the unit (one per side).
- Slide the cover back and lift the cover straight up.

3. Remove the screw holding the current loop option to the motherboard.
4. Disconnect the current loop option PCA from the appropriate connector on the motherboard (see Figure 3-7).
5. Each connector, J19 and J23, requires two shunts. Place one shunt on the two leftmost pins and the second shunt on the two adjacent pins (see Figure 3-7).
6. Reattach the top cover to the analyzer.
7. Attach a voltage-sensing, recording device to that output.
8. Calibrate the analog output as described in Section 6.8.3.2.

### 3.3.1.5. CONNECTING THE STATUS OUTPUTS

The Status Outputs report analyzer conditions via optically isolated NPN transistors, which sink up to 50 mA of DC current. These outputs can be used to interface with devices that accept logic-level digital inputs, such as Programmable Logic Controllers (PLCs). Each Status bit is an open collector output that can withstand up to 40 VDC. All of the emitters of these transistors are tied together and available at pin D.

**ATTENTION**

**COULD DAMAGE INSTRUMENT AND VOID WARRANTY**

**Most PLC's have internal provisions for limiting the current that the input will draw from an external device. When connecting to a unit that does not have this feature, an external dropping resistor must be used to limit the current through the transistor output to less than 50 mA. At 50 mA, the transistor will drop approximately 1.2V from its collector to emitter.**

The status outputs are accessed via a rear panel 12-pin connector labeled STATUS (Figure 3-8). Pin-outs for this connector are:

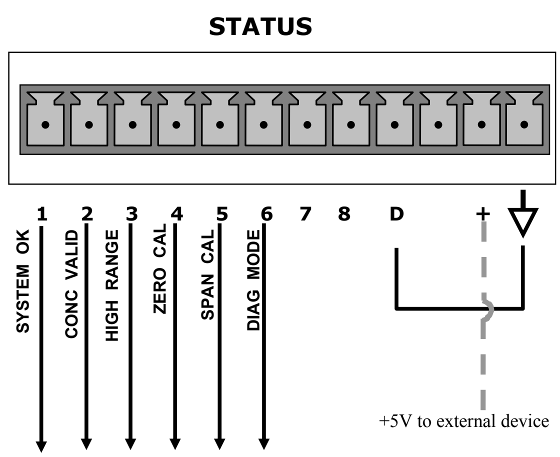


**Figure 3-8: Status Output Connector**

**Table 3-6: Status Output Pin Assignments**

| OUTPUT # | STATUS DEFINITION | CONDITION |
|---|---|---|
| 1 | **SYSTEM OK** | On if no faults are present. |
| 2 | **CONC VALID** | On if $NO_2$ concentration measurement is valid.<br>If the $NO_2$ concentration measurement is invalid, this bit is OFF. |
| 3 | **HIGH RANGE** | On if unit is in high range of DUAL or AUTO Range Modes. |
| 4 | **ZERO CAL** | On whenever the instrument is in **CALZ** mode. |
| 5 | **SPAN CAL** | On whenever the instrument is in **CALS** mode. |
| 6 | **DIAG MODE** | On whenever the instrument is in DIAGNOSTIC mode. |
| 7-8 | SPARE | |
| D | Emitter BUS | The emitters of the transistors on pins 1 to 8 are bussed together. |
| | SPARE | |
| + | DC Power | + 5 VDC, 300 mA source maximum |
| ⏚ | Digital Ground | The ground level from the analyzer's internal DC power supplies. This connection should be used as the ground return when +5VDC power is used. |

### 3.3.1.6. CONNECTING THE CONTROL INPUTS

The 10-pin CONTROL IN connector provides three digital control inputs to remotely activate the zero and span calibration modes.

There are two methods for energizing the Control Inputs. The internal +5V available from the pin labeled "+" is the most convenient method however, to ensure that these inputs are truly isolated; a separate external 5 VDC power supply should be used.

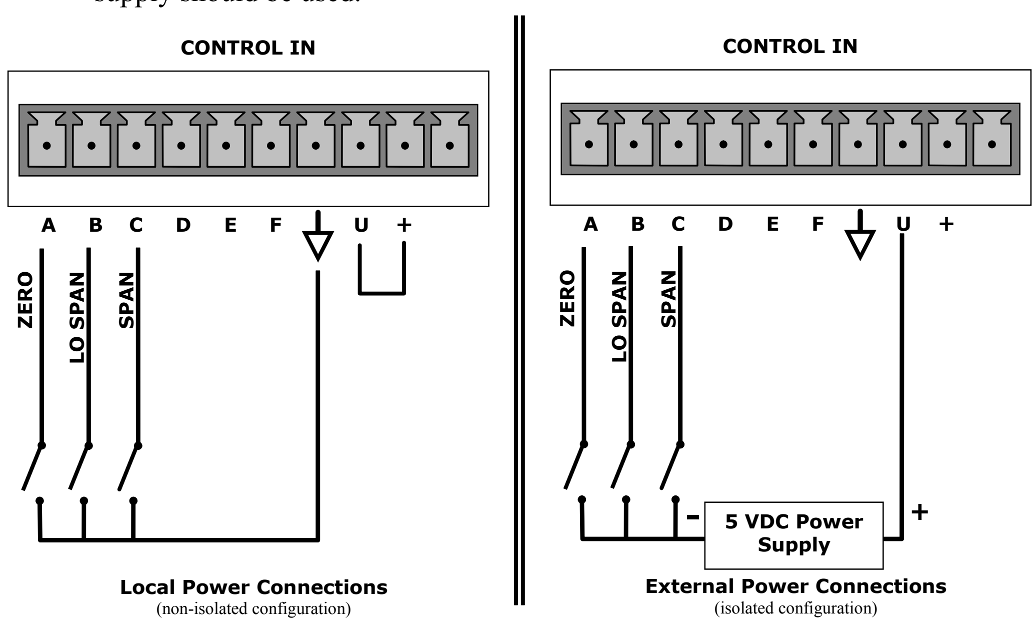


**Figure 3-9: Energizing the Control Inputs**

**Table 3-7: Control Input Pin Assignments**

| 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 LOW SPAN CAL** | The Analyzer is placed in Lo Span Calibration mode. The mode field of the display will read **LO CAL R**. |
| C | **REMOTE SPAN CAL** | The Analyzer is placed in Span Calibration mode. The mode field of the display will read **SPAN CAL R**. |
| D, E & 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). |

## 3.3.1.7. CONCENTRATION ALARM RELAY (OPTION 61)

This option for four (4) "dry contact" relays is different from and in addition to the "Contact Closures" that come standard on all TAPI instruments. Each relay has 3 pins with connections on the rear panel (refer Figure 3-10): Common (C), Normally Open (NO), and Normally Closed (NC).

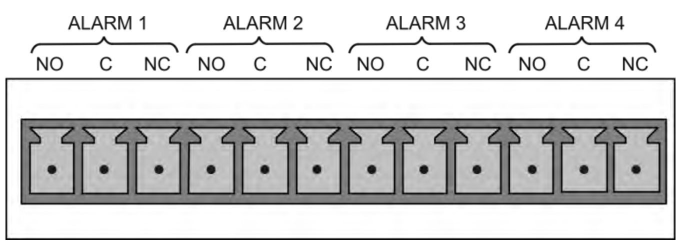


**Figure 3-10: Concentration Alarm Relay**

Alarm 1 "System OK 2"
Alarm 2 "Conc 1"
Alarm 3 "Conc 2"
Alarm 4 "Range Bit"

### *"Alarm 1" Relay*

Alarm 1, which is "System OK 2" (system OK 1, is the status bit), is in the energized state when the instrument is "OK" and there are no warnings. If there is a warning active or if the instrument is put into the "DIAG" mode, Alarm 1 will change states. This alarm has "reverse logic" meaning that if you put a meter across the Common & Normally Closed pins on the connector you will find that it is OPEN when the instrument is OK. This is so that if the instrument should turn off or lose power, it will change states and you can record this with a data logger or other recording device.

### *"Alarm 2" Relay & "Alarm 3" Relay*

The "Alarm 2 Relay" is associated with the "Concentration Alarm 1" set point in the software, and the "Alarm 3 Relay" is associated with the "Concentration Alarm 2" set point in the software.

| | |
|---|---|
| Alarm 2 Relay | $NO_2$ Alarm 1 = xxx PPM |
| Alarm 3 Relay | $NO_2$ Alarm 2 = xxx PPM |

The Alarm Relay activates any time the concentration set-point is exceeded, and will return to its normal state when the concentration value returns below the concentration set-point.

Even though the relay on the rear panel is a NON-Latching alarm & resets when the concentration falls below the alarm set point, the warning on the front panel display will remain latched until it is cleared: either push CLR on the front panel menu or clear the warning through the serial port.

### *"Alarm 4" Relay*

This relay is connected to the "range bit". If the instrument is configured for "Auto Range" and the instrument moves into the high range, it activates this relay.

#### 3.3.1.8. **CONNECTING THE COMMUNICATIONS INTERFACES**

Connectors for remote communications interfaces are: **Ethernet**, **USB**, **RS-232**, **RS-232 Multidrop** and **RS-485** (each described here). In addition to using the appropriate cables, each type of communication method must be configured using the SETUP>COMM menu (see Section 6.6 for a brief description of the SETUP>COMM menu, and Section 7 for communications configuration).

### *Ethernet Connection*

For network or Internet communication with the analyzer, connect an Ethernet cable from the analyzer's rear panel ETHERNET interface connector to an Ethernet port. Although the analyzer is shipped with DHCP enabled by default (Section 7.5.2), it should be manually assigned a static IP address.

**Configuration**: (manual, i.e., static) Section 7.5.1.

## USB Connection

The USB option can be used for direct communication between the analyzer and a PC; connect a USB cable between the analyzer and computer USB ports. This USB connection can only be used when the **COM2** port is not in use except for RS-232 Multidrop communication.

**Configuration**: Section 7.6.

**Note** **If this option is installed, the rear panel COM2 port cannot be used for anything other than Multidrop communication.**

## RS-232 Connection

For **RS-232** communications with data terminal equipment (**DTE**) or with data communication equipment (**DCE**) connect either a DB9-female-to-DB9-female cable (Teledyne API part number WR000077) or a DB9-female-to-DB25-male cable (Option 60A), as applicable, from the analyzer's rear panel RS-232 port to the device. Adjust the rear panel DCE-DTE switch to select DTE or DCE as appropriate (Section 7.1).

**Configuration**: Section 7.3

**IMPORTANT** **IMPACT ON READINGS OR DATA**

**Cables that appear to be compatible because of matching connectors may incorporate internal wiring that makes the link inoperable. Check cables acquired from sources other than Teledyne API for pin assignments (Figure 3-11) before using.**

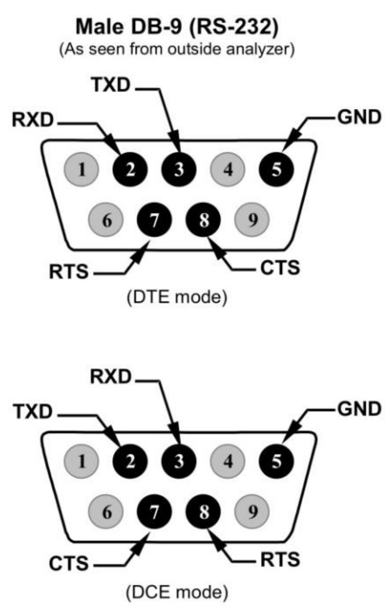


**Figure 3-11: Rear Panel Connector Pin-Outs for RS-232 Mode**

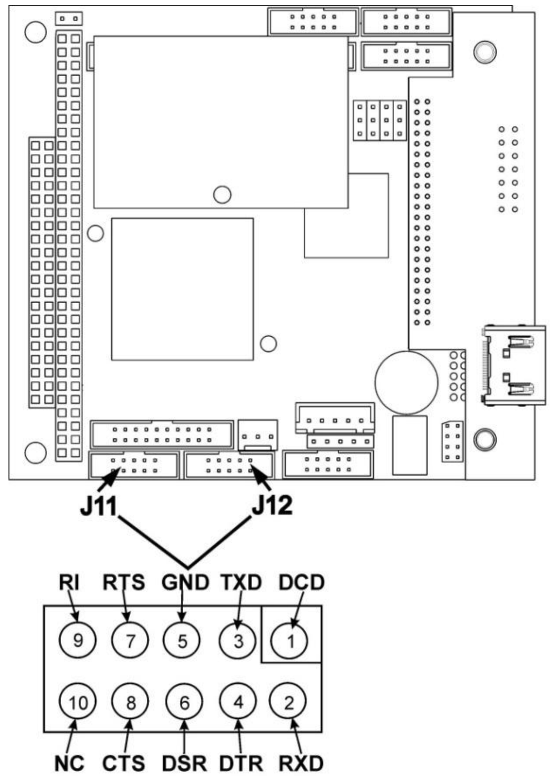


**Figure 3-12: Pin Assignments for J11, J12 Connectors on CPU Board.**

Teledyne API offers either of two mating cables, to select for your use:

- P/N WR000077, a DB-9 female to DB-9 female cable, 6 feet long. Allows connection of the serial ports of most personal computers.
- P/N WR000024, 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 the RS-232 port. Once a cable is connected between the analyzer and a computer or modem, both the red and green LEDs should be on.

- If the lights are not lit, locate the small switch on the rear panel to switch it between DTE and DCE modes.
- If both LEDs are still not illuminated, ensure that the cable properly constructed.

Received from the factory, the analyzer is set up to emulate an RS-232 DCE device.

**RS-232 (COM1)**: RS-232 (fixed) DB-9 male connector

- **Baud rate**: 115200 bits per second (baud)
- **Data Bits**: 8 data bits with 1 stop bit
- **Parity**: None

**COM2**: RS-232 (configurable to RS 485), DB-9 female connector

- Baud rate:19200 bits per second (baud)
- Data Bits: 8 data bits with 1 stop bit
- Parity: None

### *RS-232 Multidrop (Option 62) Connection*

When the RS-232 Multidrop option is installed, connection adjustments and configuration through the menu system are required. This section provides instructions for the internal connection adjustments, then for external connections, and ends with instructions for menu-driven configuration.

**Note** **Because the RS-232 Multidrop option uses both the RS232 and COM2 DB9 connectors on the analyzer's rear panel to connect the chain of instruments, COM2 port is no longer available for separate RS-232 or RS-485 operation.**

**ATTENTION** **COULD DAMAGE INSTRUMENT AND VOID WARRANTY**

**Printed Circuit Assemblies (PCAs) are sensitive to electro-static discharges (ESD) too small to be felt by the human nervous system. Failure to use ESD protection when working with electronic assemblies will void the instrument warranty. Please learn more about preventing ESD damage in our manual, *Fundamentals of ESD*, PN 04786, available on our website at http://www.teledyne-api.com in Help Center>Product Manuals, under Special Manuals.**

In each instrument with the Multidrop option there is a shunt that jumpers two pins on the serial Multidrop and LVDS printed circuit assembly (PCA), as shown in Figure 3-13. This shunt must be removed from all instruments except that designated as last in the multidrop chain, which must remain terminated. This requires powering off and opening each instrument and making the following adjustments:

1. With **NO power** to the instrument, remove its top cover and lay the rear panel open for access to the Multidrop/LVDS PCA, which is seated on the CPU.
2. On the Multidrop/LVDS PCA's JP2 connector, remove the shunt that jumpers Pins 21 ↔ 22 as indicated in. (Do this for all but the last instrument in the chain where the shunt should remain at Pins 21 ↔ 22).
3. Check that the following cable connections are made in *all* instruments (again refer to Figure 3-13):
   - J3 on the Multidrop/LVDS PCA to the CPU's COM1 connector
     (Note that the CPU's COM2 connector is not used in Multidrop)
   - J4 on the Multidrop/LVDS PCA to J12 on the motherboard
   - J1 on the Multidrop/LVDS PCS to the front panel LCD

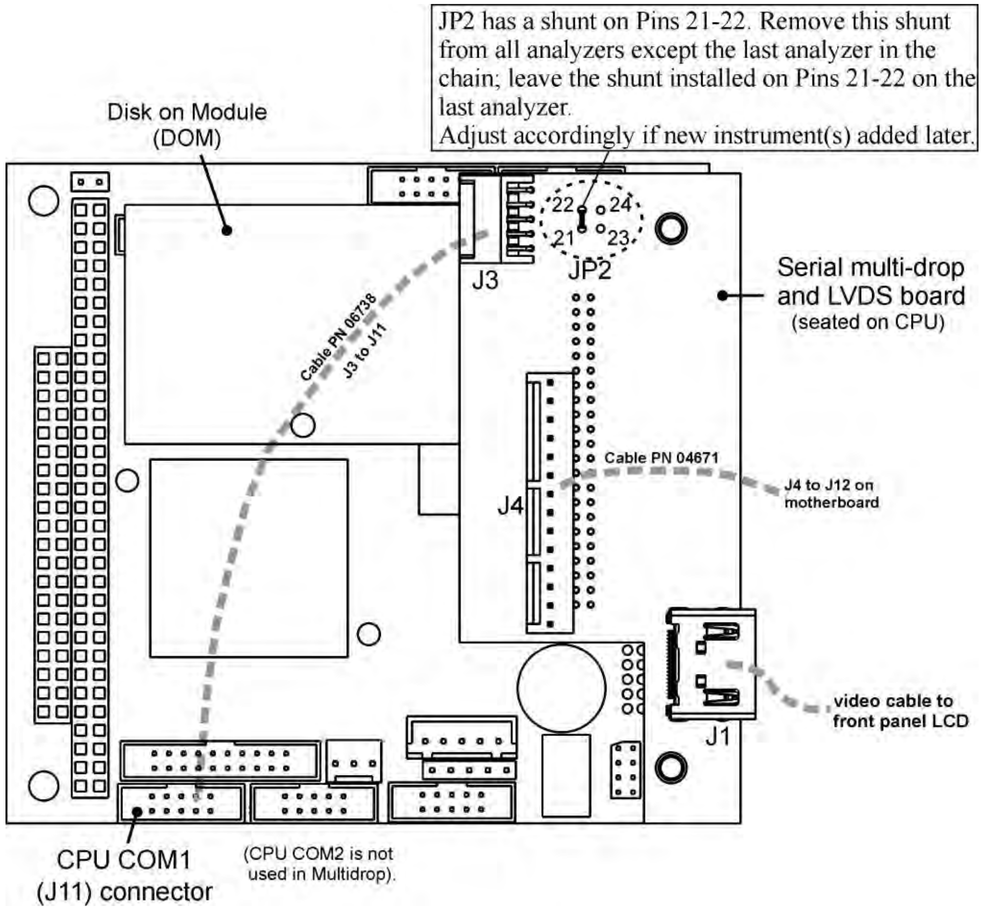


**Figure 3-13: Jumper and Cables for Multidrop Mode**

(Note: If you are adding an instrument to the end of a previously configured chain, remove the shunt between Pins 21 ↔ 22 of JP2 on the Multidrop/LVDS PCA in the instrument that was previously the last instrument in the chain.)

4. Close the instrument.
5. Referring to Figure 3-14 use straight-through DB9 male → DB9 female cables to interconnect the host RS232 port to the first analyzer's RS232 port; then from the first analyzer's COM2 port to the second analyzer's RS232 port; from the second analyzer's COM2 port to the third analyzer's RS232 port, etc., connecting in this fashion up to eight analyzers, subject to the distance limitations of the RS-232 standard.
6. On the rear panel of each analyzer, adjust the DCE DTE switch so that the green and the red LEDs (RX and TX) of the COM1 connector (labeled RS232) are both lit. (Ensure you are using the correct RS-232 cables internally wired specifically for RS-232 communication; see Section 3.3.1.8: Connecting the Communications Interfaces, "RS-232 Connection").

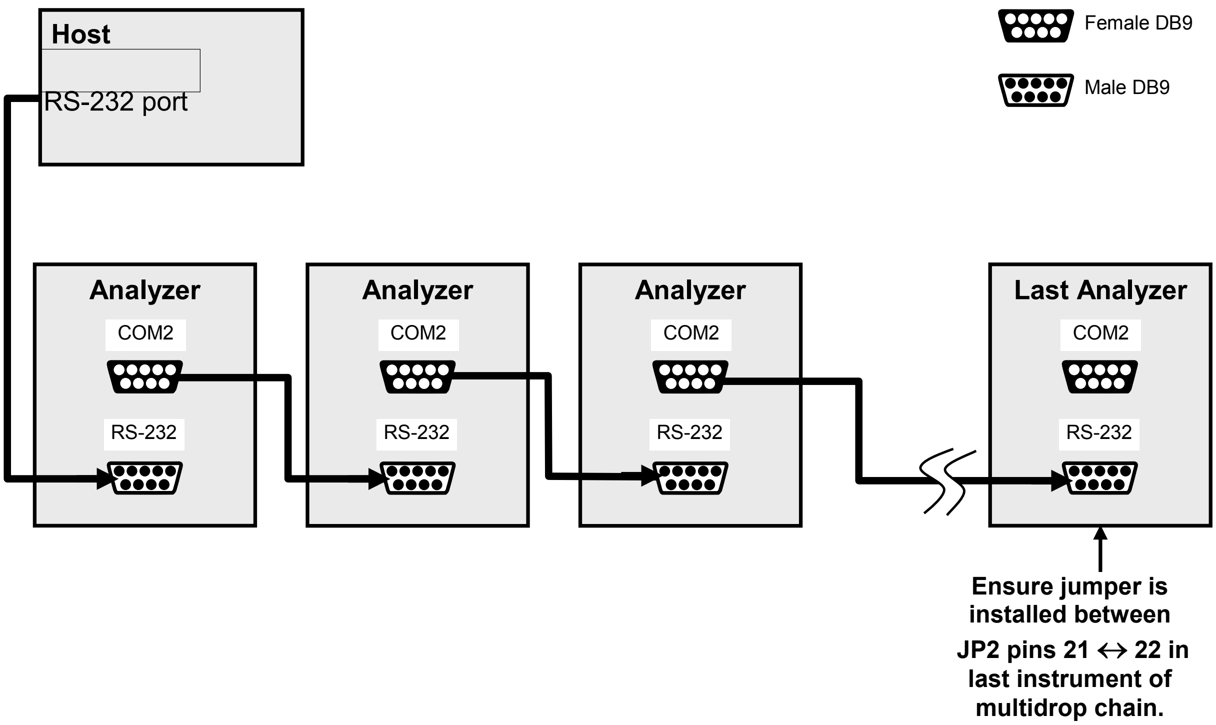


**Figure 3-14: RS-232-Multidrop PCA Host/Analyzer Interconnect Diagram**

7. BEFORE communicating from the host, power on the instruments and check that the Machine ID code is unique for each (Section 6.6.1).
   a. In the SETUP Mode menu go to SETUP>MORE>COMM>ID. The default ID is typically the model number or "0".
   b. to change the identification number, press the button below the digit to be changed.
   c. Press/select ENTER to accept the new ID for that instrument.
8. Next, in the SETUP>MORE>COMM>COM1 menu (do not use the COM2 menu for multidrop), edit the COM1 MODE parameter as follows: press/select EDIT and set only QUIET MODE, COMPUTER MODE, and MULTIDROP MODE to ON. Do not change any other settings.
9. Press/select ENTER to accept the changed settings, and ensure that COM1 MODE now shows 35.
10. Press/select SET> to go to the COM1 BAUD RATE menu and ensure it reads the same for all instruments (edit as needed so that all instruments are set at the same baud rate).

**Note** **The (communication) Host instrument can address only one instrument at a time, each by its unique ID (see step 7 above).**

**Note** **Teledyne API recommends setting up the first link, between the Host and the first analyzer, and testing it before setting up the rest of the chain.**

### *RS-485 Connection (Option)*

As delivered from the factory, **COM2** is configured for RS-232 communications. This port can be reconfigured for operation as a non-isolated, half-duplex RS-485 port. Using COM2 for RS-485 communication will disable the USB port. To reconfigure this port for RS-485 communication, please contact the factory.

## 3.3.2. PNEUMATIC CONNECTIONS

This section provides not only pneumatic connection information, but also important information about the gases required for accurate calibration (Section 3.3.2.1); it also illustrates the pneumatic layout for the analyzer, including valve option.

Before making the pneumatic connections, carefully note the following cautionary and additional messages:

**CAUTION – GENERAL SAFETY HAZARD**

**In units with a permeation tube option installed, the vacuum pump must be connected and powered on to maintain constant gas flow through the analyzer at all times. Insufficient gas flow allows gas to build up to levels that will contaminate the instrument or present a safety hazard to personnel.**

**Remove the permeation tube when taking the analyzer out of operation (Section 11.3.2 provides removal instructions), and store in a sealed container (use original container that tube was shipped in).**

**CAUTION**

**GENERAL SAFETY HAZARD**

**Do not vent calibration gas, exhaust gas or sample gas into enclosed areas.**

**ATTENTION**

**COULD DAMAGE INSTRUMENT AND VOID WARRANTY**

**Venting Pressurized Gas:**

In applications where any gas (span gas, zero air supply, sample gas) is received from a pressurized manifold, a vent must be provided to equalize the gas with ambient atmospheric pressure before it enters the analyzer to ensure that the gases input do not exceed the maximum inlet pressure of the analyzer, as well as to prevent back diffusion and pressure effects. These vents should be:

- **at least 0.2m long**
- **no more than 2m long**
- **vented outside the shelter.**

**Avoiding Introduction of Debris into Optical Cell:**

Sudden, large changes in pressure can forcibly move debris past the filters (sample/exhaust) and into the optical cell. To avoid this, relieve pressure slowly when the system is under vacuum and/or pressure.

**Dust Plugs:**

Remove dust plugs from rear panel exhaust and supply line fittings before powering on/operating instrument. These plugs should be kept for reuse in the event of future storage or shipping to prevent debris from entering the pneumatics.

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Sample and calibration gases should only come into contact with PTFE tubing.**

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Run a leak check once the appropriate pneumatic connections have been made; check all pneumatic fittings for leaks using the procedures defined in Section 11.3.3.**

### 3.3.2.1. ABOUT ZERO AIR AND CALIBRATION (SPAN) GAS

Zero air and span gas are required for accurate calibration.

**Note** **Zero air and span gases must be supplied at twice the instrument's specified gas flow rate. Therefore, the T500U zero and span gases should be supplied to their respective inlets in excess of 1800 $cm^3$/min (~900 $cm^3$/min x 2).**

## *Zero Air*

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.

For the T500U this means zero air should be devoid of $NO_2$ and $H_2O$ vapor.

- If your application is not a measurement in ambient air, the zero calibration gas should be matched to the composition of the gas being measured.
- Pure nitrogen ($N_2$) could be used as a zero gas for applications where $NO_2$ is measured in nitrogen.

## *Calibration (Span) Gas*

Calibration gas is specifically mixed to match the chemical composition of the type of gas being measured at near full scale of the desired reporting range. To measure $NO_2$ with the T500U analyzer, it is recommended that you use a span gas with a concentration equal to 80% of the measurement range for your application

EXAMPLE:

- If the application is to measure $NO_2$ in ambient air between 0 ppb and 500 ppb, an appropriate span gas would be 400 ppb.
- If the application is to measure $NO_2$ in ambient air between 0 ppb and 100 ppb, an appropriate span gas would be 80 ppb.

Cylinders of calibrated $NO_2$ gas traceable to NIST specifications (also referred to as EPA protocol calibration gases or Standard Reference Materials) are commercially available.

**Note** **TAPI recommends the use of $NO_2$ permeation tubes for performing routine calibration checks.**

## *Span Gas for Multipoint Calibration*

Some applications, such as EPA monitoring, require a multipoint calibration where span gases of different concentrations are needed. We recommend using an $NO_2$ gas of higher concentration combined with a gas dilution calibrator such as a Teledyne API Model T700. This type of calibrator mixes a high concentration gas with zero air to accurately produce span gas of the desired concentration. Linearity profiles can be automated with this model and run unattended overnight.

If a dynamic dilution system such as the Teledyne API Model T700 is used to dilute high concentration gas standards to low, ambient concentrations, ensure that the $NO_2$ concentration of the reference gas matches the dilution range of the calibrator.

Choose the $NO_2$ gas concentration so that the dynamic dilution system operates in its mid-range and not at the extremes of its dilution capabilities.

EXAMPLE:

- A dilution calibrator with 10-1000 dilution ratio will not be able to accurately dilute a 5000 ppm $NO_2$ gas to a final concentration of 500 ppb, as this would operate at the very extreme dilution setting.
- A 50 ppm $NO_2$ gas in nitrogen is much more suitable to calibrate the T500U analyzer (dilution ratio of 200, in the mid-range of the system's capabilities).

### 3.3.2.2. BASIC CONNECTIONS FROM CALIBRATOR, WITH AND WITHOUT SPAN GAS

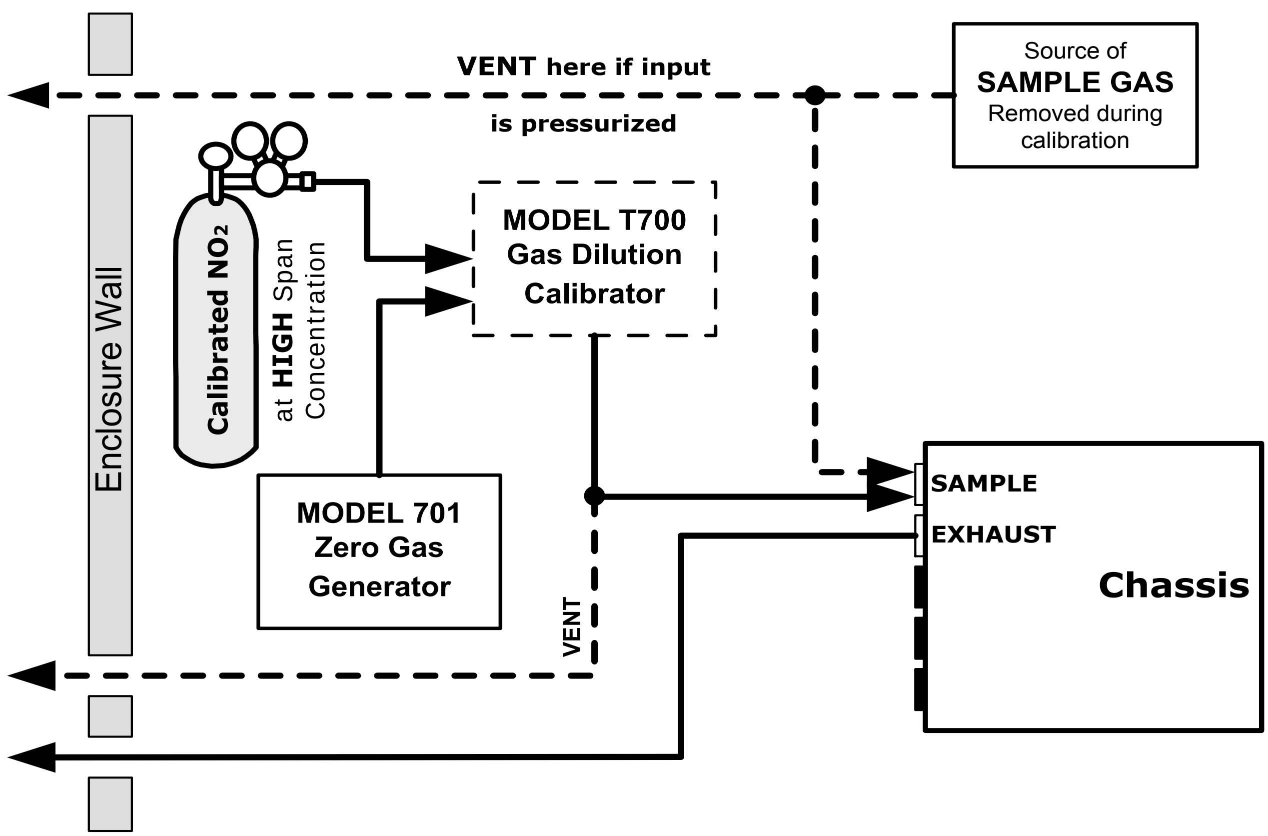


**Figure 3-15: Gas Line Connections from Calibrator – Basic T500U Configuration**

For the T500U analyzer in its basic configuration, attach the following pneumatic lines:

### *Sample Gas Source*

Connect a sample gas line to the SAMPLE inlet

- Use PTFE tubing; minimum OD ¼”.
- Sample Gas pressure must not exceed ambient atmospheric pressure by more than 1.0 psig.
- Follow cautionary guidelines for pressurized manifold.

### *Calibration Gas Sources*

- **CAL GAS & ZERO AIR SOURCES**: The source of calibration gas is also attached to the **SAMPLE** inlet, but only when a calibration operation is actually being performed.
  - Use PTFE tubing; minimum OD ¼”.

### *Venting*

In order to prevent back diffusion and pressure effects, both the span gas and zero air supply lines should be:

- Vented outside the shelter.
- Minimum OD ¼”.
- No less than 2 meters in length.
- No greater than 10 meters in length.

### *Exhaust Outlet*

Attach an exhaust line to the EXHAUST outlet fitting. The exhaust line should be:

- Use PTFE tubing; minimum OD ¼”.
- No greater than 10 meters in length.
- Vented outside the shelter.

**Note**

**Once the appropriate pneumatic connections have been made, check all pneumatic fittings for leaks using the procedures defined in Sections 11.3.3 (or 11.3.3.1 for detailed check if leak suspected).**

## Pneumatic Layouts

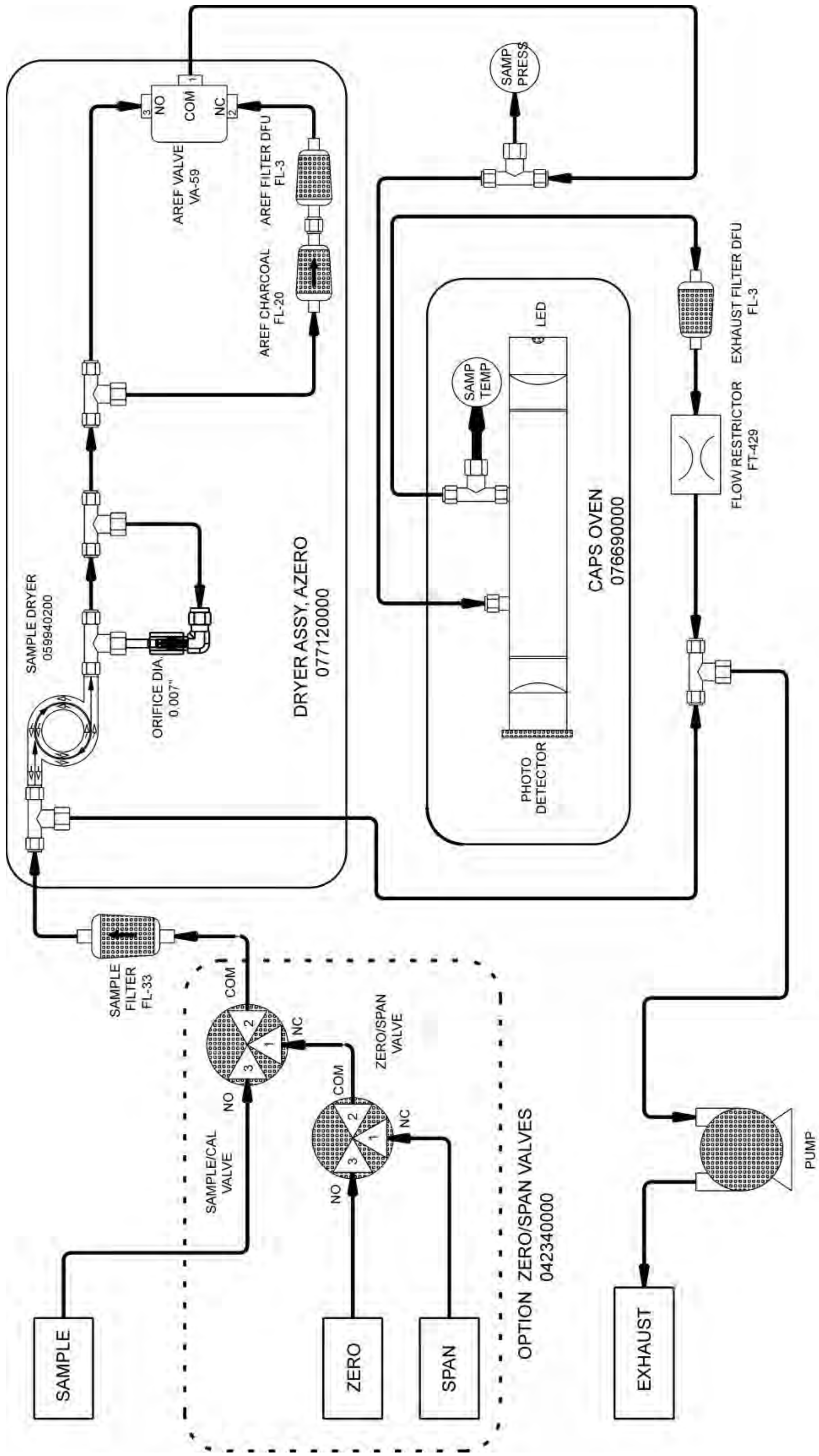


**Figure 3-16: T500U Pneumatics with Zero Span Valves Option**

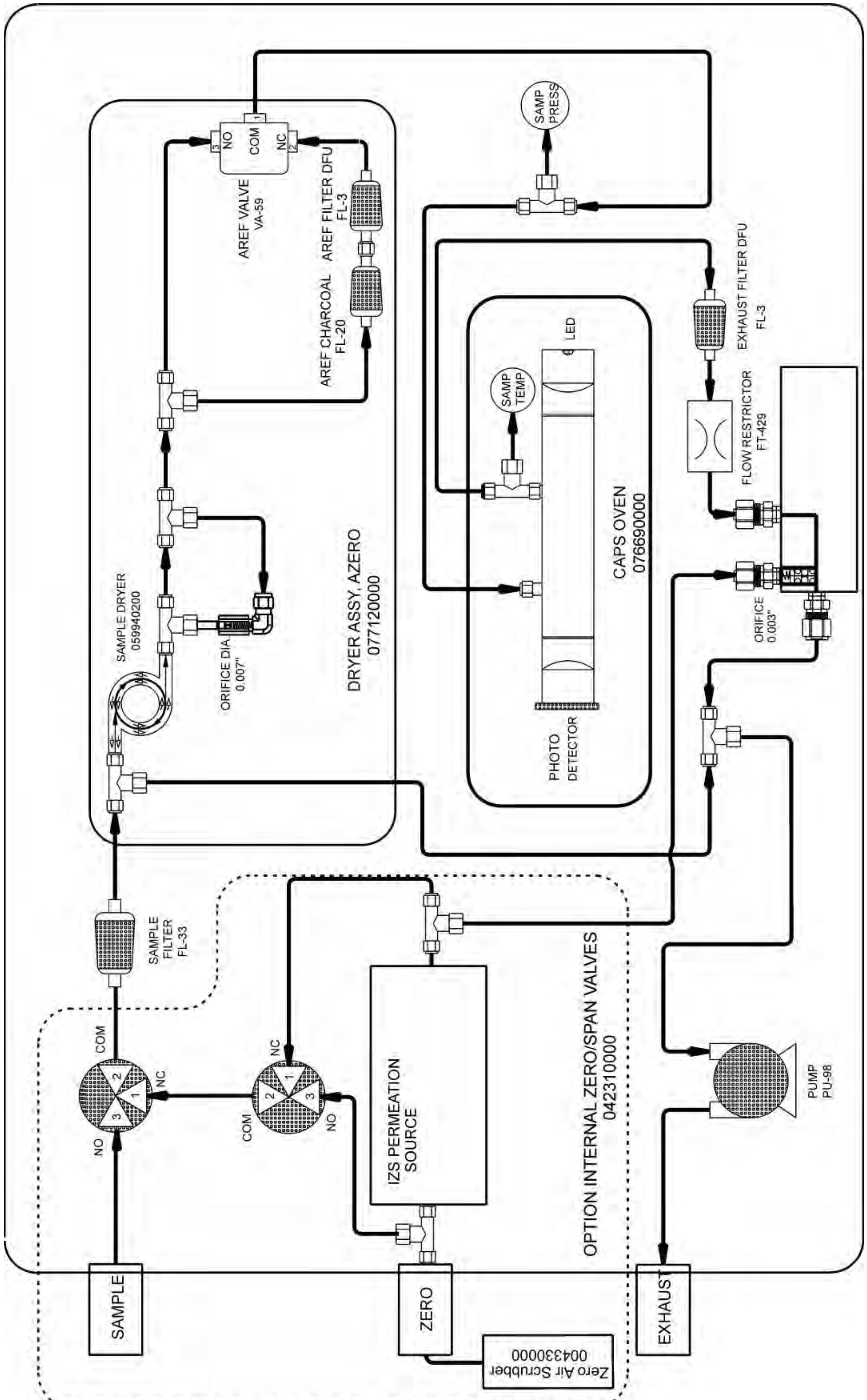


**Figure 3-17: T500U Pneumatics with Internal Zero Span Valves Option**

# 4. OVERVIEW OF OPERATING MODES

To assist in navigating the analyzer's software, a series of menu trees is available for reference in Appendix A of this manual.

**Note** **Some control buttons on the touch screen do not appear if they are not applicable to the operation at hand or if an invalid setting was input.**

The T500U analyzer software has several operating modes, the most commonly used of which is the **SAMPLE** mode. In this mode, a continuous read-out of the $NO_2$ concentration can be viewed on the front panel and output as an analog voltage from rear panel terminals.

The second most commonly used operating mode is **SETUP**, which is used to configure the various subsystems, such as the Data Acquisition System (DAS), the reporting ranges, or the communication channels. **SETUP** mode is also used for performing various diagnostic tests during troubleshooting.

Figure 4-1 shows in the Mode field that the unit is operating in SAMPLE Mode.


**Figure 4-1: Front Panel Display**

Table 4-1 describes other operating modes

**Table 4-1: Analyzer Operating Modes**

| MODE | EXPLANATION |
|---|---|
| **DIAG** | One of the analyzer's diagnostic modes is active. |
| **AREF** | Periodically an internal valve activates diverting the sample gas through a charcoal scrubber. The auto reference value is measured during this period. |
| **LO CAL A** | Unit is performing LOW SPAN calibration initiated automatically by the analyzer's AUTOCAL feature |
| **LO CAL R** | Unit is performing LOW SPAN calibration initiated remotely through the COM ports or digital control inputs. |
| **M-P CAL** | This is the basic calibration mode of the instrument and is activated by pressing the CAL button. |
| **SAMPLE** | Sampling normally, flashing text indicates the adaptive filter has tripped due to a change in concentration. |
| **SETUP** | SETUP mode is being used to configure the analyzer. The gas measurement will continue during setup. |
| **SAMPLE A**[1] | Indicates that unit is in SAMPLE mode and AUTOCAL feature is activated. |
| **SPAN CAL A**[1] | Unit is performing SPAN calibration initiated automatically by the analyzer's AUTOCAL feature |
| **SPAN CAL M**[1] | Unit is performing SPAN calibration initiated manually by the user. |
| **SPAN CAL R**[1] | Unit is performing SPAN calibration initiated remotely through the COM ports or digital control inputs. |
| **ZERO CAL A**[1] | Unit is performing ZERO calibration procedure initiated automatically by the AUTOCAL feature |
| **ZERO CAL M**[1] | Unit is performing ZERO calibration procedure initiated manually by the user. |
| **ZERO CAL R**[1] | Unit is performing ZERO calibration procedure initiated remotely through the COM ports or digital control inputs. |
| [1] Only Appears on units with the Z/S or IZS valve option. | |

# 4.1. SAMPLE MODE

SAMPLE is the standard operating mode. In this mode, the instrument is continually calculating the $NO_2$ concentration. These values are displayed in the **CONC** field of the analyzer's front panel display during **SAMPLE** mode.

Also in this mode the **PARAM** field will display any warning messages (Section 4.1.2) as well as the test functions (Section 4.1.1), which provide information about the operational status of the analyzer.

## 4.1.1. TEST FUNCTIONS

**TEST** functions provide information about the various parameters related to the analyzer's operation and its measurement of gas concentration. Section 5.2 provides information about these functions.

### 4.1.2. WARNING MESSAGES

The most common and serious instrument failures will activate Warning Messages, which are displayed on the analyzer's Front Panel. A table of Warning Messages and their descriptions is presented in Table 5-1, Section 5.1.1.

## 4.2. CALIBRATION MODE

**Note** **Always perform Zero calibration *before* Span calibration.**

Pressing the CAL button, switches the analyzer into calibration mode. In this mode the user can, in conjunction with introducing zero or span gases of known concentrations into the analyzer cause it to adjust and recalculate the slope (gain) and offset of its measurement range.

**Note** **This mode is also used to check the current calibration status of the instrument.**

If the instrument includes one of the available zero/span valve options, the **SAMPLE** mode display will also include **CALZ** and **CALS** buttons. Pressing either of these buttons also puts the instrument into calibration mode.

- The **CALZ** button is used to initiate a calibration of the analyzer's zero point using zero air.
- The **CALS** button is used to calibrate the span point of the analyzer's current reporting range using span gas.

**Note** **It is recommended that this span calibration be performed at 80% of full scale of the analyzer's currently selected reporting range.**

**EXAMPLE:**

**If the reporting range is set for 0 to 500 ppb, an appropriate span point would be 400 ppb.**

Due to their critical importance and complexity, calibration operations are described in in Section 10, which details setting up and performing standard calibration operations or checks.

For information on using the automatic calibrations feature (**ACAL**) in conjunction with the calibration valve options, see Sections 10.4.6 and 10.5.

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**To avoid inadvertent adjustments to critical settings, activate calibration security by enabling password protection in the SETUP – PASS menu.**

# 4.3. SETUP MODE

The SETUP Mode contains a variety of choices that are used to configure the analyzer's hardware and software features, perform diagnostic procedures, gather information on the instruments performance and configure or access data from the internal data acquisition system (DAS). For a visual representation of the software menu trees, refer to Appendix A.

SETUP Mode is divided between Primary and Secondary Setup menus and can be protected through password security through the SETUP>PASS menu (Section 6.4) to prevent unauthorized or inadvertent configuration adjustments.

## 4.3.1. PRIMARY SETUP MENU

The areas accessed and configured under the primary SETUP Mode menu are shown in Table 4-2.

**Table 4-2: Primary Setup Mode Features and Functions**

| MODE OR FEATURE | CONTROL BUTTON LABEL | DESCRIPTION |
|---|---|---|
| Analyzer Configuration | **CFG** | Lists button hardware and software configuration information. |
| *Auto Cal Feature* | ***ACAL*** | *Used to set up and operate the AutoCal feature.*<br>*(Only appears if the Zero/Span valve option is installed).* |
| Internal Data Acquisition (DAS) | **DAS** | Used to set up the DAS system and view recorded data. |
| Analog Output Reporting Range Configuration | **RNGE** | Used to configure the output signals generated by the instrument's analog outputs. |
| Calibration Password Security | **PASS** | Turns the calibration password feature ON/OFF. |
| Internal Clock Configuration | **CLK** | Used to set or adjust the instrument's internal clock. |
| (Advanced **SETUP** features) | **MORE** | Jumps to the secondary setup menu. |

## 4.3.2. SECONDARY SETUP MENU (SETUP →MORE)

Table 4-3 presents advanced feature under the secondary SETUP Mode menu.

**Table 4-3: Secondary Setup Mode Features and Functions**

| MODE OR FEATURE | CONTROL BUTTON LABEL | DESCRIPTION |
|---|---|---|
| External Communication Channel Configuration | **COMM** | Used to set up and operate the analyzer's various external I/O channels including RS-232; RS-485, modem communication and/or Ethernet access. |
| System Status Variables | **VARS** | Used to view various variables related to the instruments current operational status.<br>• Changes made to any variable are not acknowledged and recorded in the instrument's memory until the **ENTR** button is pressed.<br>• Pressing the **EXIT** button ignores the new setting.<br>• If the **EXIT** button is pressed before the **ENTR** button, the analyzer will beep alerting the user that the newly entered value has been lost. |
| System Diagnostic Features and Analog Output Configuration | **DIAG** | Used to access a variety of functions that are used to configure, test or diagnose problems with a variety of the analyzer's basic systems.<br>Most notably, the menus used to configure the output signals generated by the instruments' analog outputs are located here. |
| Auto Reference | **AREF** | Can be used to expedite the AREF loss measurement prior to conducting a Zero/Span calibration.<br>Note that AREF is disabled during calibrations until the unit is placed back in SAMPLE mode. |
| Alarm option (if installed) | **ALRM** | Used to provide notice when concentration values are out of range. (Only appears if the Alarm option is installed). |

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Any changes made to a variable during the SETUP procedures are not acknowledged by the instrument until the ENTR button is pressed. If the EXIT button is pressed before the ENTR button, the analyzer will make an audible signal before exiting the menu, alerting the user that the newly entered value had not been accepted.**

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# 5. STARTUP, FUNCTIONAL CHECKS, AND INITIAL CALIBRATION

## 5.1. STARTUP

For accurate results, allow the monitor to run for at least 60 minutes to reach a stable operating temperature.

### 5.1.1. WARNING MESSAGES

Because internal temperatures and other conditions may be outside the specified limits during the analyzer's warm-up period, the software will suppress most warning conditions for 45 minutes after power up. If warning messages persist after the 45 minutes warm up period is over, investigate their cause using the troubleshooting guidelines in Section 13.1.

To view and clear warning messages, press:

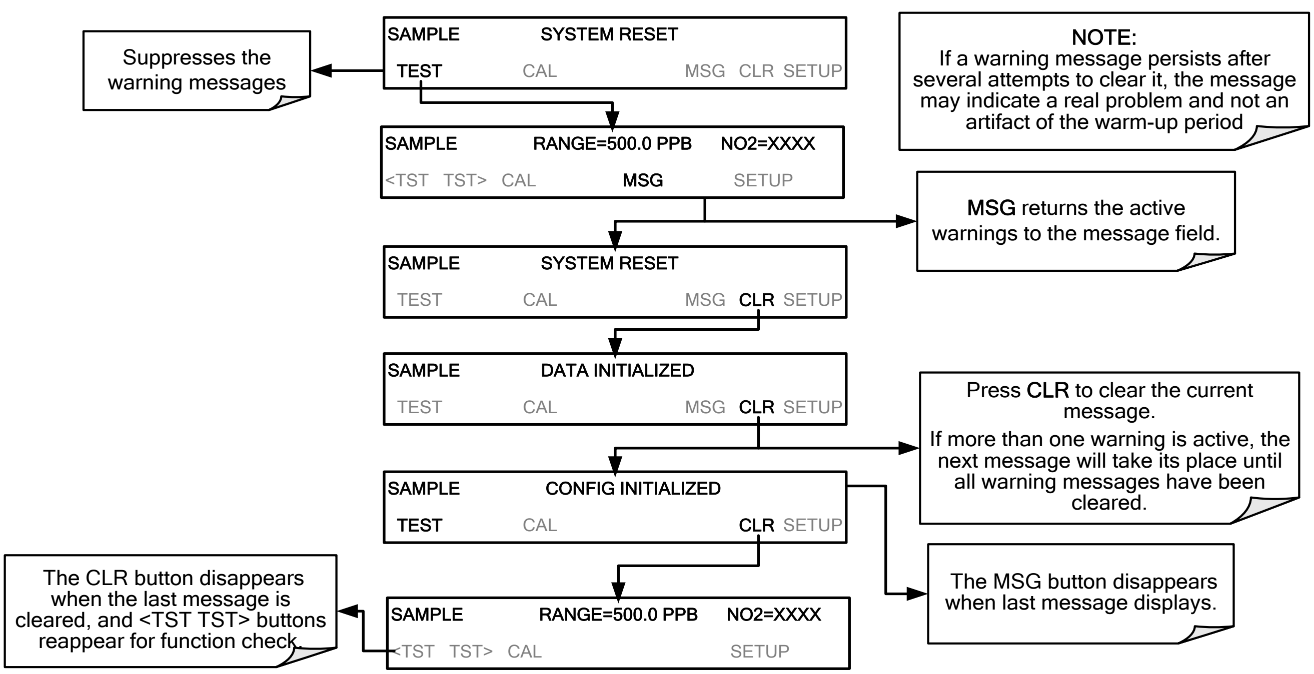


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**Table 5-1: Possible Warning Messages at Start-Up**

| Message Text | Description |
|---|---|
| **SYSTEM SERVICE** | System service interval has elapsed, per hours specified by *SVC_INTERVAL* variable. |
| **SYSTEM RESET**[1] | Instrument was power-cycled or the CPU was reset. |
| **CONFIG INITIALIZED** | Configuration storage was reset to factory configuration or erased. |
| **DATA INITIALIZED** | Data storage was erased. |
| **CANNOT DYN ZERO**[2] | Contact closure zero calibration failed while *DYN_ZERO* was set to *ON*. |
| **CANNOT DYN SPAN**[3] | Contact closure span calibration failed while *DYN_SPAN* was set to *ON*. |
| **$NO_2$ ALARM1 WARN**[4] | $NO_2$ concentration alarm limit #1 exceeded |
| **$NO_2$ ALARM2 WARN**[4] | $NO_2$ concentration alarm limit #2 exceeded |
| **MANIFOLD TEMP WARN**[4] | Manifold temperature outside of warning limits specified by *MANIFOLD_SET* variable. |
| **IZS TEMP WARNING**[4] | IZS Oven temperature outside of warning limits specified by *IZS_SET* variable. |
| **OVEN TEMP WARNING** | Oven temperature outside of warning limits specified by *OVEN_TEMP_SET* variable. |
| **SAMPLE PRESS WARN** | Sample pressure outside of warning limits specified by *SAMP_PRESS_SET* variable. |
| **SAMPLE TEMP WARN** | Sample temperature outside of warning limits specified by *SAMP_TEMP_SET* variable. |
| **BOX TEMP WARNING** | Chassis temperature outside of warning limits specified by *BOX_SET* variable. |
| **AUTO REF WARNING**[5] | Auto-ref value outside of limit specified by *AREF_LIMIT* variable. |
| **REAR BOARD NOT DET** | Rear board was not detected during power up. |
| **RELAY BOARD WARN** | Firmware is unable to communicate with the relay board. |
| **FRONT PANEL WARN** | Firmware is unable to communicate with the front panel. |
| **INTERNAL PUMP OFF** | Internal pump is not running. |
| **ANALOG CAL WARNING** | The A/D or at least one D/A channel has not been calibrated. |

[1] Cleared 45 minutes after power up.
[2] Cleared the next time successful zero calibration is performed.
[3] Cleared the next time successful span calibration is performed.
[4] Options Installed: Concentration alarm, Manifold, and Permeation Oven.
[5] Applies when AREF is enabled.

# 5.2. FUNCTIONAL CHECKS

After warm-up, verify that the software properly supports any hardware options that are installed and that the analyzer is functioning within allowable operating parameters (Appendix C shows the list of test functions and their expected values; the enclosed *Final Test and Validation Data sheet* lists these values as they appeared before the instrument left the factory).

These functions can also be used as diagnostic tools for troubleshooting a performance problem (see Section 13). To view the current values of these parameters on the analyzer’s front panel press the button sequence illustrated as follows.

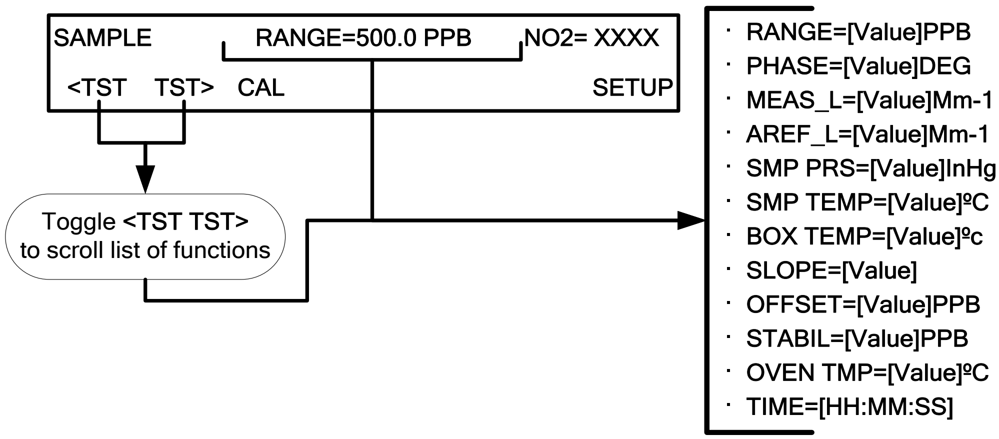



**Table 5-2: Test Functions Defined**

| DISPLAY | PARAMETER | UNITS | DESCRIPTION |
|---|---|---|---|
| **RANGE** | RANGE | PPB<br>PPM<br>UGM<br>MGM | The Full Scale limit at which the reporting range of the analyzer's ANALOG OUTPUTS is currently set.<br>**THIS IS NOT** the Physical Range of the instrument. See Section 6.3 for more information. |
| **PHASE** | PHASE | DEG | Measurement phase value. |
| **MEAS_L** | MEASURE LOSS | $Mm^{-1}$ | Measurement loss value. (Mega ($10^6$) per meter) |
| **AREF_L** | AUTOREF LOSS | $Mm^{-1}$ | Auto reference value (to null any baseline drift from the measurement). |
| **SMP PRS** | SAMPRESS | InHg | Sample pressure. |
| **SMP TEMP** | SAMPTEMP | ºC | Sample temperature. |
| **BOX TEMP** | BOXTEMP | ºC | Temperature inside the analyzer chassis. |
| **SLOPE** | SLOPE | n/a | The slope for current range, computed during span calibration. |
| **OFFSET** | OFFSET | PPB | The offset for current range, computed during zero calibration. |
| **STABIL** | STABILITY | PPB | The standard deviation of concentration STABILITY<br>• Data points are recorded every ten seconds (default; this frequency can be changed in the STABIL_FREQ variable).<br>• The calculation uses the last 25 data points (default; this number of samples can be changed in the STABIL_SAMPLES variable). |
| **OVEN TMP** | OVEN TEMP | ºC | Oven temperature |
| **TEST*** | TESTCHAN | MV | *(When DIAG>TEST CHAN OUTPUT is configured for a test function). Displays the signal level of the Test Function that is currently being produced by the Analog Output Channel **A4**. |
| **TIME** | CLOCKTIME | HH:MM:SS | The current time. This is used to create a time stamp on DAS readings, and by the AutoCal feature to trigger calibration events. |

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**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. 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.**

# 5.3. INITIAL CALIBRATION

This section provides the initial calibration procedures. To perform the following calibration, sources for zero air and calibration (span) gas are required for input into the inlet/outlet fittings on the back of the analyzer (see Section 3.3.2.1).

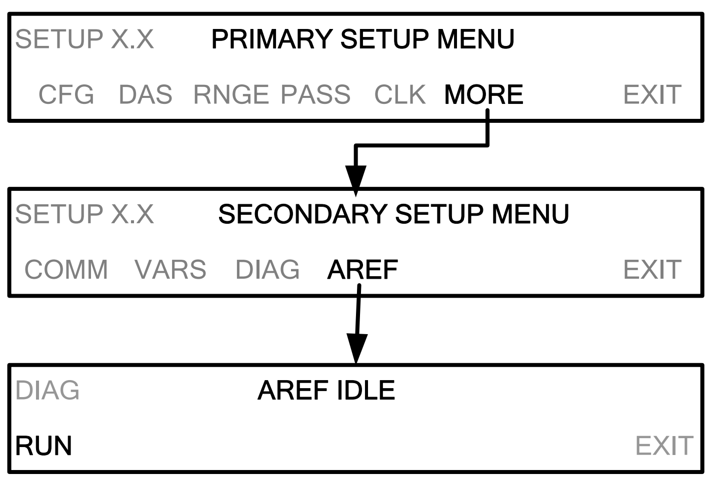
**Note** **A start-up period of 4-5 hours is recommended prior to performing a calibration on the analyzer.**

The method for performing an initial calibration for the T500U nitrogen dioxide analyzer differs slightly depending on whether valve options are installed.

- See Section 5.3.1 for instructions for initial calibration of the T500U analyzers in their base configuration.
- See Sections 10.4 and 10.4.6 for information regarding setup and calibration of T500U analyzers with Z/S Valve options.

In either case, any time an initial calibration is in order, i.e. starting the analyzer for the first time or after maintenance on the mirrors, conducting a manual AREF may be required (Auto Reference: reference loss measurement). This expedites the AREF_L value to match current measurements. The AREF_L value is based on the average of the last four readings taken one hour apart. Repeat the process if large changes in the AREF_L value occur. Both the AREF_L and MEAS_L readings should be similar while sampling zero air.

To run a manual AREF, press SETUP>MORE>AREF>RUN:




Press RUN to run the AREF feature; message reads, AREF RUNNING, and the RUN button becomes the STOP button. Press EXIT to return to the Secondary Setup menu and allow the auto reference feature to complete its course.

## 5.3.1. INITIAL CALIBRATION PROCEDURE FOR T500U ANALYZERS WITHOUT VALVE OPTIONS

The following procedure assumes that:

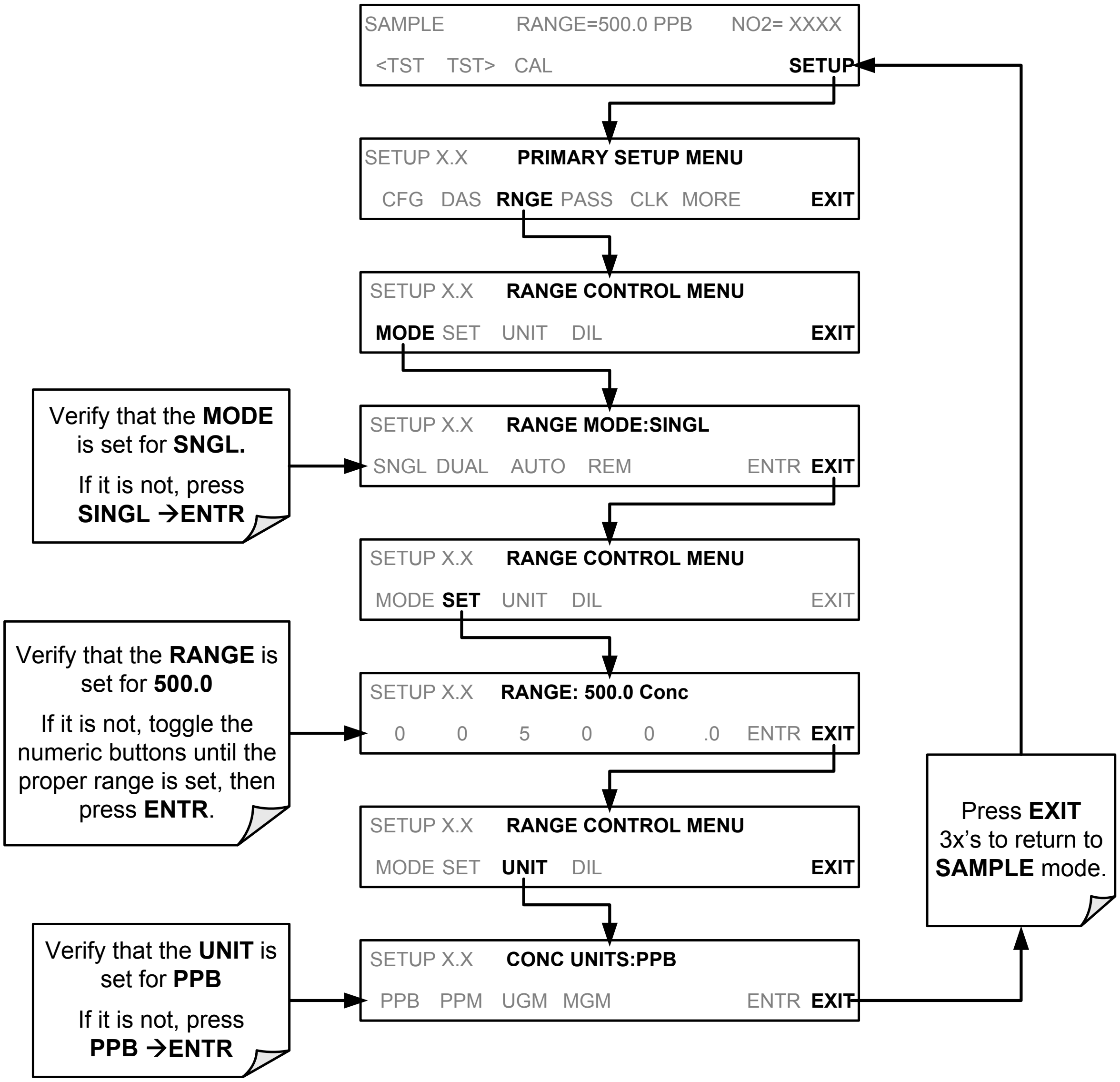
- The instrument DOES NOT have any of the available calibration valve or gas inlet options installed.
- Cal gas will be supplied through the SAMPLE gas inlet on the back of the analyzer, and
- The pneumatic setup matches that described in Section 3.3.2.2.

### 5.3.1.1. VERIFYING THE REPORTING RANGE SETTINGS

While it is possible to perform the following procedure with any range setting, we recommend that you perform this initial checkout using the following reporting range settings:

- Unit of Measure: PPB
- Reporting Range: 500 ppb
- Mode Setting: SNGL

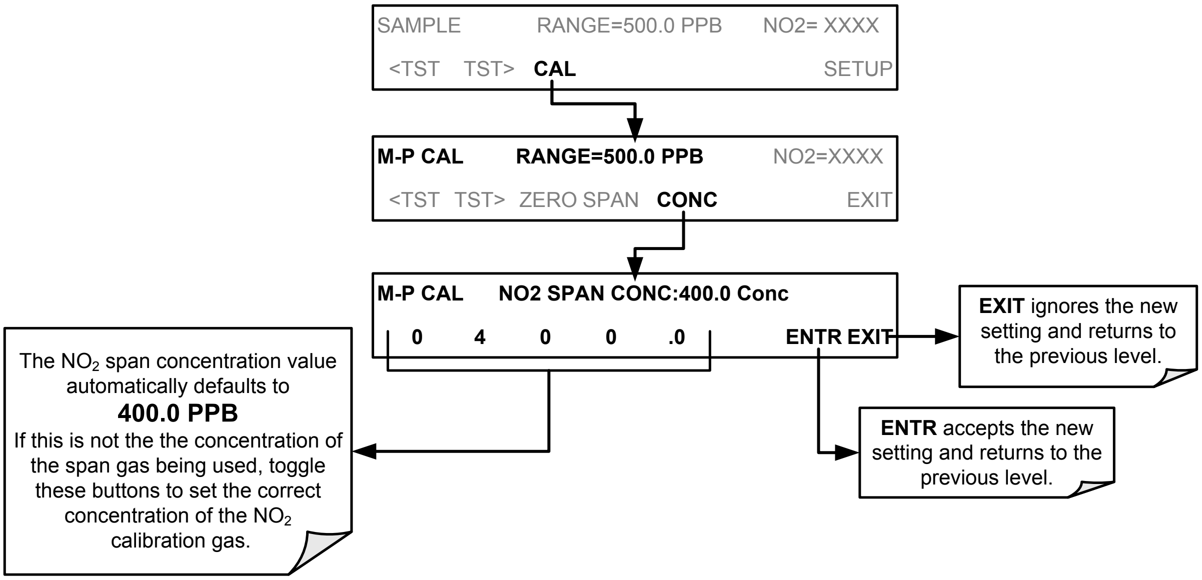
While these are the default settings for the T500U analyzer, it is recommended that you verify them before proceeding with the calibration procedure, by pressing the following menu button sequence:


SAMPLE RANGE=500.0 PPB NO2= XXXX
<TST TST> CAL SETUP
SETUP X.X PRIMARY SETUP MENU
CFG DAS RNGE PASS CLK MORE EXIT
SETUP X.X RANGE CONTROL MENU
MODE SET UNIT DIL EXIT
Verify that the MODE is set for SNGL.
If it is not, press SINGL →ENTR
SETUP X.X RANGE MODE:SINGL
SNGL DUAL AUTO REM ENTR EXIT
SETUP X.X RANGE CONTROL MENU
MODE SET UNIT DIL EXIT
Verify that the RANGE is set for 500.0
If it is not, toggle the numeric buttons until the proper range is set, then press ENTR.
SETUP X.X RANGE: 500.0 Conc
0 0 5 0 0 .0 ENTR EXIT
SETUP X.X RANGE CONTROL MENU
MODE SET UNIT DIL EXIT
Press EXIT 3x's to return to SAMPLE mode.
Verify that the UNIT is set for PPB
If it is not, press PPB →ENTR
SETUP X.X CONC UNITS:PPB
PPB PPM UGM MGM ENTR EXIT

### 5.3.1.2. VERIFYING THE EXPECTED $NO_2$ SPAN GAS CONCENTRATION

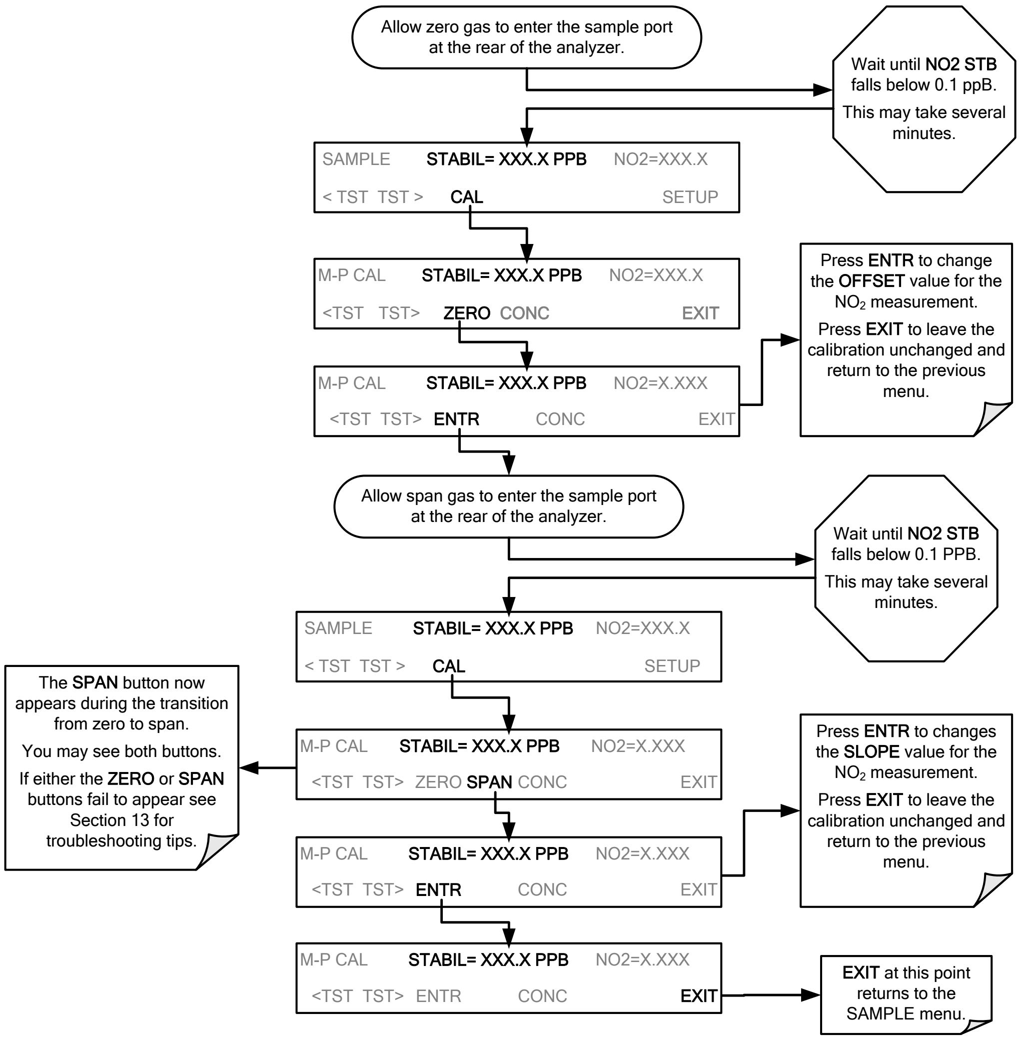
The $NO_2$ span concentration value automatically defaults to **400.0 PPB** and it is recommended that calibration gases of that concentration be used for the initial calibration of the unit.

To verify that the analyzer span setting is set for **400 PPB**, press:



### 5.3.1.3. INITIAL ZERO/SPAN CALIBRATION PROCEDURE

To perform an initial calibration, press:




The T500U analyzer is now ready for operation.

**Note**

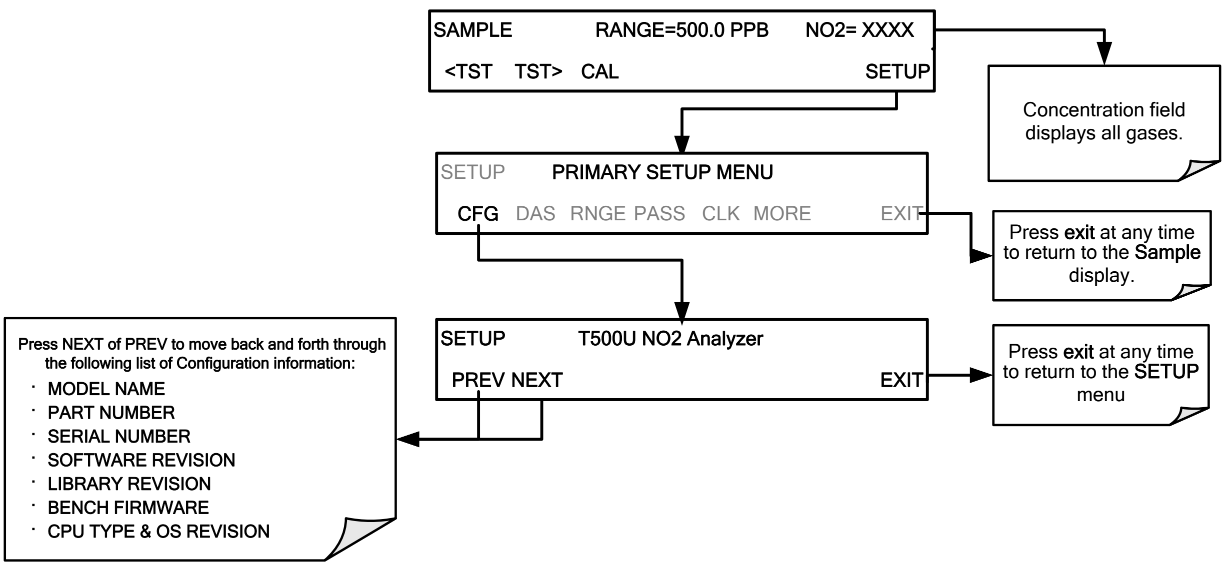
**Once you have completed the above set-up procedures, please fill out the Quality Questionnaire that was shipped with your unit and return it to Teledyne API. This information is vital to our efforts in continuously improving our service and our products for you. THANK YOU.**

# 6. SETUP

The SETUP menu provides access to the instrument parameter settings for performing configuration, calibration, reporting, and diagnostics operations.

## 6.1. CFG: CONFIGURATION INFORMATION

Pressing the CFG button displays the instrument configuration information. This display lists the analyzer model, serial number, firmware revision, software library revision, CPU type and other information. Use this information to identify the software and hardware when contacting Technical Support. Special instrument or software features or installed options may also be listed here.




## 6.2. DAS: INTERNAL DATA ACQUISITION SYSTEM

Use the SETUP>DAS menu to capture and record data. Refer to Section 8 for configuration and operation details.

## 6.3. RNGE: ANALOG OUTPUT REPORTING RANGE

Use the SETUP>RNGE menu to configure output reporting ranges, Single, Dual, and Auto.

### 6.3.1. ANALOG OUTPUT RANGES FOR $NO_2$ CONCENTRATION

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

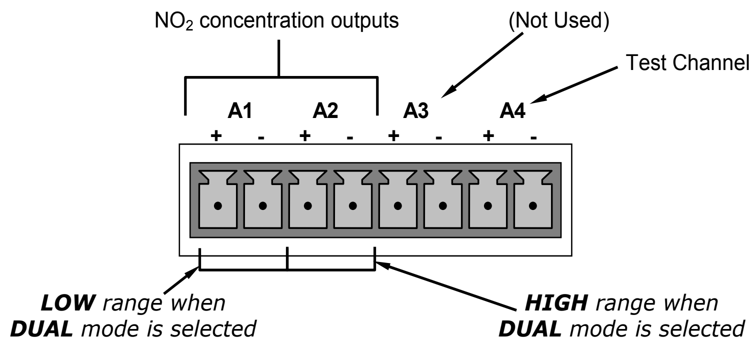



**Figure 6-1: Analog Output Connector Pin Out**

The outputs can be configured either at the factory or by the user for full scale outputs of 0.1 VDC, 1 VDC, 5 VDC or 10 VDC. Additionally **A1** and **A2** may be equipped with optional 0-20 mA DC current loop drivers and configured for any current output within that range (e.g. 0-20, 2-20, 4-20, etc.). The user may also adjust the signal level and scaling of the actual output voltage or current to match the input requirements of the recorder or data logger (Refer to Sections 6.9.4.3 and 6.9.4.5).

In its basic configuration, the **A1** and **A2** channels of the T500U output a signal that is proportional to the $NO_2$ concentration of the sample gas. Several operating modes are available which allow:

- Single range mode (**SNGL** Mode, refer to Section 6.7.4): Both outputs are slaved together and will represent the same concentration span (e.g. 0-500 ppb); however their electronic signal levels may be configured for different ranges (e.g. 0-10VDC vs. 0-0.1 VDC – Refer to Section 6.9.4).
- Dual range mode (**DUAL** mode, refer to Section 6.7.5): The two outputs can be configured for separate and independent concentration ranges as well as separate electronic signal levels.
- Auto range mode (**AUTO** mode, refer to Section 6.7.6) gives the analyzer the ability to automatically switch the A1 and A2 analog outputs between two ranges (low and high) dynamically as the concentration value fluctuates.

**EXAMPLE:**

**A1** OUTPUT: Output Signal = 0-5 VDC representing 0-100 ppb concentration values

**A2** OUTPUT: Output Signal = 0–10 VDC representing 0-500 ppb concentration values.

**A4** OUTPUT: Test channel; e.g., Sample Pressure = 0-5V

Output **A3** is not available on the T500U Analyzer.

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**The instrument does not remember upper range limits settings associated with the individual modes. Changes made to the range limits (e.g. 400 ppb → 600 ppb) when in one particular mode will alter the range limit settings for the other modes.**

**When switching between reporting range modes, ALWAYS check and reset the upper range limits for the new mode selection..**

## 6.3.2. ANALOG OUTPUT REPORTING RANGE DEFAULT SETTINGS

The default setting for these the reporting ranges of the analog output channels **A1, A2** and **A4** are:

- SNGL mode
- 0 to 500.0 ppb
- 0 to 5 VDC

## 6.3.3. SETUP → RNGE → MODE

Single range mode (**SNGL**) is the default range mode for reporting the $NO_2$ gas concentration outputs using the same range span (see Section 6.3.3.1).

Dual range mode (**DUAL**) allows the $NO_2$ analog outputs to be set with different reporting range spans (see Section 6.3.3.2).

Automatic range mode (**AUTO**) allows the analyzer to automatically switch the reporting range between two user upper span limits (designated LOW and HIGH) based on the actual concentrations being measured for each (see Section 6.3.3.3).

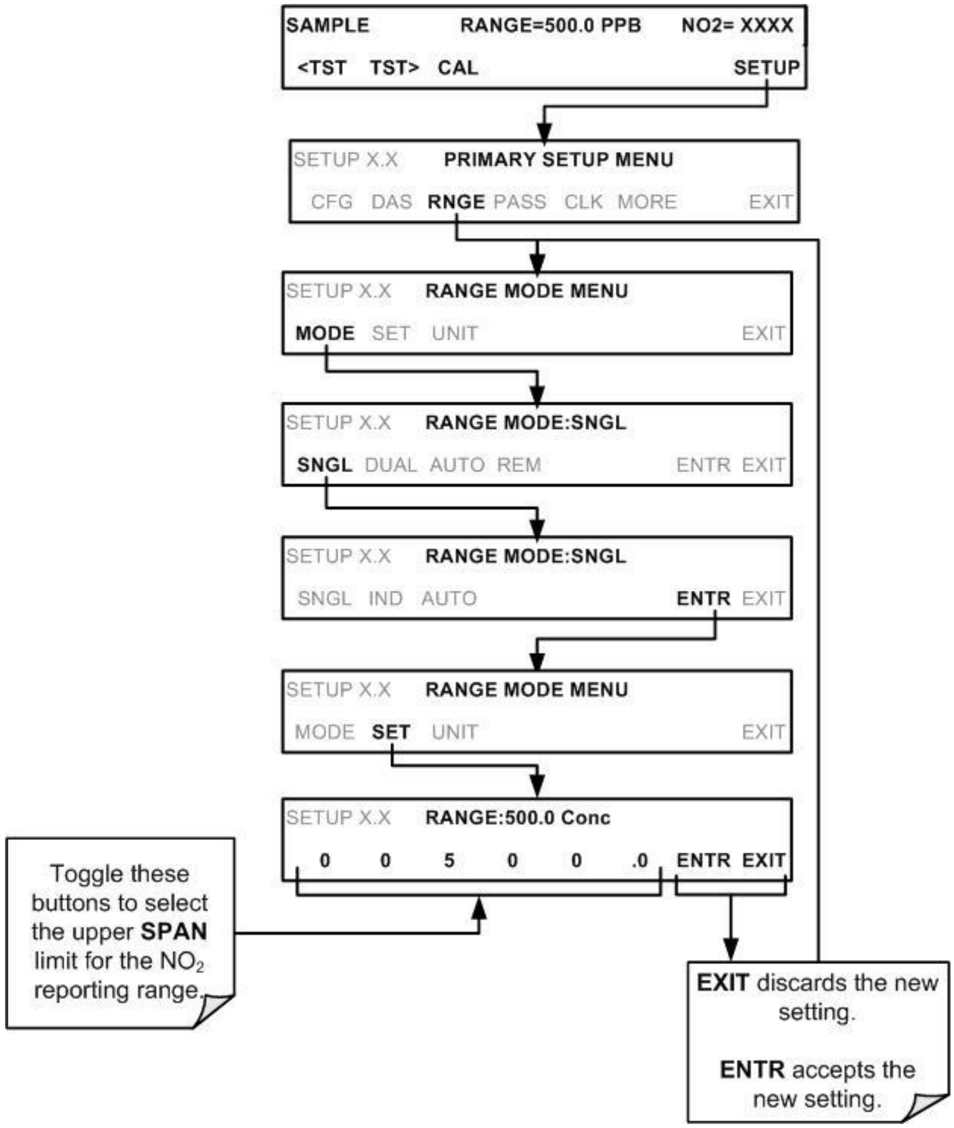
### 6.3.3.1. SETUP → RNGE → MODE → SNGL: SINGLE RANGE MODE CONFIGURATION

**Note** **Single Range is the default reporting range mode for the analyzer.**

When the single range mode is selected (**SNGL**), all analog concentration outputs (**A1, A2**) are slaved together and set to the same reporting range limits (e.g. 500.0 ppb).

Although both outputs share the same concentration reporting range, the electronic signal ranges of the analog outputs may still be configured for different values (e.g. 0-5 VDC, 0-10 VDC, etc.; see Section 6.8.3.1).

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



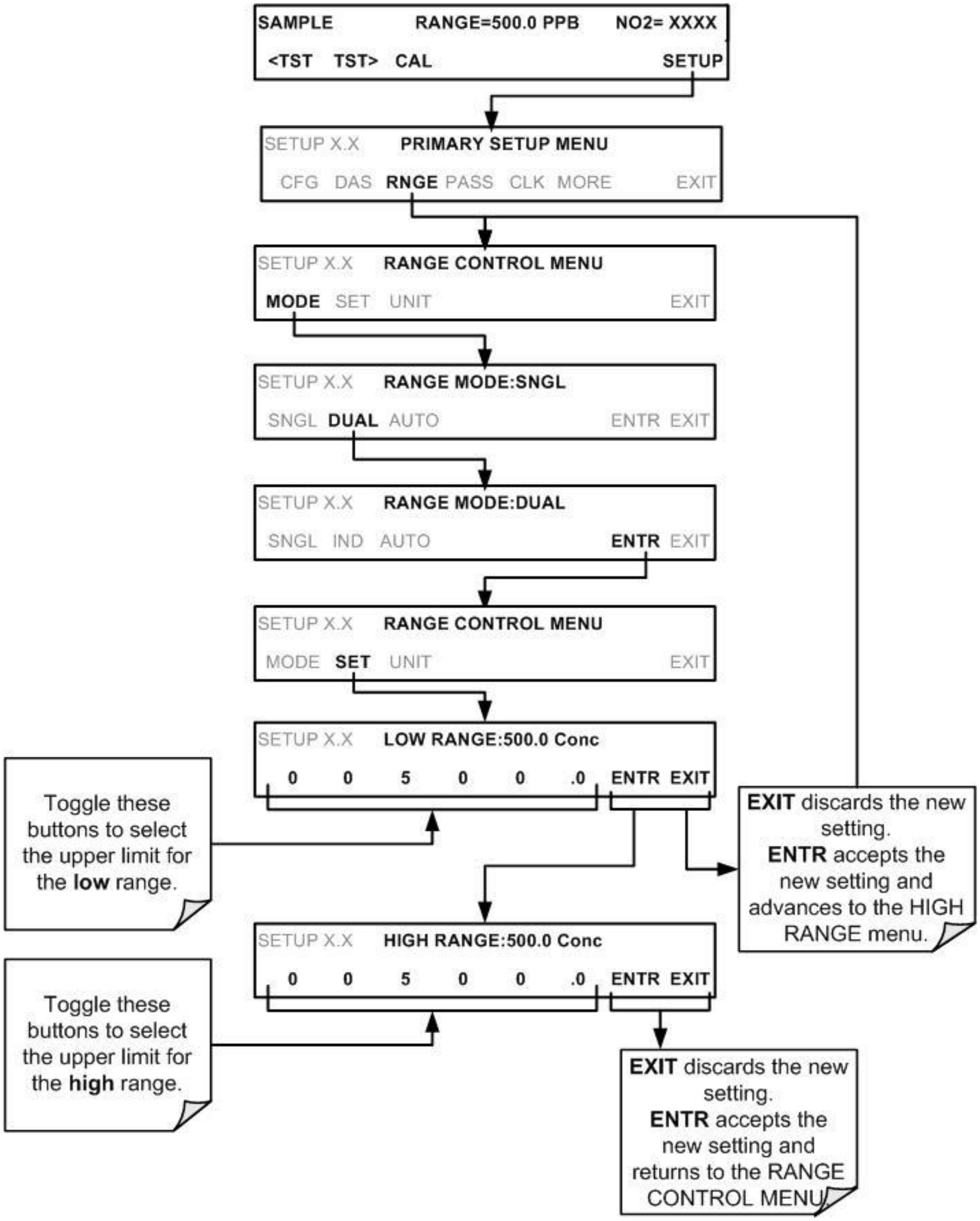

### 6.3.3.2. SETUP → RNGE → MODE → DUAL: DUAL RANGE MODE CONFIGURATION

Selecting Dual Range mode allows the **A1** and **A2** outputs to be configured with different reporting ranges. The analyzer software calls these two ranges low and high. The low range setting corresponds with the analog output labeled **A1** on the rear panel of the instrument. The high range setting corresponds with the **A2** output. While the software names these two ranges low and high, they do not have to be configured that way. For example: the low range can be set for a span of 0-150 ppb while the high range is set for 0-50 ppb.

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

- Range1: The range setting for the A1 output.
- Range2: The range setting for the A2 output.

To set the ranges press the following control button sequence:




**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**In DUAL range mode the LOW and HIGH ranges have separate slopes and offsets for computing $NO_2$ concentration. The two ranges must be independently calibrated.**

### 6.3.3.3. SETUP → RNGE → MODE → AUTO: AUTO RANGE MODE CONFIGURATION

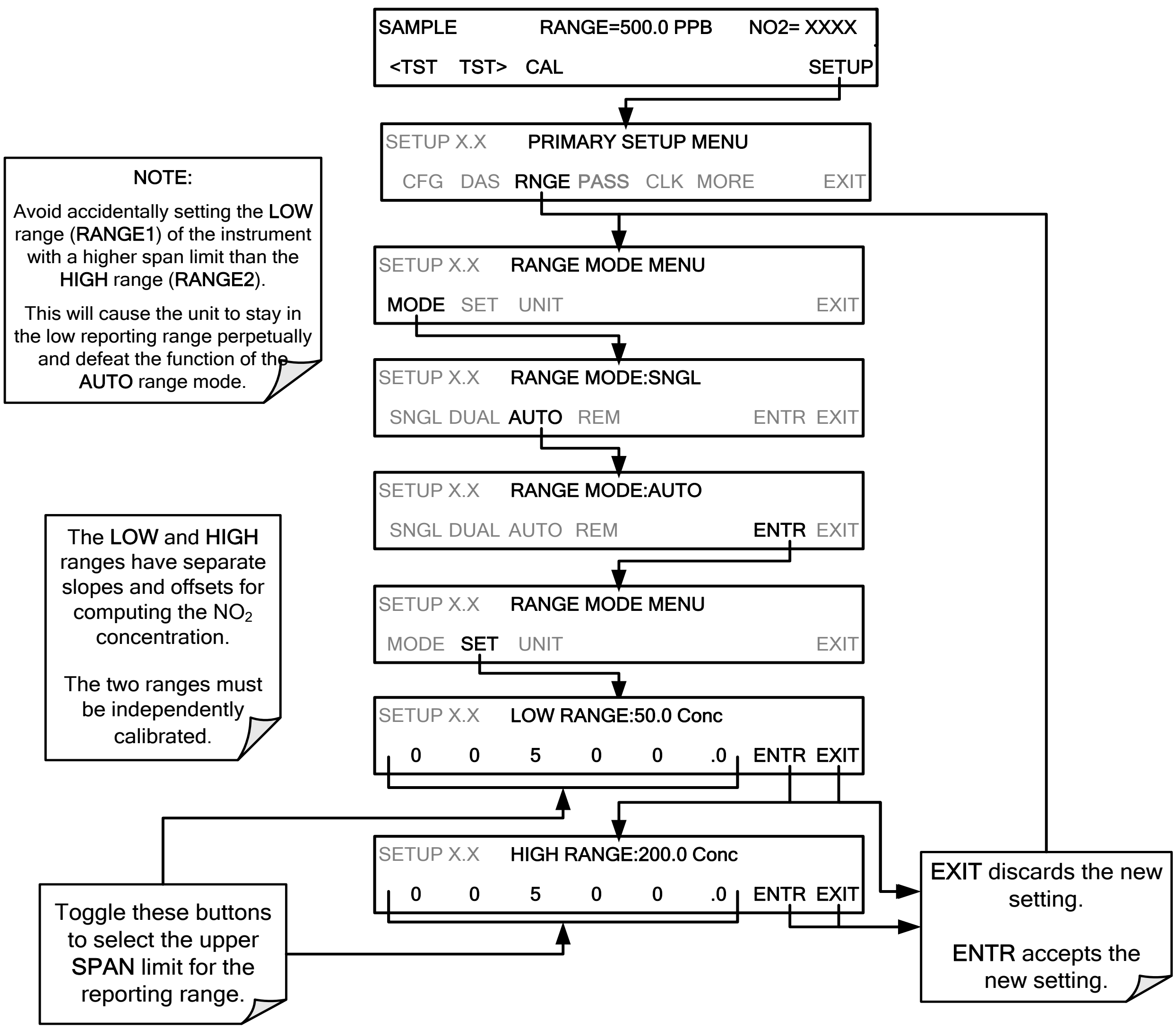
In **AUTO** range mode, the analyzer automatically switches the reporting range between two user-defined ranges (**LOW** and **HIGH**).

- The unit will switch from **LOW** range to **HIGH** range when the $NO_2$ concentration exceeds 98% of the low range span.
- The unit will return from **HIGH** range back to **LOW** range once the $NO_2$ concentration falls below 75% of the low range span.

Also the **RANGE** test function displayed on the front panel will be replaced by two separate functions:

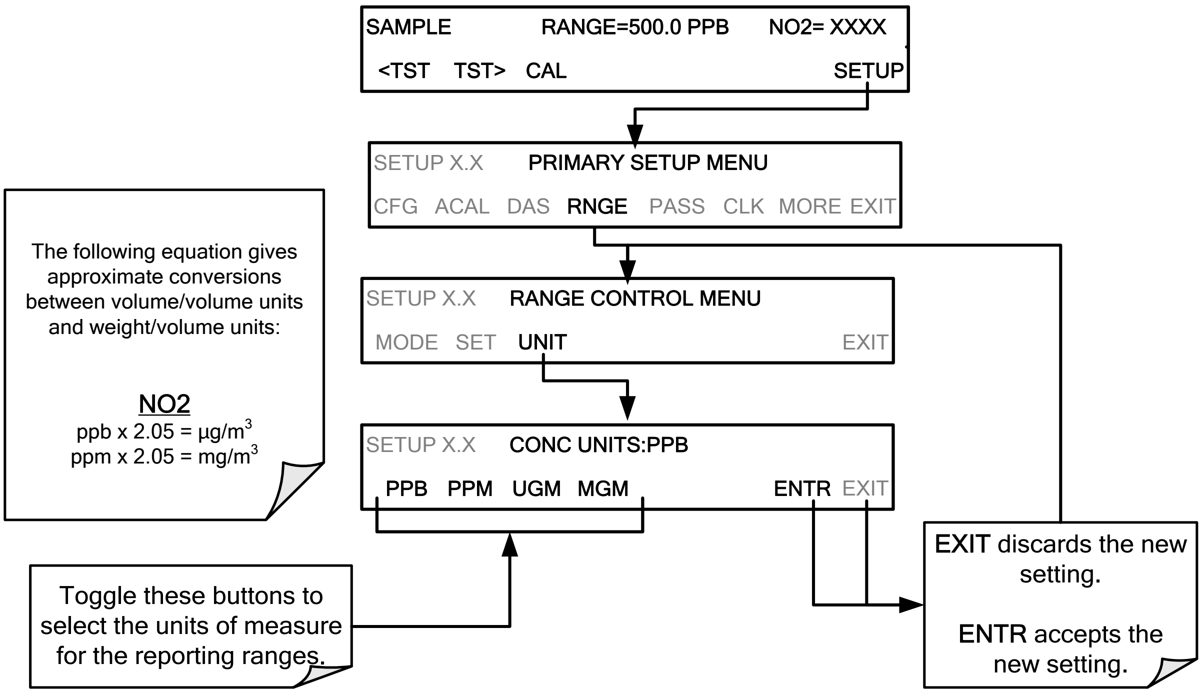
- RANGE1: The LOW range setting for all analog outputs.
- RANGE2: The HIGH range setting for all analog outputs.

The **LOW/HIGH** range status is also reported through the external, digital status bits (Section 3.3.1.4). To set individual ranges press the following menu sequence.



### 6.3.3.4. SETUP → RNGE → UNIT: SETTING THE REPORTING RANGE UNITS OF MEASURE

The T500U can display and report concentrations in ppb, ppm, ug/m$^3$, mg/m$^3$ units. Changing units affects all of the COM port values, and all of the display values for all reporting ranges. To change the units of measure press**:**




**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Concentrations displayed in mg/m$^3$ and ug/m$^3$ use 0°C @ 760 mmHg for Standard Temperature and Pressure (STP).**

**Consult your local regulations for the STP used by your agency. (Example: US EPA uses 25°C as the reference temperature).**

**Once the Units of Measurement have been changed from volumetric (ppb or ppm) to mass units (ug/m$^3$ or mg/m$^3$) the analyzer MUST be recalibrated, as the "expected span values" previously in effect will no longer be valid.**

**Simply entering new expected span values without running the entire calibration routine is not sufficient. This will also counteract any discrepancies between STP definitions.**

### 6.3.3.5. SETUP → RNGE → DIL: USING THE OPTIONAL DILUTION RATIO FEATURE

The dilution ratio feature is a software utility option designed for applications where the sample gas is diluted before being analyzed by the T500U. Typically this occurs in continuous emission monitoring (CEM) applications where the quality of gas in a smoke stack is being tested and the sampling method used to remove the gas from the stack dilutes the gas. Once the degree of dilution is known, this feature allows the user to add an appropriate scaling factor to the analyzer's $NO_2$ concentration calculations so that the measurement range and concentration values displayed on the instrument's front panel display and reported via the instruments various outputs reflect the undiluted values.

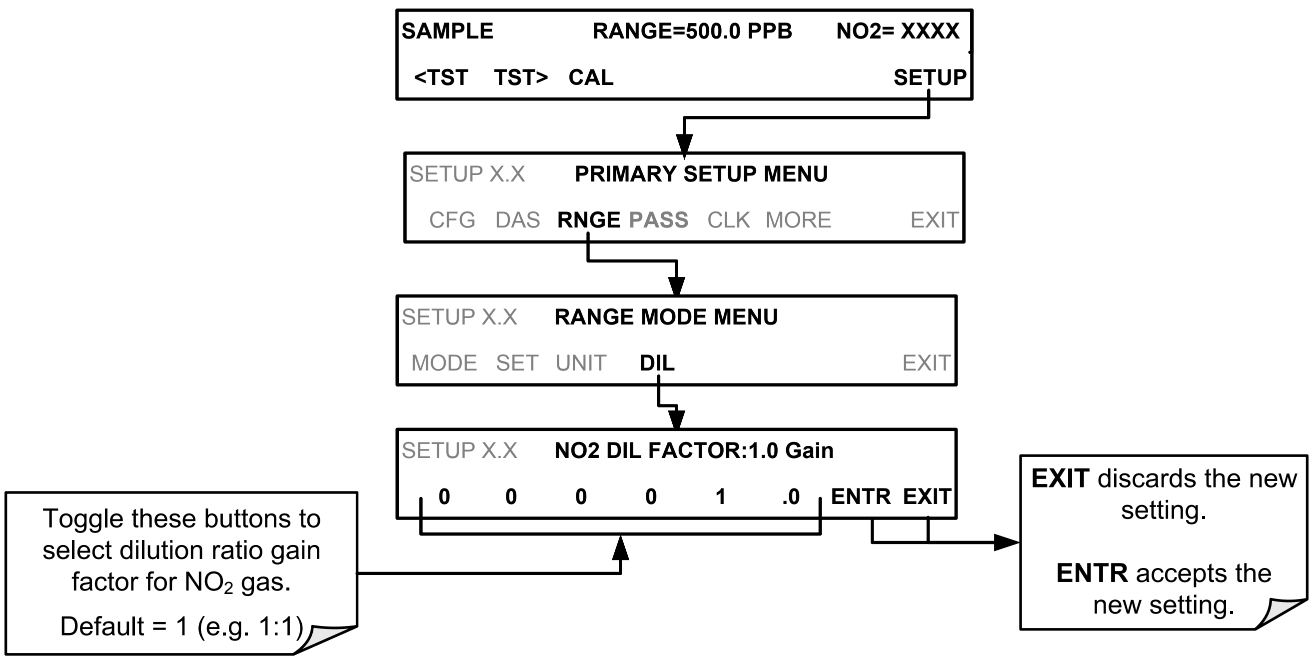
Using the Dilution Ratio option is a 4-step process:

1. Select the appropriate units of measure (see Section 6.3.3.4).

2. Select the reporting range mode and set the reporting range upper limit (see Section 6.3.3).

   - Ensure that the upper span limit entered for the reporting range is the maximum expected concentration of the **UNDILUTED** gas.

3. Set the dilution factor as a gain (e.g., a value of 20 means 20 parts diluent and 1 part of sample gas):




4. Calibrate the analyzer.

   - Ensure that the calibration span gas is either supplied through the same dilution system as the sample gas or has an appropriately lower actual concentration.

EXAMPLE: If the reporting range limit is set for 1 ppm and the dilution ratio of the sample gas is 20 gain, either:

- a span gas with the concentration of 1 ppm can be used if the span gas passes through the same dilution steps as the sample gas, or;
- a 0.05 ppm span gas must be used if the span gas **IS NOT** routed through the dilution system.

# 6.4. PASS: PASSWORD PROTECTION

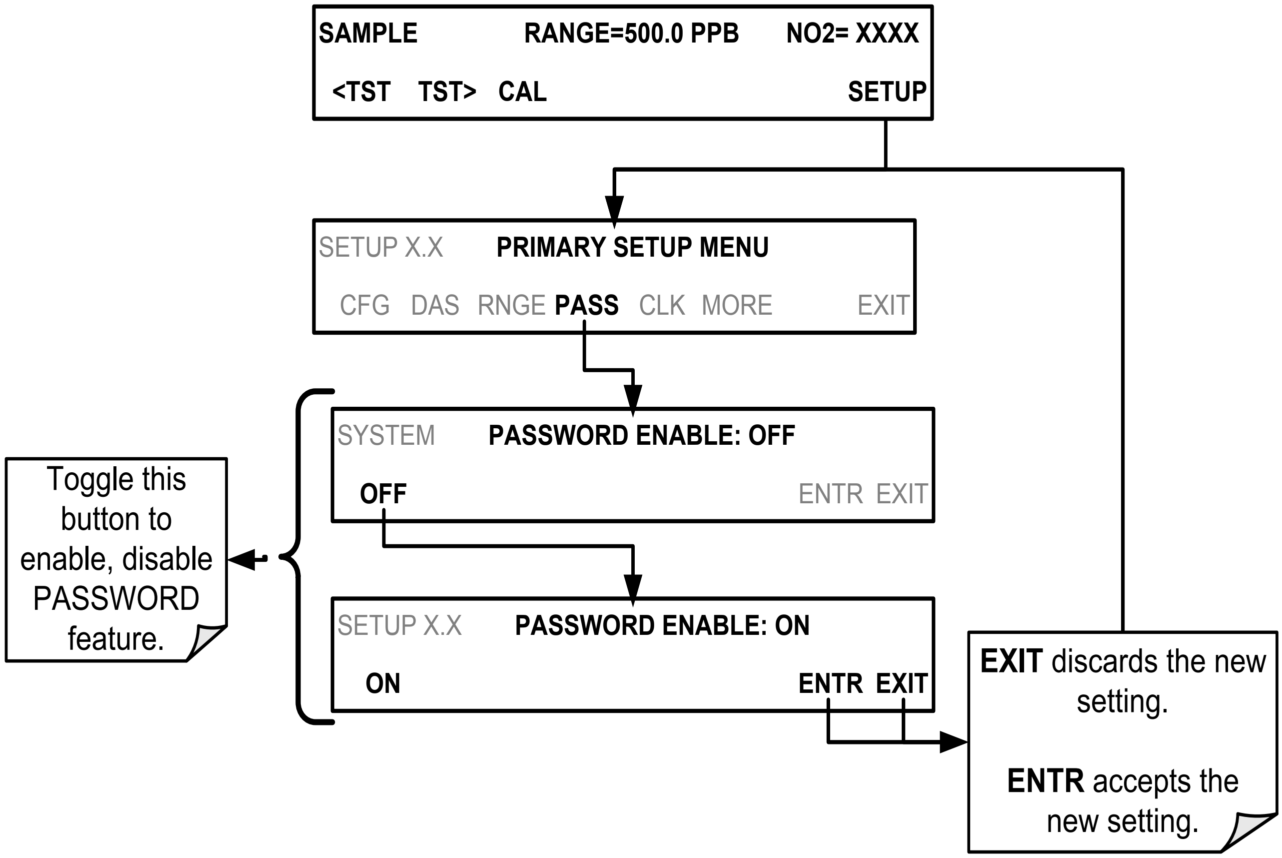
The T500U provides password protection of the calibration and setup functions to prevent unauthorized adjustments. When the passwords have been SETUP>PASS>ON), the system will prompt the user for a password anytime a password-protected function (e.g., SETUP>MORE>DIAG) is selected. This allows normal operation of the instrument, but requires the password (101) to access to the menus under SETUP. When PASSWORD is disabled (SETUP>PASS>OFF), any operator can enter the Primary Setup (SETUP) and Secondary Setup (SETUP>MORE) menus. Whether PASSWORD is enabled or disabled, a password (default 818) is required to enter the VARS or DIAG menus in the SETUP>MORE menu.

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

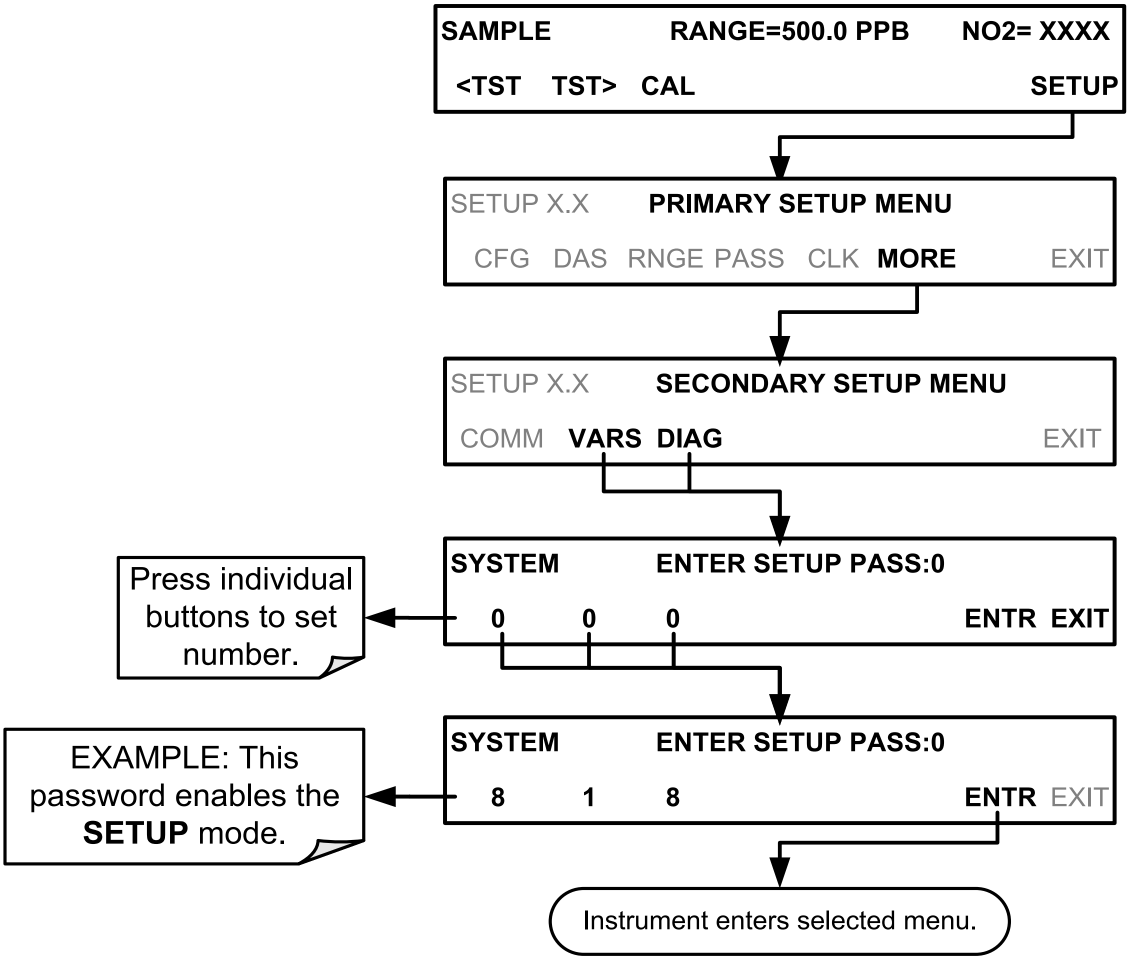
**Table 6-1: Password Levels**

| PASSWORD | LEVEL | MENU ACCESS ALLOWED |
|---|---|---|
| Null (no password required) | Operation | Functions of the menu for general operation. |
| 101 | Configuration/Maintenance | Access to Primary Setup and Secondary SETUP Menus when PASSWORD is enabled. |
| 818 | Configuration/Maintenance | Access to Secondary SETUP Submenus **VARS** and **DIAG** whether PASSWORD is enabled or disabled. |

To enable passwords, press:




Example: If all passwords are enabled, the following touchscreen control sequence would be required to enter the **VARS** or **DIAG** submenus:




**Note**

**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. In this case, only press ENTR to access the password-protected menus.**

To disable the PASSWORD feature after it has been turned ON, the SETUP menu first requires a password; once the password has been input and the ENTR button pressed, the PRIMARY SETUP MENU appears, and now the PASS menu can be accessed, where pressing the ON button turns PASSWORD ENABLE back to OFF, and pressing the ENTR button accepts the change (Table 6-1).

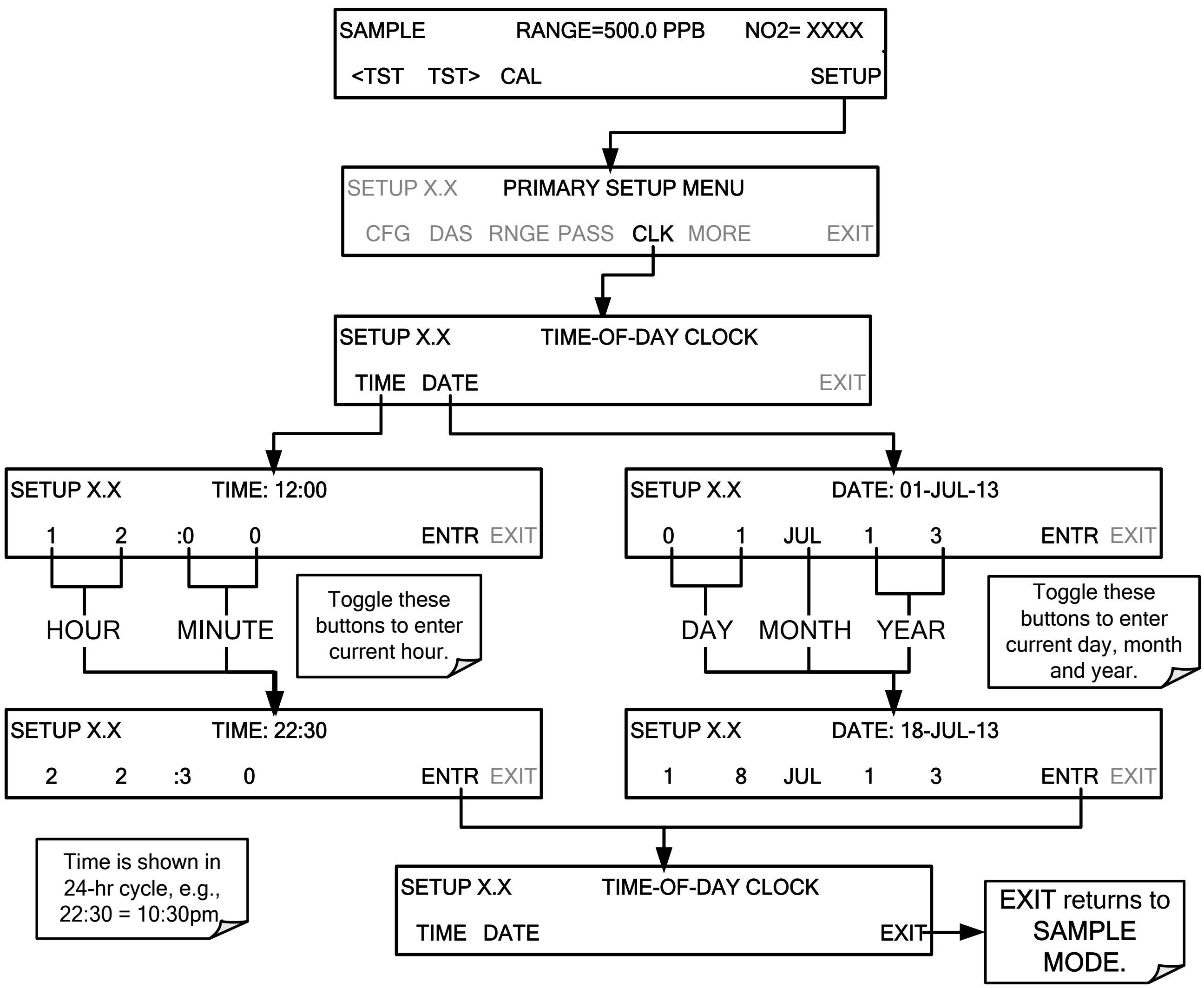
# 6.5. CLK: CLOCK, SETTING TIME AND DATE

Sets time and date of clock; its speed can be adjusted to compensate for faster or slower CPU clocks. Press SETUP>CLK to access the clock.

## 6.5.1. SETTING THE TIME OF DAY

The time-of-day feature of the internal clock supports the **DURATION** step of the automatic calibration (**ACAL**) sequence feature, has a built-in clock for the AutoCal timer, for the time TEST function, and for time stamps on COM port messages and on DAS data entries.

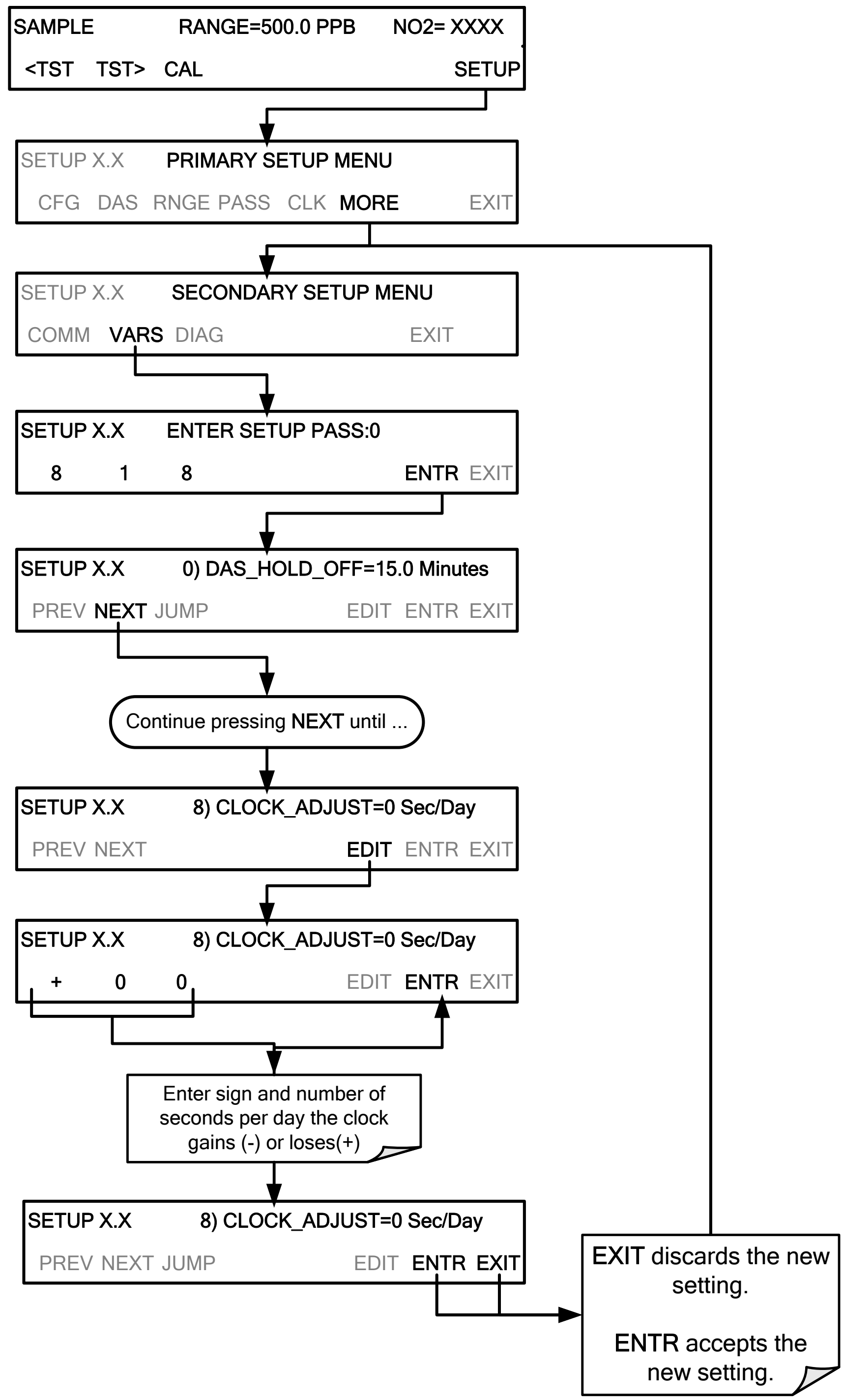
To set the clock's time and date, press:



## 6.5.2. ADJUSTING THE INTERNAL CLOCK'S SPEED

In order to compensate for CPU clocks that run fast or slow, you can adjust a variable called **CLOCK_ADJ** to speed up or slow down the clock by a fixed amount every day.

The **CLOCK_ADJ** variable is accessed via the **VARS** submenu: To change the value of this variable, press:



# 6.6. MORE>COMM: COMMUNICATIONS PORTS

This section introduces the communications setup menu; Section 7 provides the setup instructions and operation information.

Press SETUP>MORE>COMM to arrive at the communications menu.

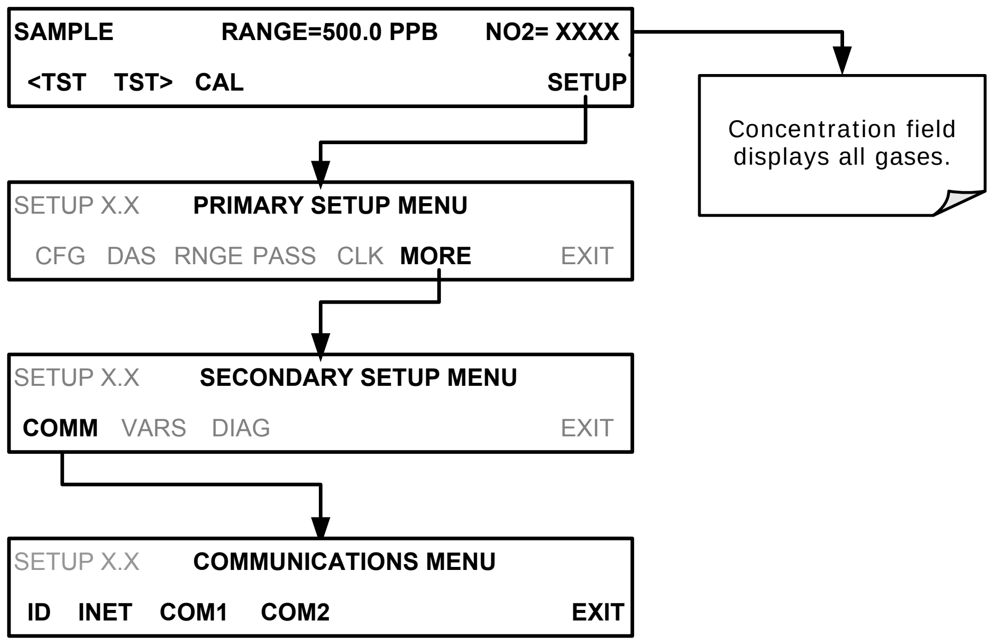



**Figure 6-2. SETUP – COMM Menu**

## 6.6.1. ID (MACHINE IDENTIFICATION)

In the SETUP>MORE>COMM menu press ID to display and/or change the Machine ID, which must be changed to a unique identifier (number) when more than one instrument of the same model is used:

- in an RS-232 multidrop configuration (Sections 3.3.1.8)
- on the same Ethernet LAN (Section 7.5)
- when applying MODBUS protocol (Section 7.7)

The default ID is either **0** or the same as the model number, e.g., **0500** for the Model T500U. Press any button(s) in the MACHINE ID menu (Figure 6-3) until the Machine ID in the Parameter field displays the desired identifier.

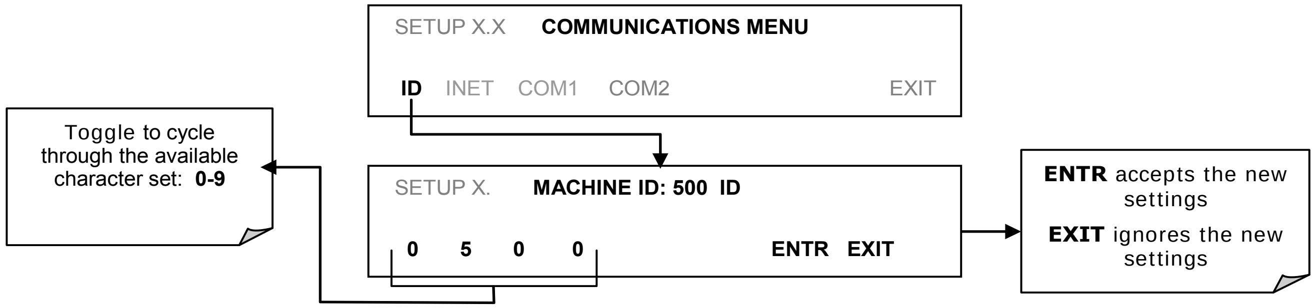



**Figure 6-3. COMM– Machine ID**

The ID can be any unique 4-digit number and can also be used to identify analyzers in any number of ways (e.g. location numbers, company asset number, etc.)

### 6.6.2. INET (ETHERNET)

Use SETUP>COMM>INET to configure Ethernet communications, whether manually or via DHCP. Please see Section 7.5.2 for configuration details.

### 6.6.3. COM1[COM2] (MODE, BAUDE RATE AND TEST PORT)

Use the SETUP>COMM>COM1[COM2] menus to:

- configure communication modes (Section 7.2.1)
- view/set the baud rate (Section 7.2.2)
- test the connections of the com ports (Section 7.2.3).

Configuring COM1 or COM2 requires setting the DCE DTE switch on the rear panel. Section 7.1 provides DCE DTE information.

## 6.7. MORE>VARS: VARIABLES SETUP AND DEFINITION

Use the SETUP>MORE>VARS menu to adjust the settings for software variables that define certain operational parameters.

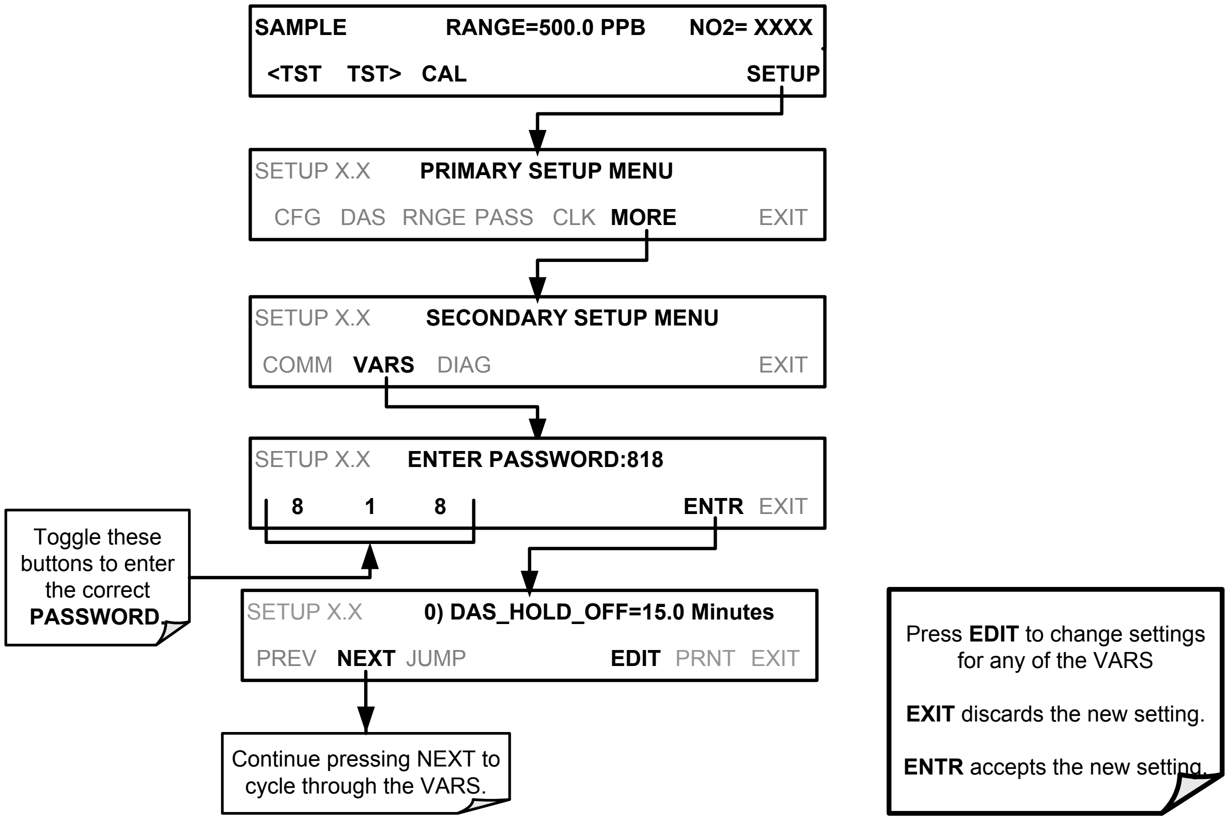
Table 6-2 lists variables that are available within the 818 password protected level. See Appendix A for a detailed listing of the T500U variables that are accessible through the remote interface.

**Table 6-2: Variables (VARS)**

| NO. | VARIABLE | DESCRIPTION | ALLOWED VALUES | VARS DEFAULT VALUES |
|---|---|---|---|---|
| **0** | **DAS_HOLD_OFF** | Changes the Internal Data Acquisition System (DAS) **HOLDOFF** timer: No data is stored in the DAS channels during situations when the software considers the data to be questionable such as during warm up of just after the instrument returns from one of its calibration mode to **SAMPLE** Mode. | May be set for intervals between 0.5 – 20 min | **15 min.** |
| **1** | **CONC_PRECISION** | Sets the number of significant digits to the right of the decimal point display of concentration and stability values. | AUTO, 1, 2, 3, 4 | **3** |
| **2** | **CLOCK_ADJ** | Adjusts the speed of the analyzer's clock. Choose **+** sign if the clock is too slow; choose **-** sign if the clock is too fast. | -60 to +60 s/day | **0 sec** |
| **3** | **SERVICE_CLEAR** | Resets the service timer. Pressing OFF turns the setting to ON. ENTR resets the timer to 0 and returns the setting to OFF. | ON/OFF | **OFF** |
| **4** | **TIME_SINCE_SVC** | Displays number of hours since last service (since SERVICE_CLEAR was reset). | 0-500000 | **0 Hrs** |
| **5** | **SVC_INTERVAL** | Sets the number of hours between service reminders. | 0-100000 | **0 Hrs** |

**Note** **There is a 2-sec latency period between the time a VARS value is changed and its storage into the analyzer's memory. DO NOT turn the analyzer off during this period or the new setting will be lost.**

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



# 6.8. MORE>DIAG: DIAGNOSTICS FUNCTIONS

A series of diagnostic tools is grouped together under the **SETUP→MORE→DIAG** menu. The parameters are dependent on firmware revision (see Appendix A). These tools can be used in a variety of troubleshooting and diagnostic procedures and are referred to in many places of the maintenance and troubleshooting sections of this manual.

The various operating modes available under the **DIAG** menu, using password 818, are:

**Table 6-3: Diagnostic Mode (DIAG) Functions**

| DIAG SUBMENU | SUBMENU FUNCTION | MANUAL 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**. | 6.8.1, 13.1.3 |
| **ANALOG OUTPUT** | 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. | 6.8.2, 13.6.6.1 |
| **ANALOG I/O CONFIGURATION** | The signal levels of the instruments analog outputs may be calibrated (either individually or as a group). Various electronic parameters such as signal span, and offset are available for viewing and configuration. | 6.8.3 |
| **TEST CHAN OUTPUT** | Selects one of the available test channel signals to output over the **A4** analog output channel. | 6.8.4 |
| **NO2 LED DISABLE** | Allows the user to turn off the LED without cycling instrument power. | 6.8.5 |
| **PUMP DISABLE** | Allows the user to turn off the internal pump without cycling instrument power. | 6.8.6 |

To access the various **DIAG** submenus, press the following buttons:

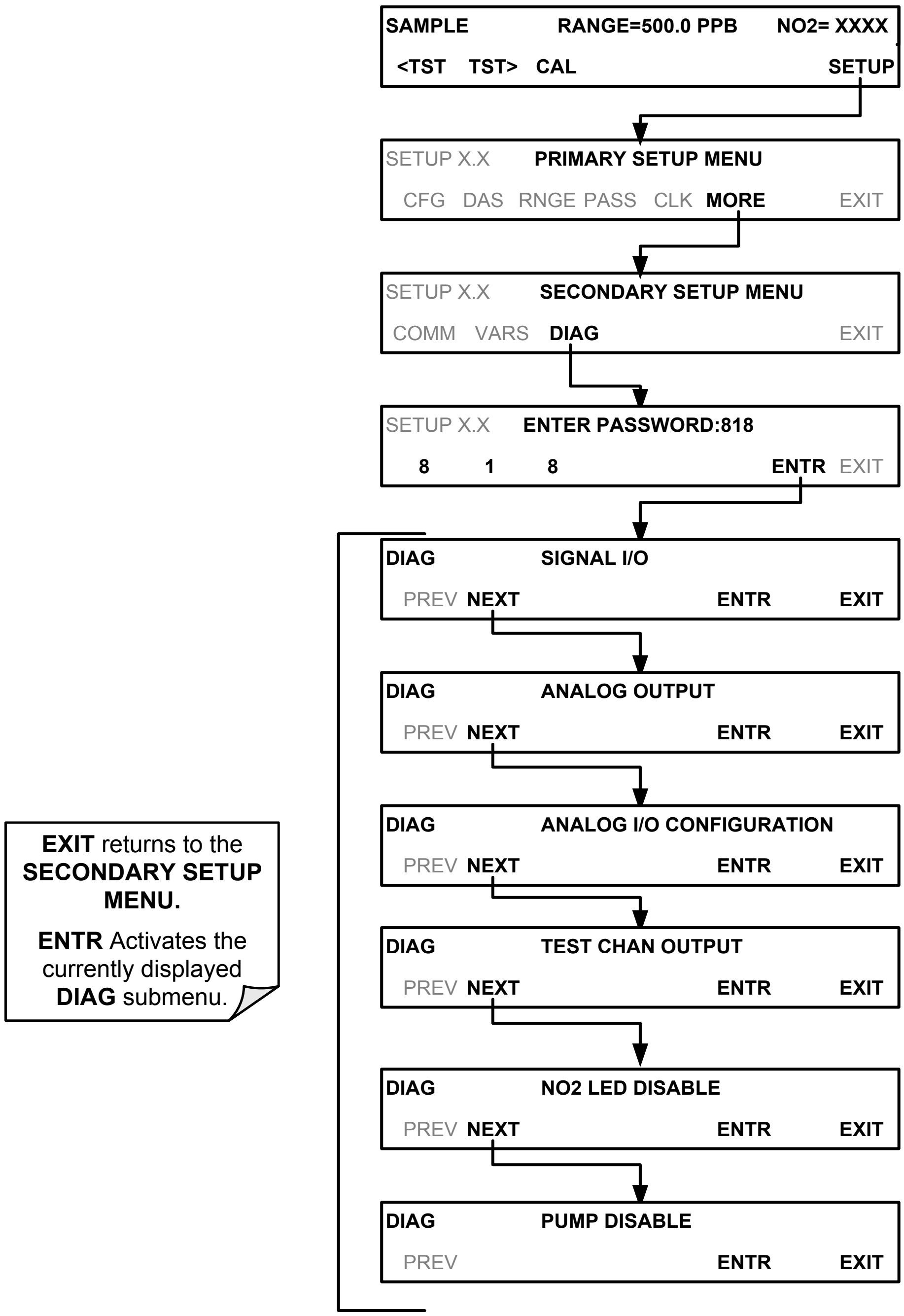
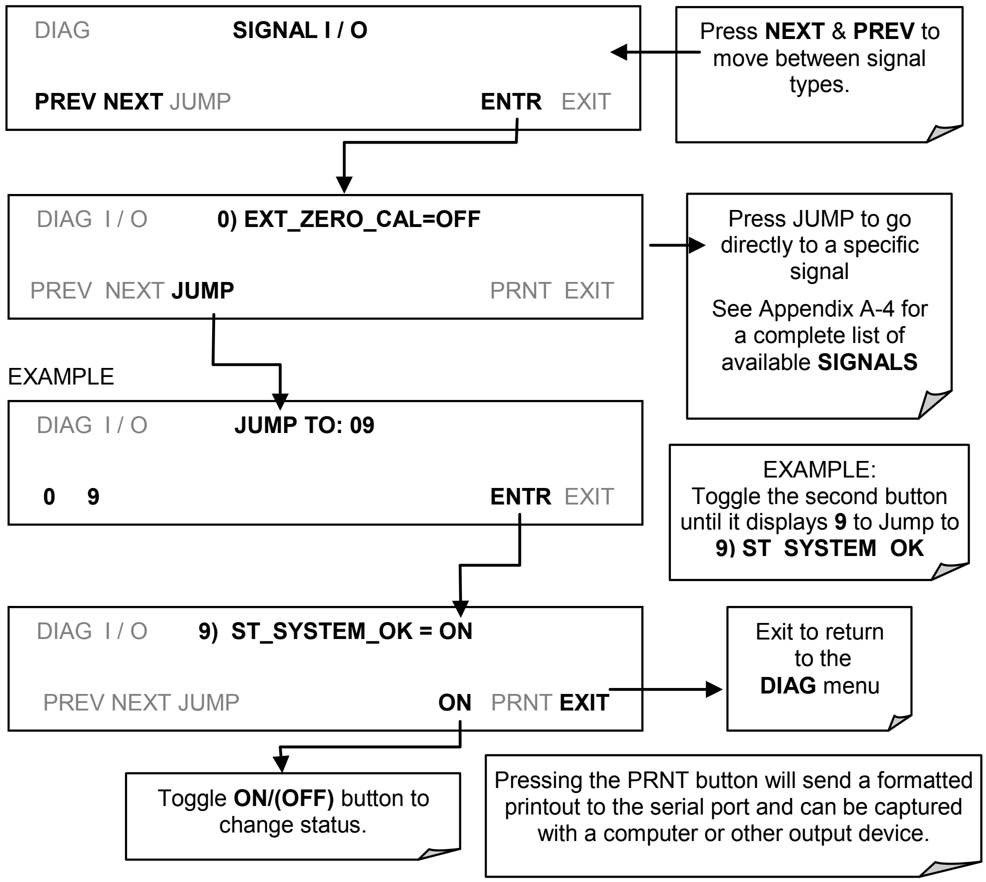



**Figure 6-4: Accessing the DIAG Submenus**

## 6.8.1. SIGNAL I/O

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

Access the signal I/O test mode from the DIAG Menu (Figure 6-4), then press:




## 6.8.2. ANALOG OUTPUT (DIAG AOUT)

Analog Output (AOUT) is used to verify functionality and accuracy of the analog outputs. The test forces all 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.

Section 13.6.6.1 presents instructions for use in troubleshooting and service.

## 6.8.3. ANALOG I/O CONFIGURATION (DIAG AIO)

The T500U analyzer comes equipped with three analog outputs (refer to Figure 3-6). The first two outputs, **A1 & A2** (A3 is not used) carry analog signals that represent the currently measured $NO_2$ concentrating, (see Section 6.3.1). The third, **A4**, outputs a signal that can be set to represent the current value of one of several test functions (see Table 6-8 in Section 6.8.4Table 6-8).

The following table lists the analog I/O functions that are available in the T500U analyzer.

**Table 6-4: DIAG - Analog I/O Functions**

| SUB MENU | FUNCTION | MANUAL SECTION |
|---|---|---|
| **AOUT CALIBRATED** | Initiates a calibration of the **A1**, **A2**, and **A4** analog output channels that determines the slope and offset inherent in the circuitry of each output.<br>These values are stored and applied to the output signals by the CPU automatically. | 6.8.3.1 |
| **CONC_OUT_1** | Sets the basic electronic configuration of the **A1** output ($NO_2$ Concentration).<br>There are four options:<br>• **RANGE**: Selects the signal type (voltage or current loop) and level of the output<br>• **REC OFS**: Allows them input of a DC offset to let the user manually adjust the output level<br>• **AUTO CAL**: Enables / Disables the **AOUT CALIBRATION** Feature<br>• **CALIBRATED**: Performs the same calibration as **AOUT CALIBRATED**, but on this one channel only. | 6.8.2 |
| **CONC_OUT_2** | • Same as for CONC_OUT_1 but for analog channel **A2** (NO Concentration) | |
| **TEST OUTPUT** | • Same as for CONC_OUT_1 but for analog channel **A4** (TEST CHANNEL) | 6.8.4 |
| **AIN CALIBRATED** | Initiates a calibration of the A-to-D Converter circuit located on the Motherboard. | 6.8.3.10 |
| **XIN1**<br>.<br>.<br>.<br>**XIN8** | For each of 8 external analog inputs channels, shows the gain, offset, engineering units, and whether the channel is to show up as a Test function. | 6.8.3.11 |

To access the **ANALOG I/O CONFIGURATION** sub menu, press:

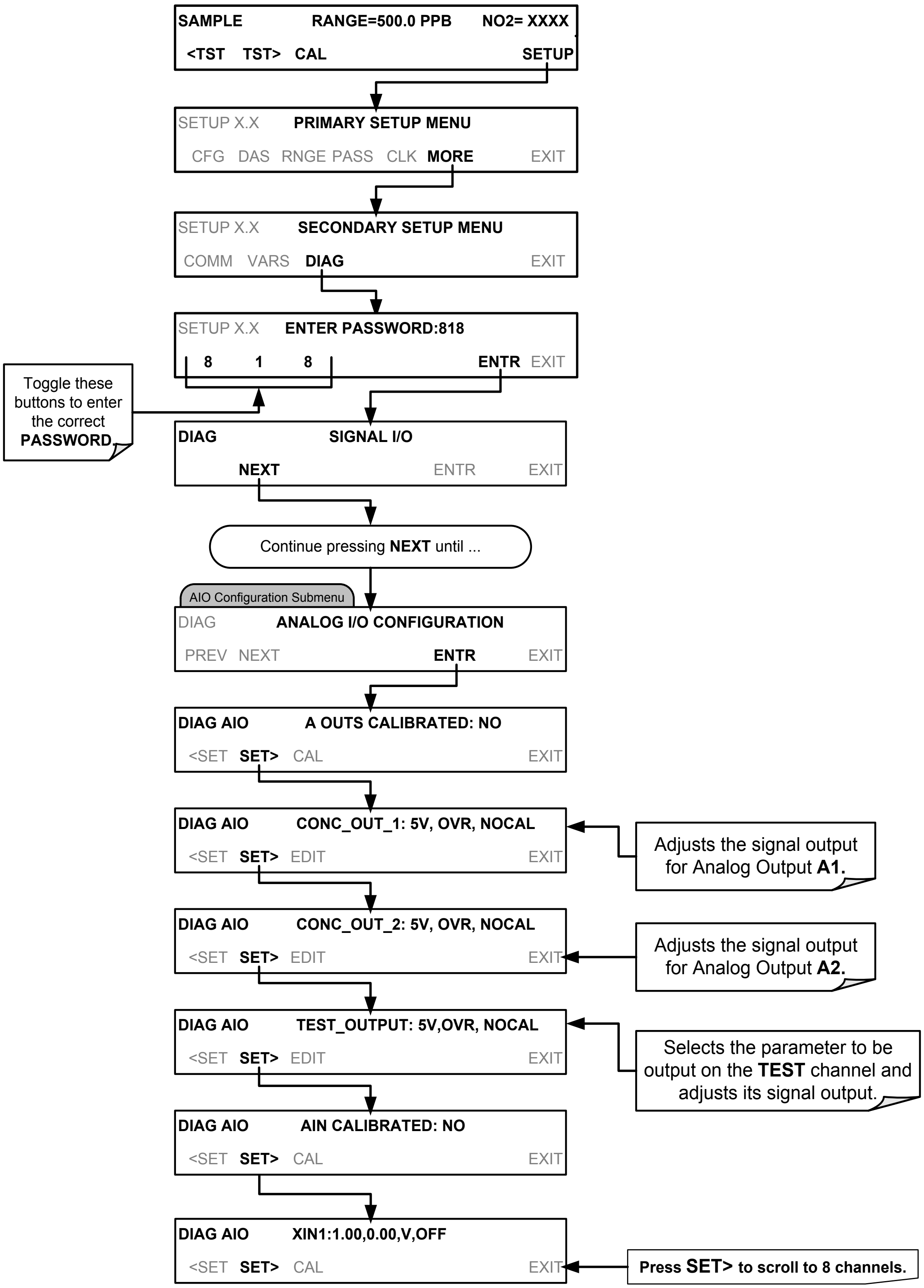



**Figure 6-5: Accessing the Analog I/O Configuration Submenus**

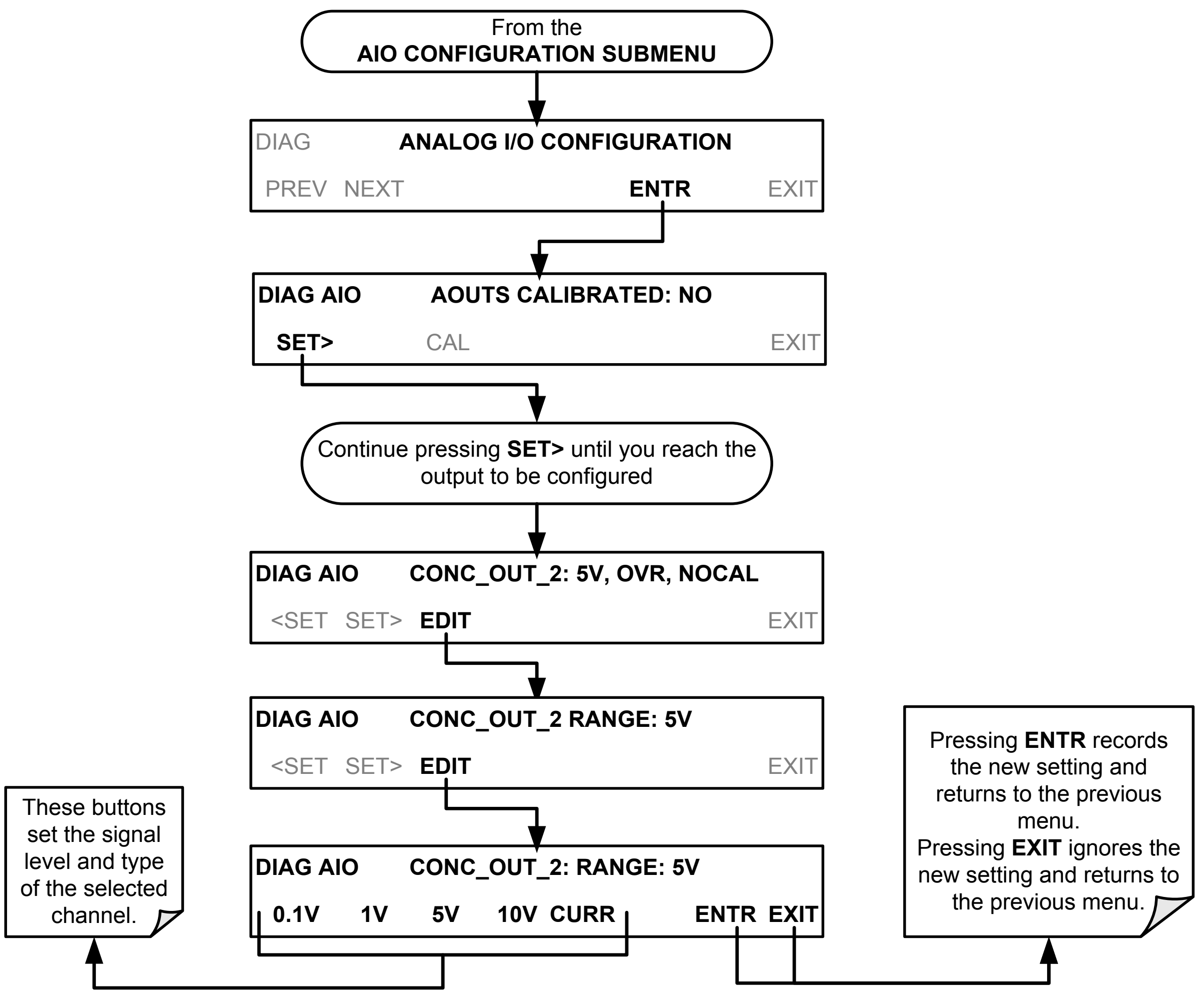
### 6.8.3.1. **ANALOG OUTPUT VOLTAGE / CURRENT RANGE SELECTION**

In its standard configuration the analog outputs are set to output a 0 – 5 VDC signals. Several other output ranges are available (see Table 6-5). Each range is usable from -5% to +5% of the rated span.

**Table 6-5: Analog Output Voltage Range Min/Max**

| RANGE NAME | RANGE SPAN | MINIMUM OUTPUT | MAXIMUM OUTPUT |
|---|---|---|---|
| **0.1V** | 0-100 mVDC | -5 mVDC | 105 mVDC |
| **1V** | 0-1 VDC | -0.05 VDC | 1.05 VDC |
| **5V** | 0-5 VDC | -0.25 VDC | 5.25 VDC |
| **10V** | 0-10 VDC | -0.5 VDC | 10.5 VDC |
| The default offset for all VDC ranges is 0-5 VDC. | | | |
| **CURR** | 0-20 mA | 0 mA | 20 mA |
| While these are the physical limits of the current loop modules, typical applications use 2-20 mA or 4-20 mA for the lower and upper limits. Please specify desired range when ordering this option. The default offset for all current ranges is 0 mA. | | | |

To change the output type and range, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



#### 6.8.3.2. CALIBRATION OF THE ANALOG OUTPUTS

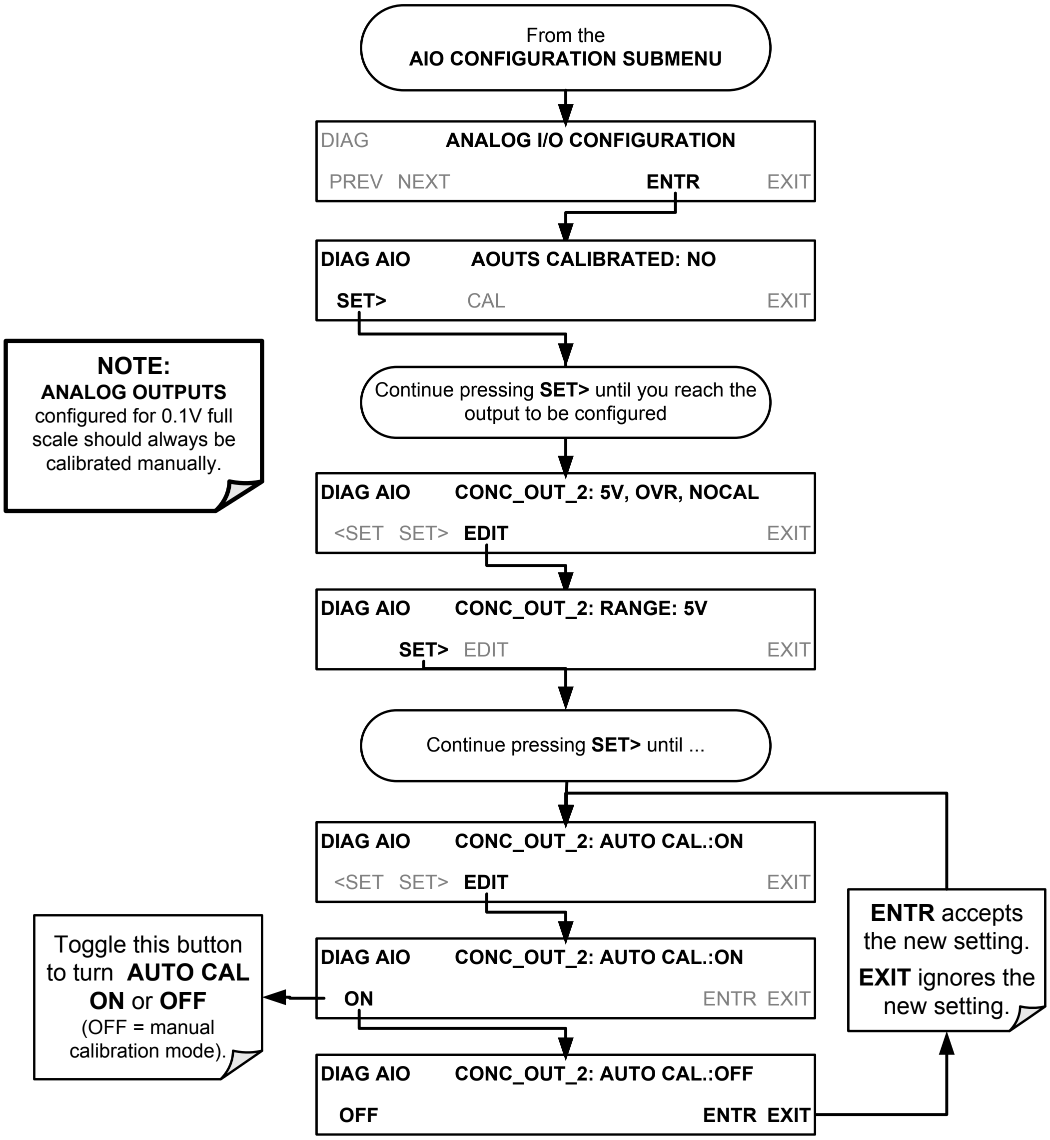
Analog output calibration should be carried out on first startup of the analyzer (performed in the factory as part of the configuration process) and whenever recalibration is required. The analog outputs can be calibrated automatically, either as a group or individually, or calibrated manually.

In its default mode, the instrument is configured for automatic calibration of all channels, which is useful for clearing any analog calibration warnings associated with channels that will not be used or connected to any input or recording device, e.g., data logger.

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. The AUTOCAL feature must be disabled first for manual calibration.

#### 6.8.3.3. ENABLING OR DISABLING THE AUTOCAL FOR AN INDIVIDUAL ANALOG OUTPUT

To enable or disable the **AutoCal** feature for an individual analog output, elect the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:




### 6.8.3.4. AUTOMATIC GROUP CALIBRATION OF THE ANALOG OUTPUTS

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

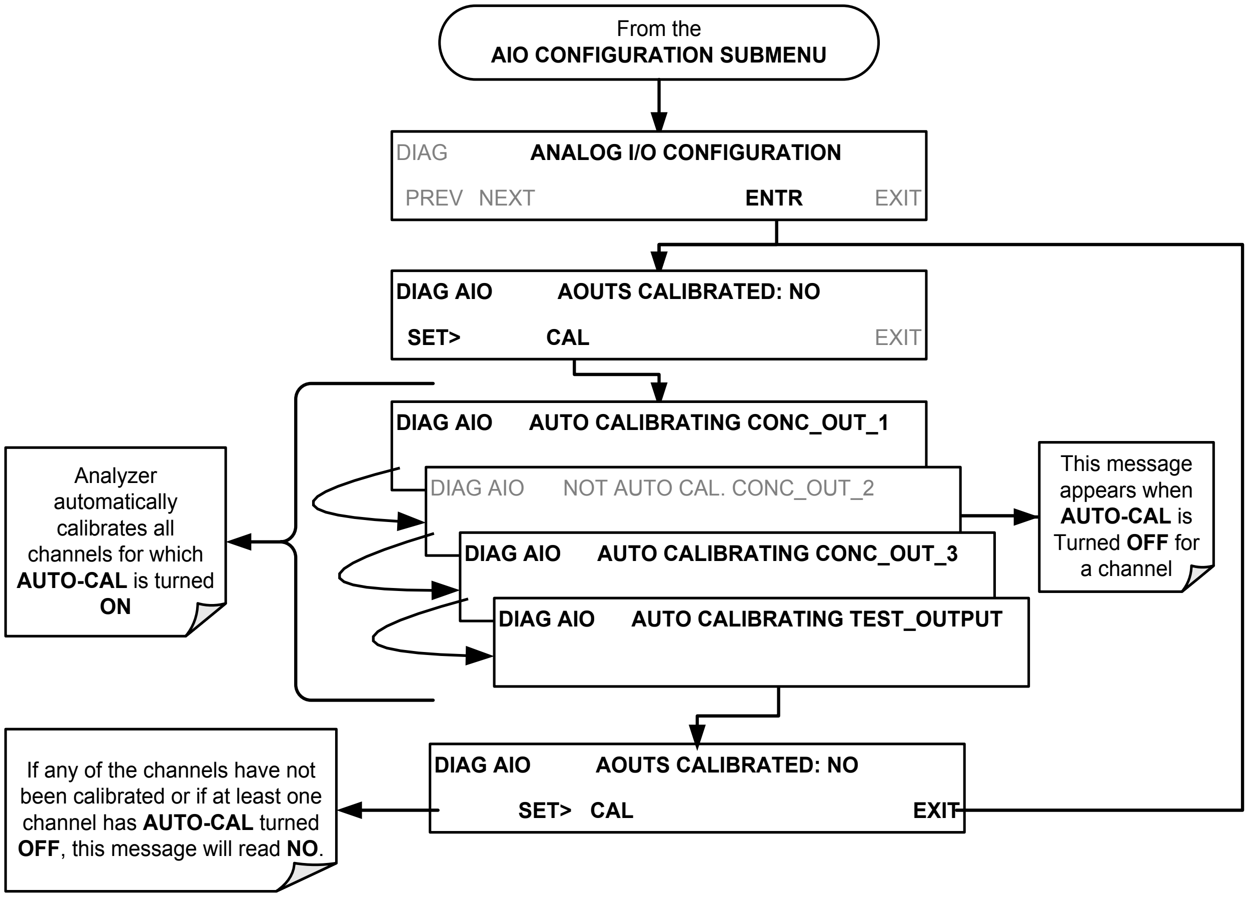
**Manual calibration should be used for any analog output set for a 0.1V output range or in cases where the outputs must be closely matched to the characteristics of the recording device.** (See Sections 6.8.3.2, 6.8.3.3, and 6.8.3.6).

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

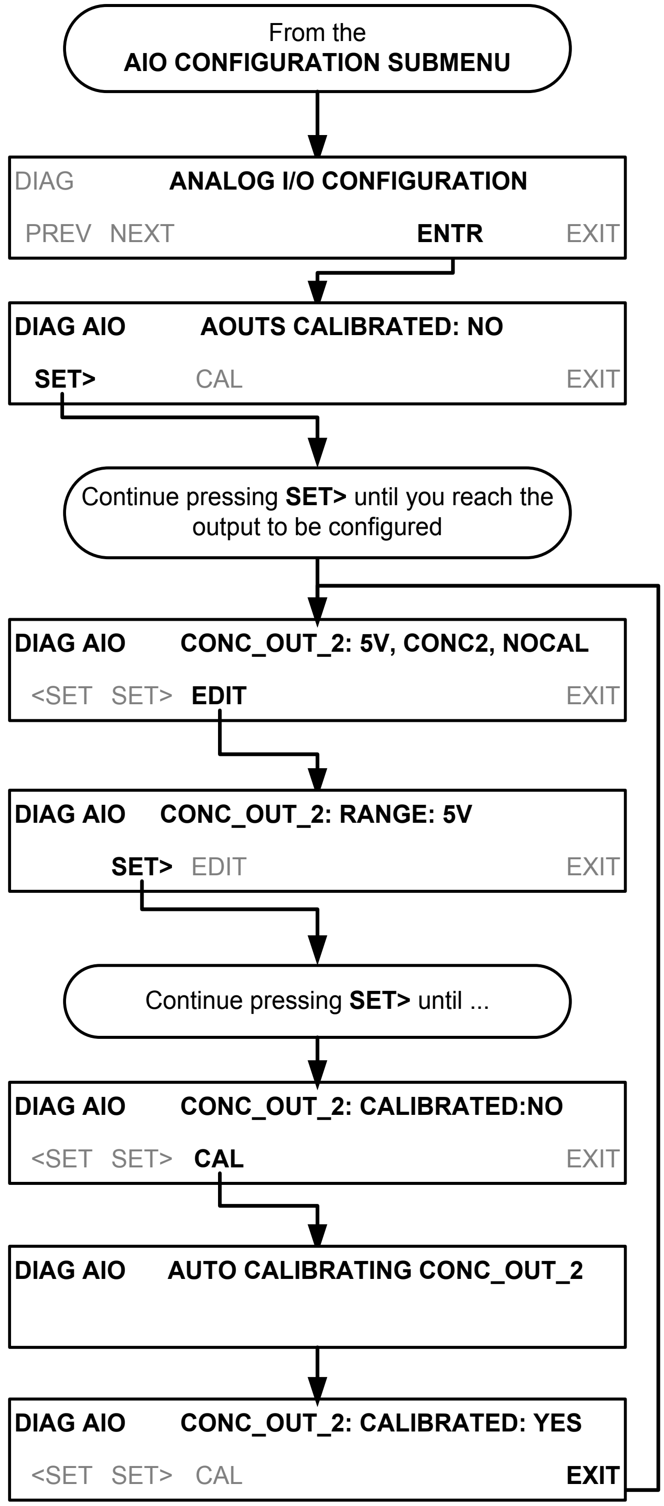
**Before performing this procedure, ensure that the AUTO CAL for each analog output is enabled.** (See Section 6.8.3.3).

To calibrate the outputs as a group with the **AOUTS CALIBRATION** command, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



### 6.8.3.5. AUTOMATIC INDIVIDUAL CALIBRATION OF THE ANALOG OUTPUTS

To use the **AUTO CAL** feature to initiate an automatic calibration for an individual analog output, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



### 6.8.3.6. MANUAL CALIBRATION OF THE ANALOG OUTPUTS CONFIGURED FOR VOLTAGE RANGES

For highest accuracy, the voltages of the analog outputs can be manually calibrated.

**Note**

**The menu for manually adjusting the analog output signal level will only appear if the AUTO-CAL feature is turned off for the channel being adjusted**. (See Section 6.8.3.3).

Calibration is performed with a voltmeter connected across the output terminals and by changing the actual output signal level using the front panel buttons in 100, 10 or 1 count increments. See Figure 3-6 for pin assignments and diagram of the analog output connector.

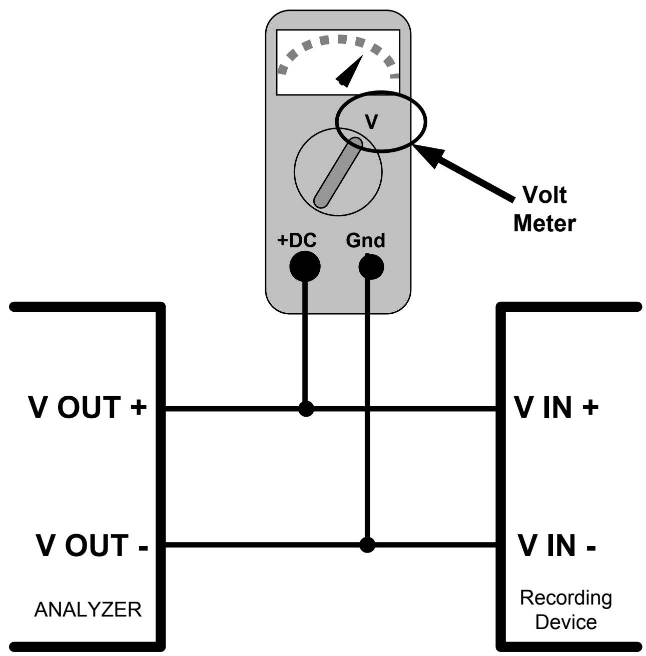
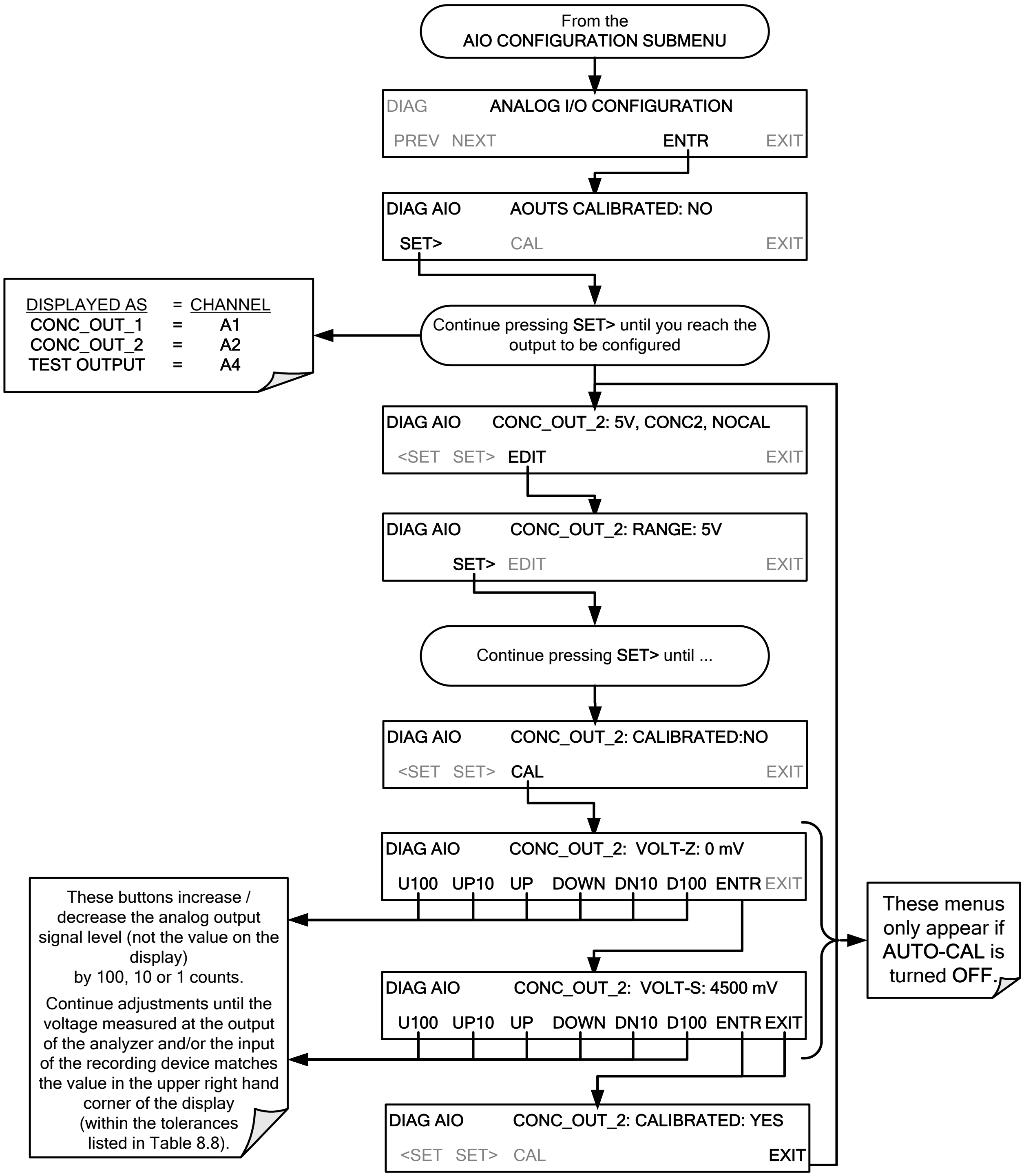



**Figure 6-6: Setup for Checking / Calibrating DCV Analog Output Signal Levels**

**Table 6-6: Voltage Tolerances for the TEST CHANNEL Calibration**

| FULL SCALE | ZERO TOLERANCE | SPAN VOLTAGE | SPAN TOLERANCE | MINIMUM ADJUSTMENT (1 count) |
|---|---|---|---|---|
| 0.1 VDC | ±0.0005V | 90 mV | ±0.001V | 0.02 mV |
| 1 VDC | ±0.001V | 900 mV | ±0.001V | 0.24 mV |
| 5 VDC | ±0.002V | 4500 mV | ±0.003V | 1.22 mV |
| 10 VDC | ±0.004V | 4500 mV | ±0.006V | 2.44 mV |

To adjust the signal levels of an analog output channel manually, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



### 6.8.3.7. MANUAL ADJUSTMENT OF CURRENT LOOP OUTPUT SPAN AND OFFSET

A current loop option may be purchased for the **A1** and **A2** Analog outputs of the analyzer. This option places circuitry in series with the output of the D-to-A converter on the motherboard that changes the normal DC voltage output to a 0-20 milliamp signal (See Section 3.3.1.4).

- The outputs can be ordered scaled to any set of limits within that 0-20 mA range, however most current loop applications call for either 0-20 mA or 4-20 mA range spans.
- All current loop outputs have a +5% over range. Ranges whose lower limit is set above 1 mA also have a –5% under range.

To switch an analog output from voltage to current loop, follow the instructions in Section 6.8.3.1 (select **CURR** from the list of options on the “Output Range” menu).

Adjusting the signal zero and span levels of the current loop output is done by raising or lowering the voltage output of the D-to-A converter circuitry on the analyzer’s motherboard. This raises or lowers the signal level produced by the current loop option circuitry.

The software allows this adjustment to be made in 100, 10 or 1 count increments. Since the exact amount by which the current signal is changed per D-to-A count varies from output-to-output and instrument–to–instrument, you will need to measure the change in the signal levels with a separate, current meter placed in series with the output circuit. See Figure 3-6 for pin assignments and diagram of the analog output connector.

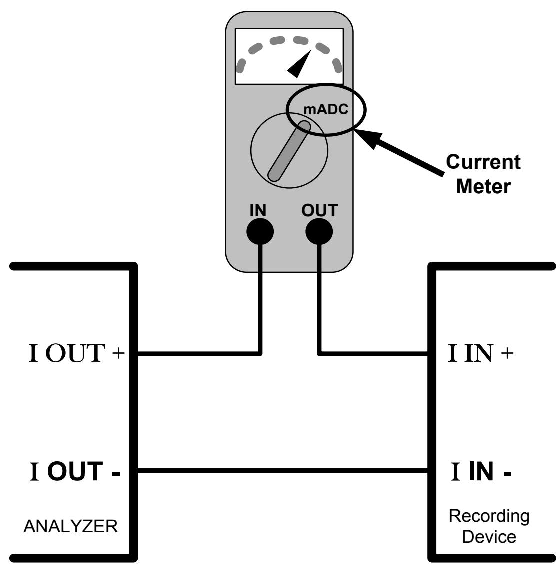
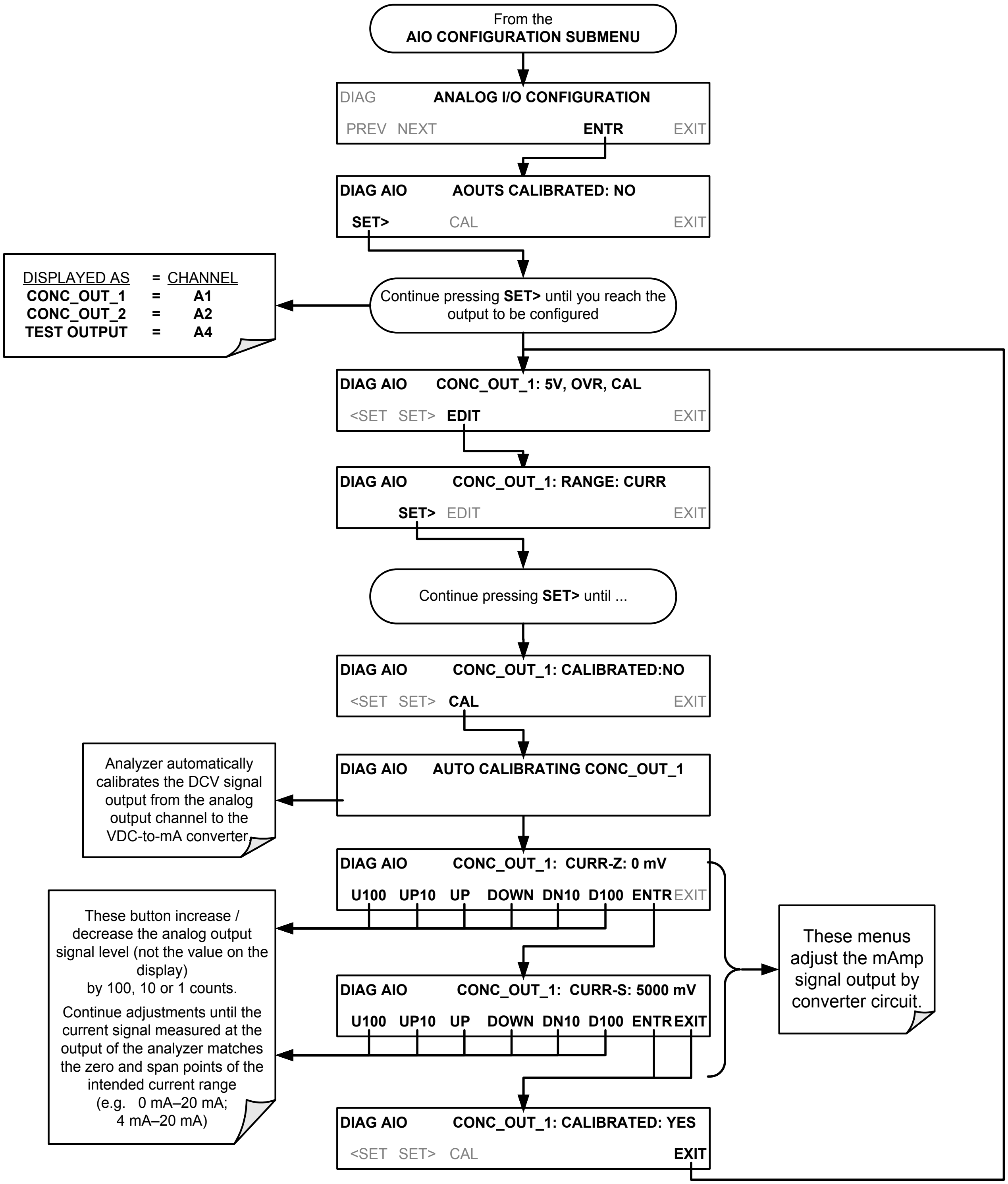



**Figure 6-7: Setup for Checking / Calibration Current Output Signal Levels Using an Ammeter**

**CAUTION – GENERAL SAFETY HAZARD**

**Do not exceed 60 V peak voltage between current loop outputs and instrument ground.**

To adjust the zero and span signal levels of the current outputs, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



An alternate method for measuring the output of the Current Loop converter is to connect a 250 ohm ±1% resistor across the current loop output in lieu of the current meter (see Figure 3-6 for pin assignments and diagram of the analog output connector). This allows the use of a voltmeter connected across the resistor to measure converter output as VDC or mVDC.

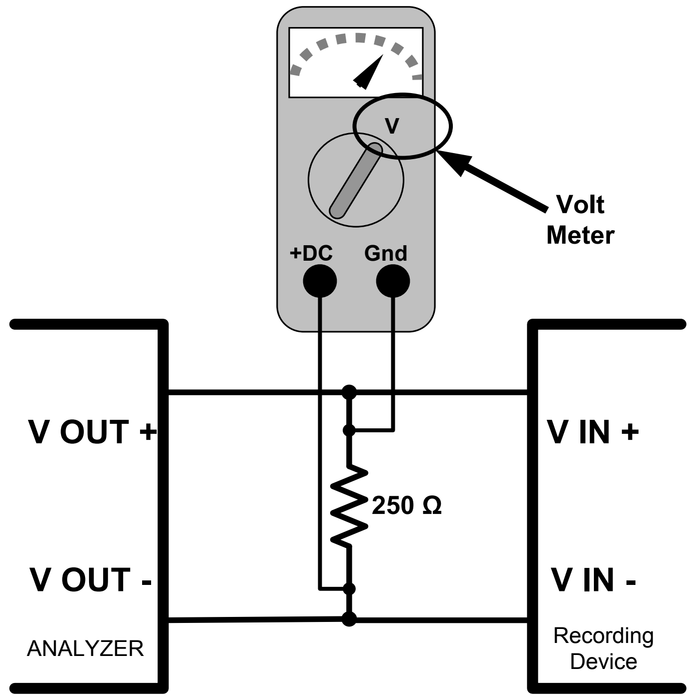



**Figure 6-8: Alternative Setup Using 250Ω Resistor for Checking Current Output Signal Levels**

In this case, follow the procedure above but adjust the output for the following values:

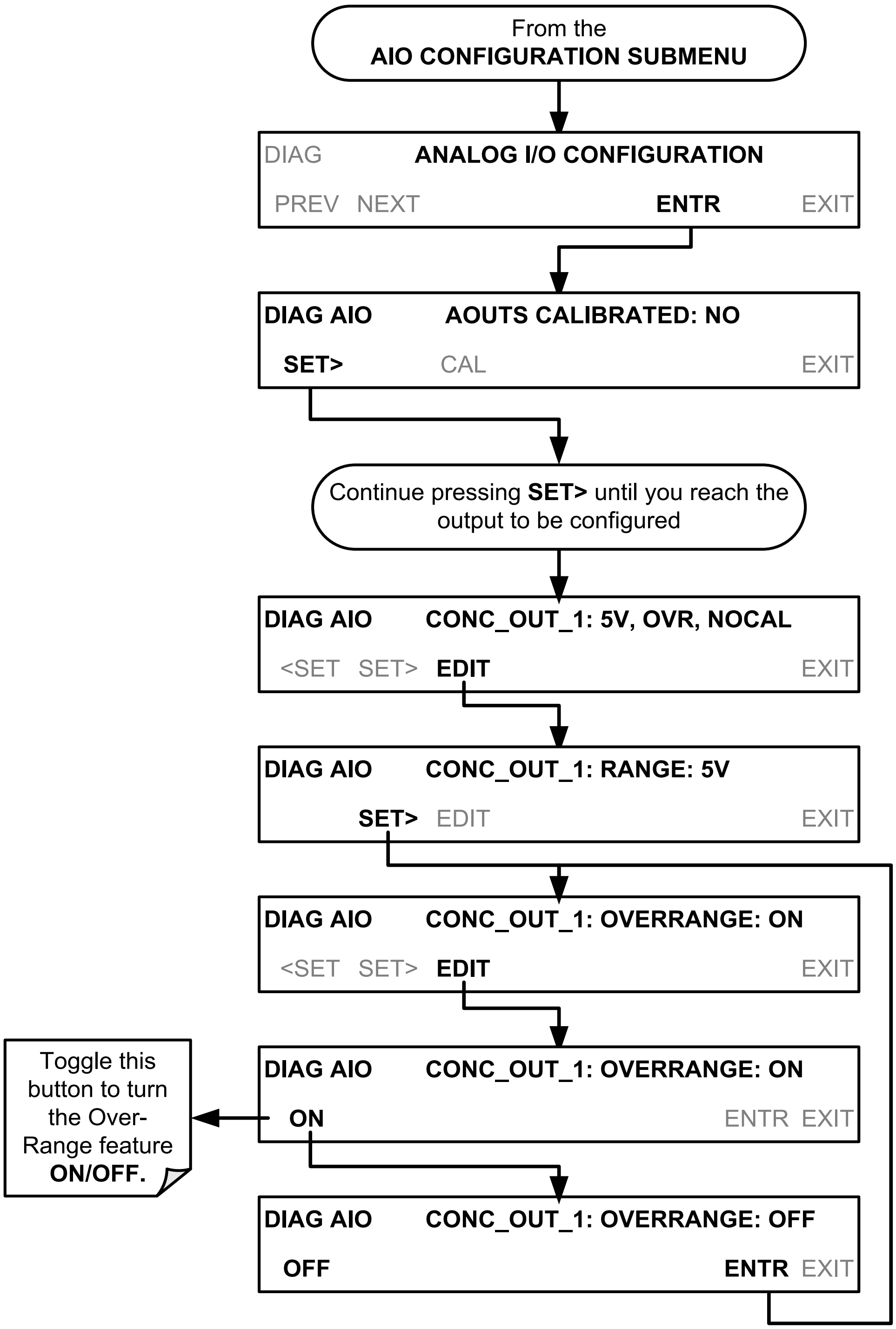
**Table 6-7: Current Loop Output Check**

| % FS | Voltage across Resistor for 2-20 mA | Voltage across Resistor for 4-20 mA |
|---|---|---|
| 0 | 500 mVDC | 1000 mVDC |
| 100 | 5000 mVDC | 5000 mVDC |

### 6.8.3.8. TURNING THE ANALOG OUTPUT OVER-RANGE FEATURE ON/OFF

In its default configuration, a ± 5% over-range is available on each of the T500U's analog outputs. This over-range can be disabled if your recording device is sensitive to excess voltage or current.

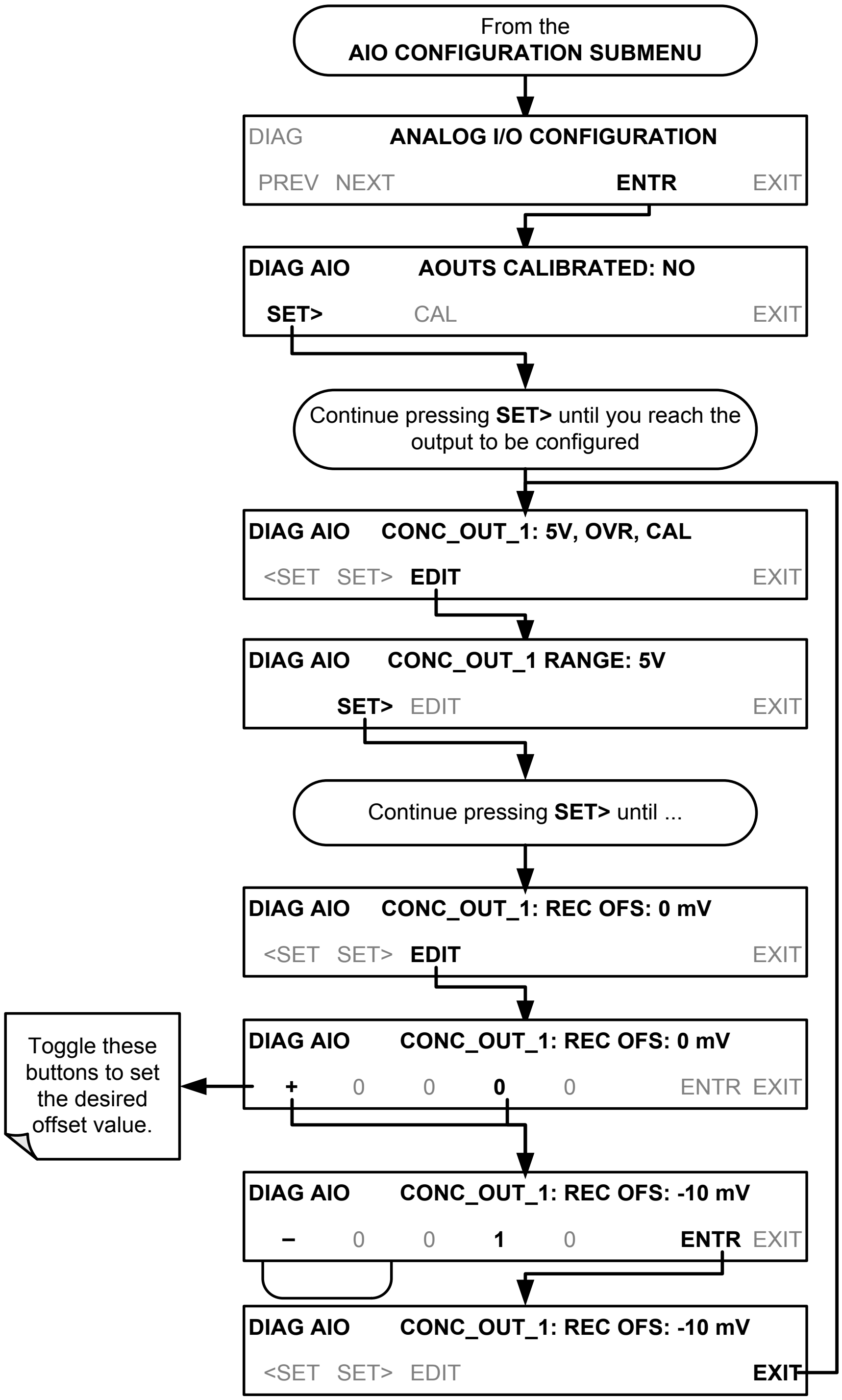
To turn the over-range feature on or off, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



### 6.8.3.9. ADDING A RECORDER OFFSET TO AN ANALOG OUTPUT

Some analog signal recorders require that the zero signal be 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 T500U by defining a zero offset, a small voltage (e.g., 10% of span).

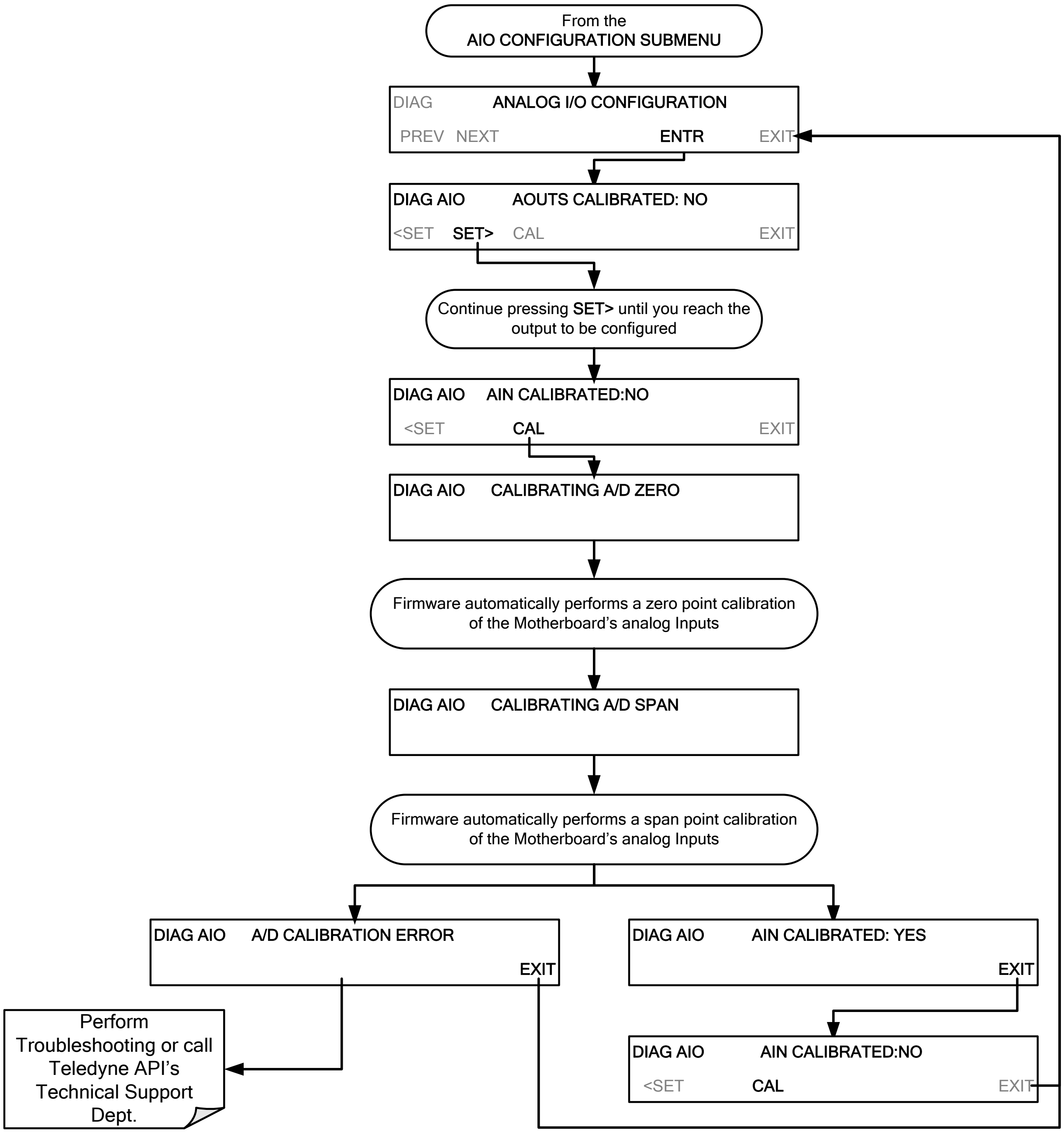
To add a zero offset to a specific analog output channel, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



### 6.8.3.10. AIN (ANALOG INPUTS) CALIBRATION

This is the submenu to conduct a calibration of the T500U analyzer's analog inputs. This calibration should only be necessary after major repair such as a replacement of CPU, motherboard or power supplies.

To perform an analog input calibration, select the **ANALOG I/O CONFIGURATION** submenu (see Figure 6-5) then press:



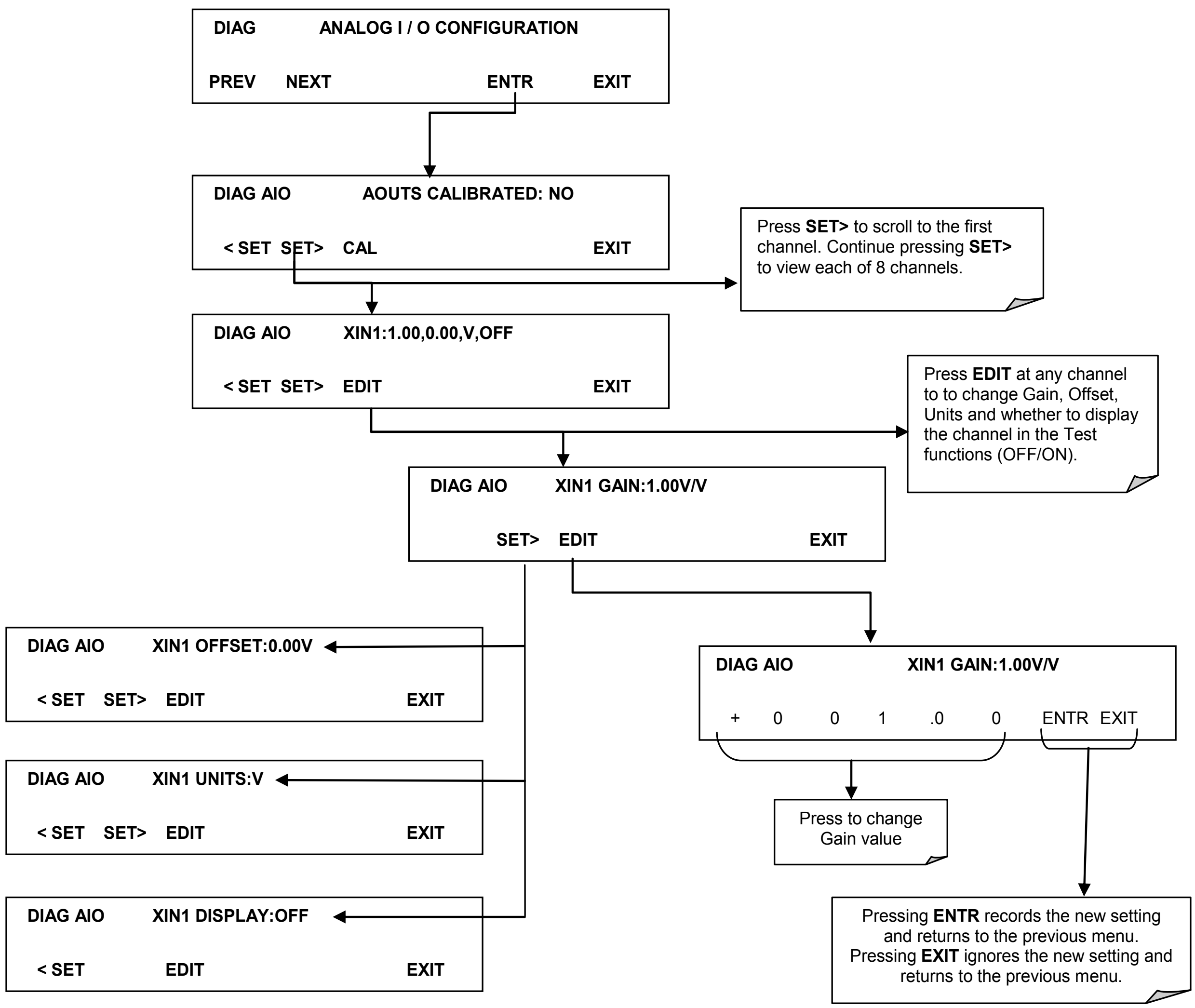
### 6.8.3.11. EXTERNAL ANALOG INPUTS (XIN1…XIN8) OPTION CONFIGURATION

To configure the analyzer's optional external analog inputs, define for each channel**:**

- gain (number of units represented by 1 volt)
- offset (volts)
- engineering units to be represented in volts (each press of the touchscreen button scrolls the list of alphanumeric characters from A-Z and 0-9)
- whether to display the channel in the Test functions

These parameters can also be captured in the internal Data Acquisition System (DAS); refer to Appendix A for Analog-In DAS parameters.

To adjust settings for the Analog Inputs option parameters press:



## 6.8.4. TEST CHAN OUTPUT (SELECTING A TEST CHANNEL FUNCTION FOR OUTPUT A4)

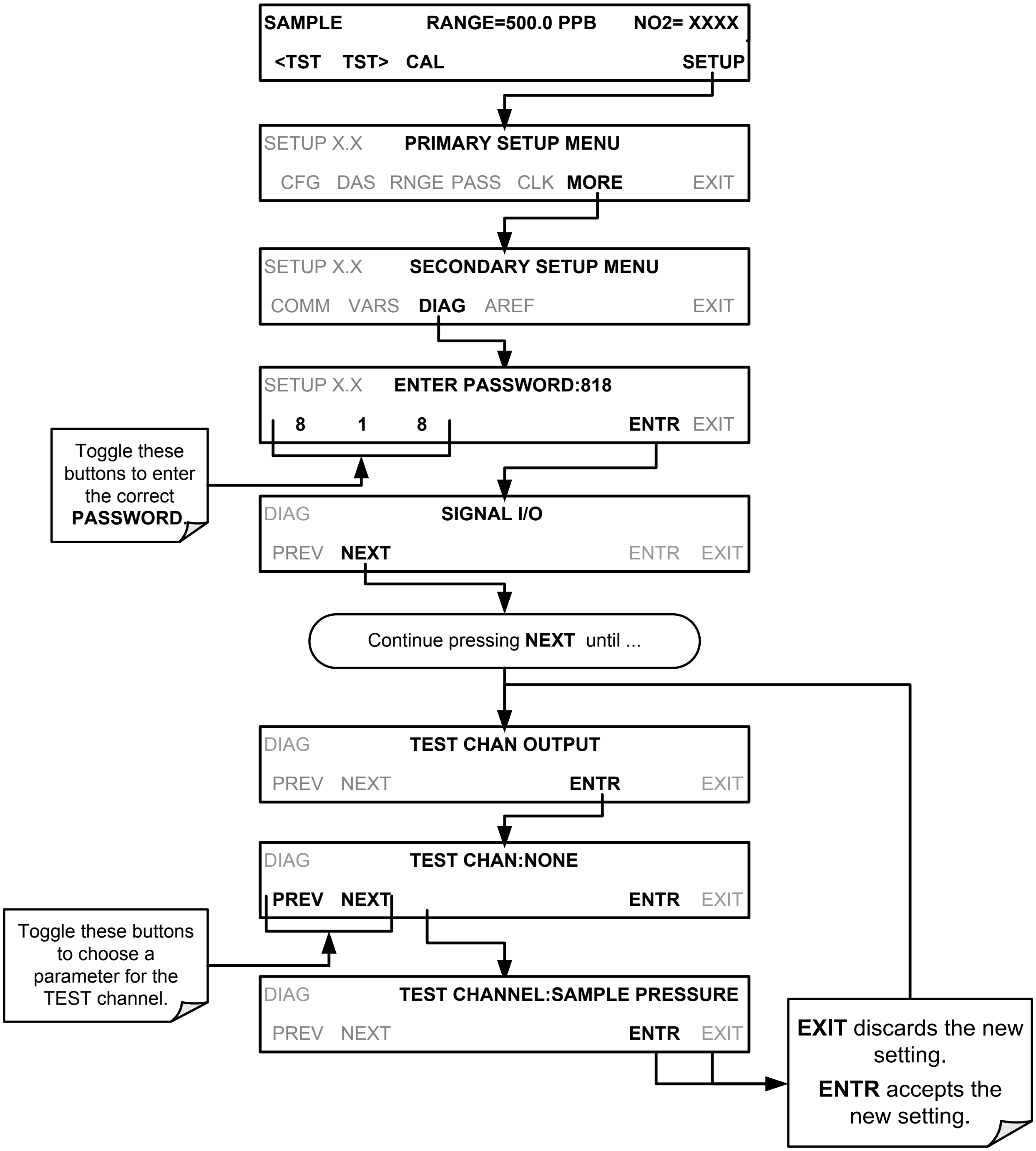
The test functions available to be reported are listed in Table 6-8:

**Table 6-8: Test Channels Functions available on the T500U's Analog Output**

| TEST CHANNEL | DESCRIPTION | ZERO | FULL SCALE |
|---|---|---|---|
| **NONE** | *TEST CHANNEL IS TURNED OFF* | | |
| **SMP PRS** | The pressure of the sample gas measured at the entrance of the Optical bench. | **Ambient InHg-A** | **32 InHg-A** |
| **SMP TEMP** | The temperature of the sample gas measured at the exhaust of the Optical bench. | **0 °C** | **70 °C** |
| **MEASURED LOSS** | Optical loss in the bench. | **400-800 Mm-1** | **1800 Mm-1** |
| **OVEN TEMP** | The temperature of the internal oven. | **0 °C** | **70 °C** |
| **BOX TEMP** | The temperature inside the chassis. | **0 °C** | **70 °C** |
| **MANIFOLD TEMP** | Option –Temperature of heated manifold. | **0 °C** | **70 °C** |
| **IZS TEMP** | The temperature inside the chassis. | **0 °C** | **70 °C** |

Once a function is selected, the instrument not only begins to output a signal on the analog output, but also adds **TEST** to the list of test functions viewable in the front panel display.

To activate the **TEST** Channel and select a function, press:



### 6.8.5. $NO_2$ LED DISABLE

This feature is available if the LED is suspected of causing faulty readings (readings that don't make sense). Access NO2 LED DISABLE in the SETUP>MORE>DIAG>… menu, and press ENTR, YES/NO to turn the LED ON or OFF.

### 6.8.6. PUMP DISABLE

This parameter in the DIAG menu is to turn the internal pump ON or OFF while keeping the instrument running. This is an important feature when maintenance is required where reading the front panel display is necessary, such as for the internal bench.

## 6.9. SETUP>MORE>AREF:

Periodically the analyzer conducts a background measurement, known as an auto reference, whereby the sample is routed through an internal charcoal scrubber. This measurement accounts for drift in the baseline loss. A manual AREF is recommended prior to initial calibration (Section 5.3).

Please note that AREF becomes disabled during calibration if the instrument stays in calibration mode (CALZ or CALS) for longer than it would normally take to run a calibration. To ensure that AREF is enabled, return to SAMPLE mode after conducting a calibration.

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# 7. COMMUNICATIONS SETUP AND OPERATION

Communication connection instructions were provided in Section 3.3.1.8.

This section provides pertinent information regarding communication equipment, describes the instrument's communications modes, presents configuration instructions for the communications ports, and provides instructions for their use, including communications protocol. Data acquisition is presented in Section 8.

## 7.1. DATA TERMINAL/COMMUNICATION EQUIPMENT (DTE DEC)

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 labeled **DCE DTE** (Figure 3-3) allows the user to set the RS-232 configuration for one of these two data devices. This switch exchanges the Receive and Transmit lines on RS-232 emulating a cross-over or null-modem cable. The switch has no effect on COM2.

## 7.2. COMMUNICATION MODES, BAUD RATE AND PORT TESTING

Use the SETUP>MORE>COMM menu to configure COM1 (labeled **RS232** on instrument rear panel) and/or COM2 (labeled **COM2** on instrument rear panel) for communication modes, baud rate and/or port testing for correct connection. If using a USB option communication connection, setup requires configuring the COM2 baud rate (Section 7.2.2).

## 7.2.1. COMMUNICATION MODES

Each of the analyzer's serial ports can be configured to operate in a number of different modes, listed in Table 7-1. As modes are selected, the analyzer sums the mode ID numbers and displays this combined number on the front panel display. For example, if quiet mode (01), computer mode (02) and Multi-Drop-Enabled mode (32) are selected, the analyzer would display a combined **MODE ID** of **35**.

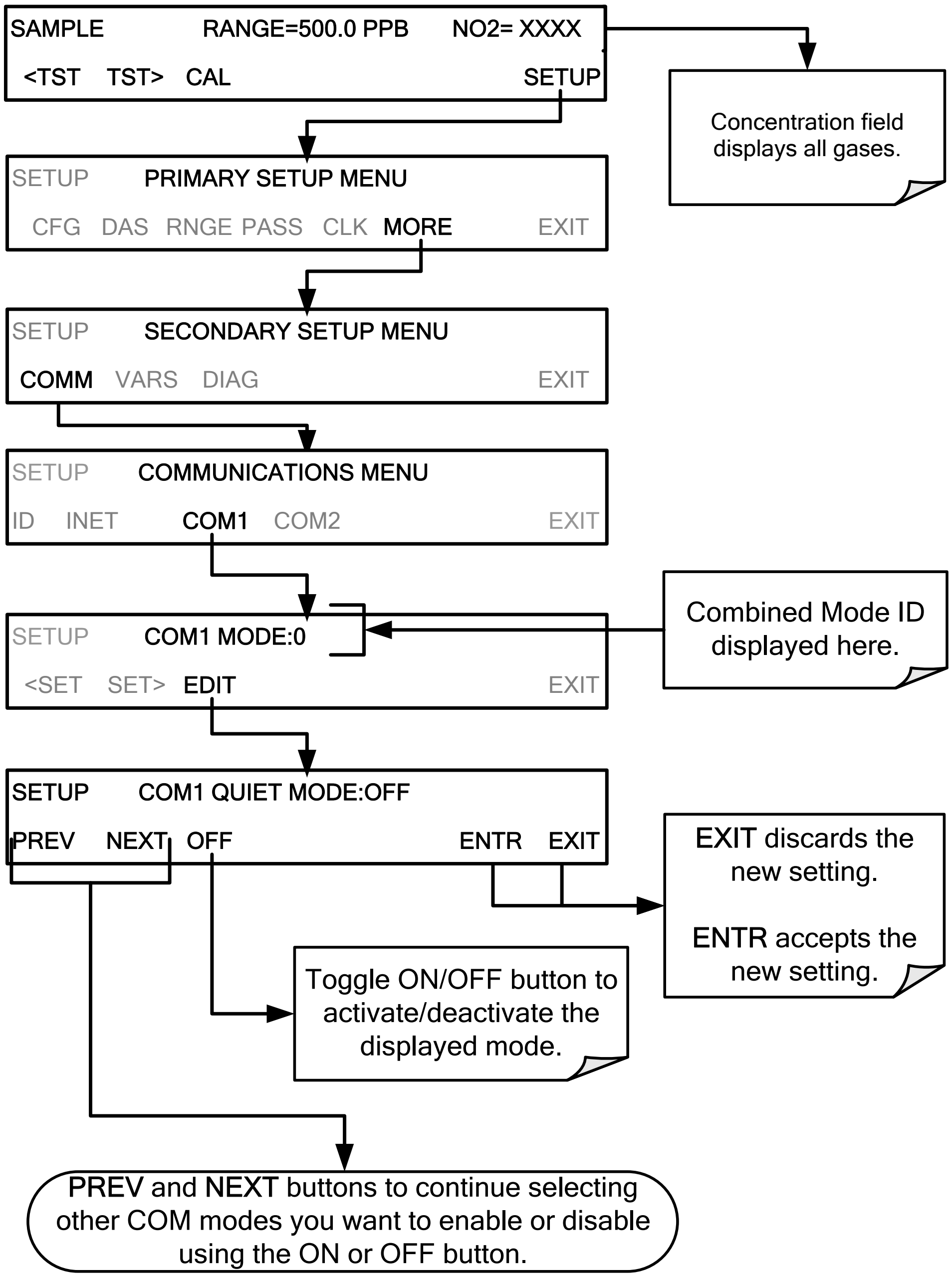
**Table 7-1: COM port Communication Modes**

| MODE[1] | ID | DESCRIPTION |
|---|---|---|
| **QUIET** | **1** | Quiet mode suppresses any feedback from the analyzer (such as warning messages) to the remote device and is typically used when the port is communicating with a computer program where such intermittent messages might cause communication problems. Such feedback is still available but a command must be issued to receive them. |
| **COMPUTER** | **2** | Computer mode inhibits echoing of typed characters and is used when the port is communicating with a computer operated control program. |
| **(RESERVED)** | **16** | |
| **E, 8, 1** | **8192** | When turned on this mode switches the COM port settings from No parity; 8 data bits; 1 stop bit to Even parity; 8 data bits; 1 stop bit. |
| **E, 7, 1** | **2048** | When turned on this mode switches the COM port settings from No parity; 8 data bits; 1 stop bit to Even parity; 7 data bits; 1 stop bit. |
| **RS-485** | **1024** | Configures the **COM2** Port for RS-485 communication. RS-485 mode has precedence over multidrop mode if both are enabled. Also, configuring for RS-485 disables the rear panel USB port. |
| **SECURITY** | **4** | When enabled, the serial port requires a password before it will respond (see Section 6.4). The only command that is active is the help screen (? CR). |
| **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. |
| **ERROR CHECKING[2]** | **128** | Fixes certain types of parity errors at certain Hessen protocol installations. |
| **XON/XOFF HANDSHAKE[2]** | **256** | Disables XON/XOFF data flow control also known as software handshaking. |
| **HARDWARE HANDSHAKE** | **8** | Enables CTS/RTS style hardwired transmission handshaking. This style of data transmission handshaking is commonly used with modems or terminal emulation protocols as well as by Teledyne Instrument's APICOM software. |
| **HARDWARE FIFO[2]** | **512** | Disables the **HARDWARE FIFO** (First In – First Out). When FIFO is enabled, it improves data transfer rate for that COM port. |
| **COMMAND PROMPT** | **4096** | Enables a command prompt when in terminal mode. |

[1] Modes are listed in the order in which they appear in the **SETUP → MORE → COMM → COM[1 OR 2] → MODE** menu

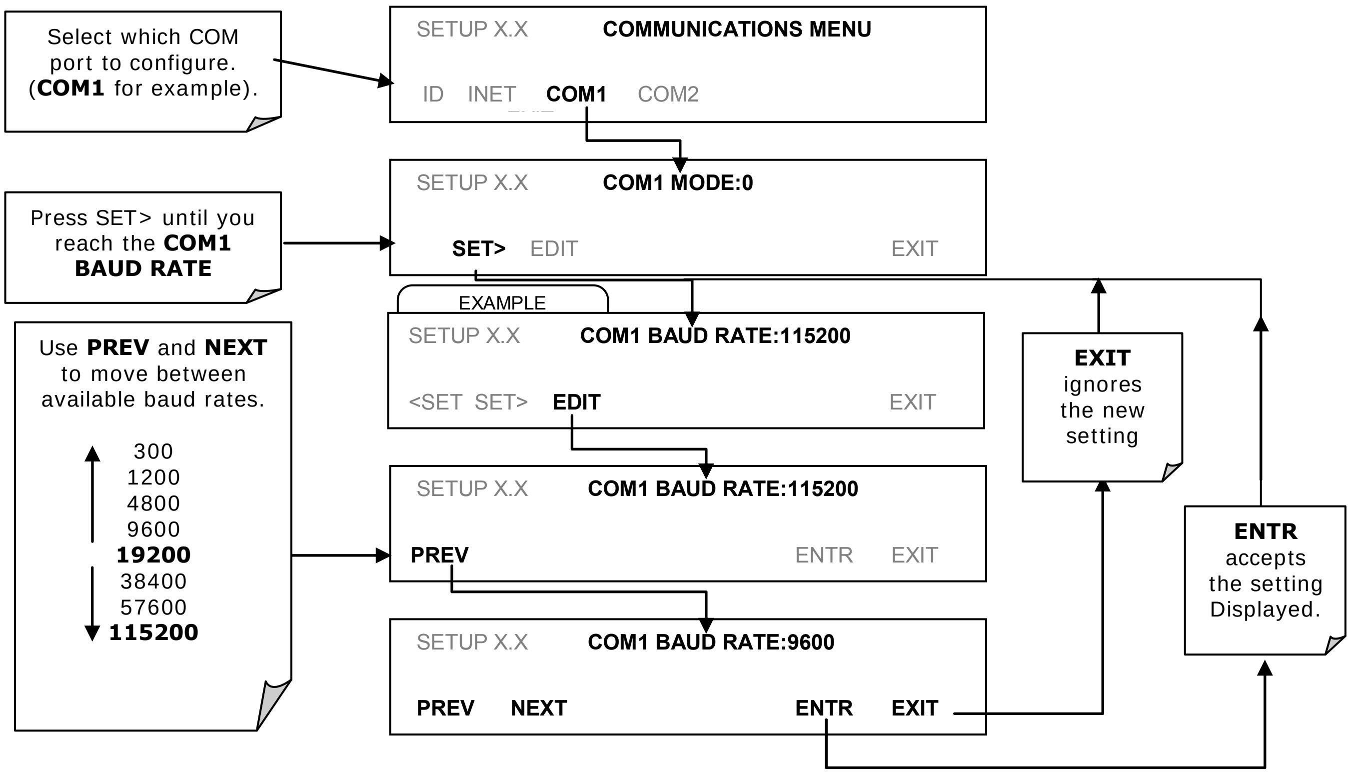
[2] The default setting for this feature is **ON.** Do not disable unless so instructed by Teledyne API's Technical Support personnel.

Communication Modes for each COM port being used must be configured independently. To turn on or off the communication modes for either COM1 or COM2, access the SETUP>MORE>[COM1 OR COM2] menu, and at the COM1 [2] Mode menu press EDIT.



## 7.2.2. COM PORT BAUD RATE

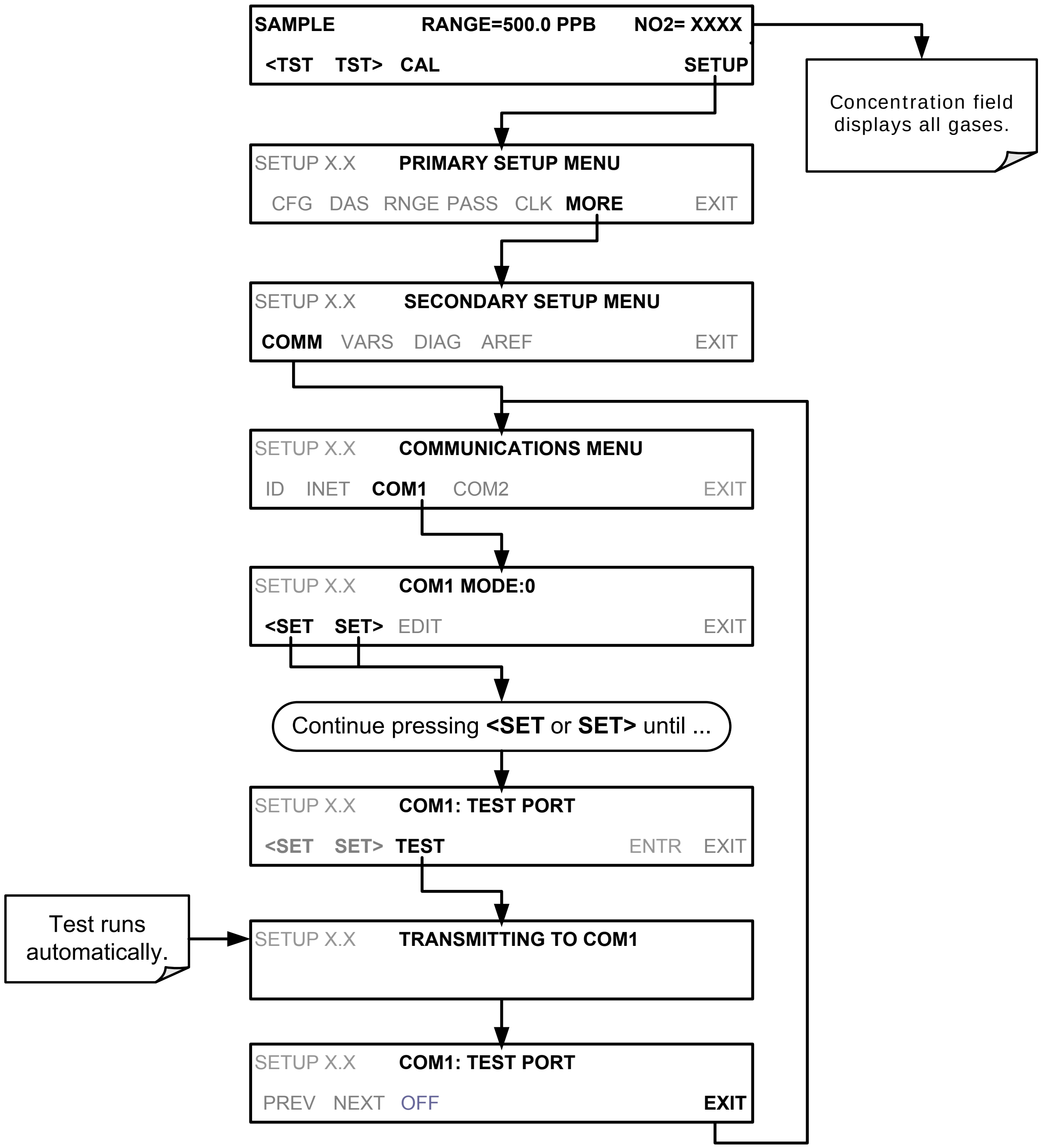
To select the baud rate of either COM port, go to SETUP>MORE>COMM and select either COM1 or COM2 as follows (use COM2 to view/match your personal computer baud rate when using the USB port, Section 7.6):



## 7.2.3. 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 button sequence:



# 7.3. RS-232

The RS232 and COM2 communications (COMM) ports operate on the RS-232 protocol (default configuration). Possible configurations for these two COM ports are summarized as follows:

- **RS232** port can also be configured to operate in single or RS-232 Multidrop mode (Option 62); refer to Section 3.3.1.8.
- **COM2** port can be left in its default configuration for standard RS-232 operation including multidrop, or it can be reconfigured for half-duplex RS-485 operation (please contact the factory for this configuration).

Note that the **COM2** port and the USB port cannot be used simultaneously except when COM2 is used for multidrop communication.

A code-activated switch (CAS) can also be used on either RS232 or COM2 port to connect typically between 2 and 16 send/receive instruments (host computer(s) printers, data loggers, analyzers, monitors, calibrators, etc.) into one communications hub. Contact Teledyne API Sales for more information on CAS systems.

To configure the analyzer's communication ports, use the SETUP>MORE>COMM menu (Section 6.6), and configure per Section 7.2 information.

# 7.4. RS-485 (OPTION)

The COM2 port of the instrument's rear panel is set up for RS-232 communication but can be reconfigured for RS-485 communication. Contact Technical Support. If this option was elected at the time of purchase, the rear panel was preconfigured at the factory. USB communications is not available when RS-485 is configured.

# 7.5. ETHERNET

When using the Ethernet interface, the analyzer can be connected to any standard 10BaseT or 100BaseT 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 network to the analyzer using APICOM, terminal emulators or other programs.

The Ethernet connector has two LEDs that are on the connector itself, indicating its current operating status.

**Table 7-2: Ethernet Status Indicators**

| LED | FUNCTION |
|---|---|
| amber (link) | On when connection to the LAN is valid. |
| green (activity | Flickers during any activity on the LAN. |

The analyzer is shipped with DHCP enabled by default. This allows the instrument to be connected to a network or router with a DHCP server. The instrument will automatically be assigned an IP address by the DHCP server (Section 7.5.2). This configuration is useful for quickly getting an instrument up and running on a network. However, for permanent Ethernet connections, a static IP address should be used. Section 7.5.1 below details static IP address configuration.

### 7.5.1. CONFIGURING ETHERNET COMMUNICATION MANUALLY (STATIC IP ADDRESS)

To configure Ethernet communication manually:

1. Connect a cable from the analyzer's Ethernet port to a Local Area Network (LAN) or Internet port.
2. From the analyzer's front panel touchscreen, access the Communications Menu (SETUP>MORE>COMM, see Figure 6-2).
3. Enter the INET menu shown in Figure 7-1, turning DHCP mode to OFF and editing the Instrument and Gateway IP addresses and Subnet Mask to the desired settings (default settings shown in Table 7-3).

Alternatively, from the computer, enter the same information through an application such as HyperTerminal.

**Internet Configuration Button Functions**

| BUTTON | FUNCTION |
|---|---|
| [0] | Location of cursor. Press to cycle through the range of numerals and available characters (“**0 – 9**” & “ **.** ”) |
| <CH CH> | Moves the cursor one character left or right. |
| DEL | Deletes a character at the cursor location. |
| ENTR | Accepts the new setting and returns to the previous menu. |
| EXIT | Ignores the new setting and returns to the previous menu. |
| Some buttons appear only when relevant. | |

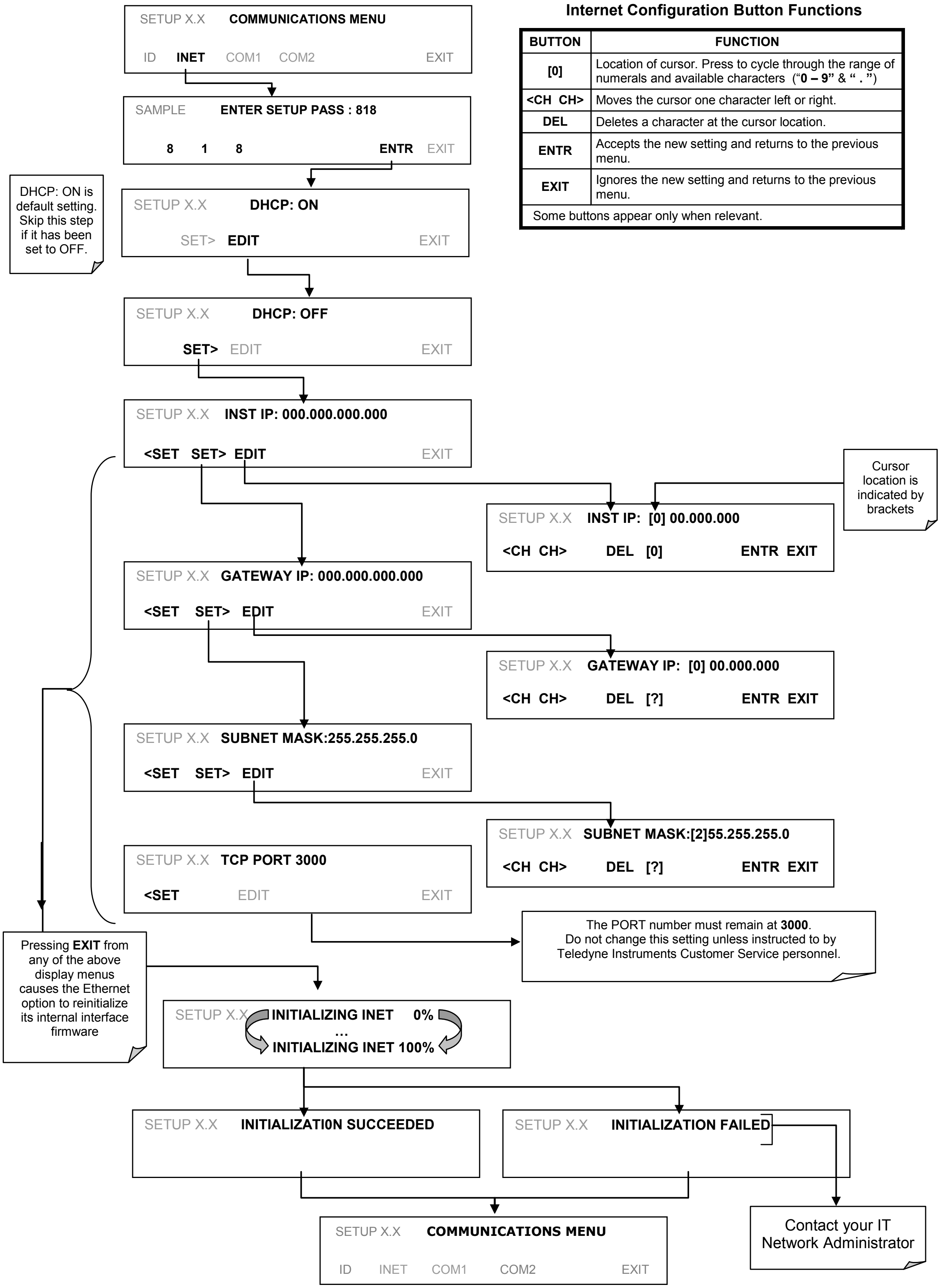



**Figure 7-1: COMM - LAN /Internet Manual Configuration**

**Table 7-3: LAN/Ethernet Default Configuration Properties**

| PROPERTY | DEFAULT STATE | DESCRIPTION |
|---|---|---|
| **DHCP** | ON | This displays whether the DHCP is turned ON or OFF. Press EDIT and toggle ON for automatic configuration after first consulting network administrator. |
| **INSTRUMENT IP ADDRESS** | | This string of four packets of 1 to 3 numbers each (e.g. 192.168.76.55.) is the address of the analyzer itself. |
| **GATEWAY IP ADDRESS** | 0.0.0.0 | Can only be edited when DHCP is set to OFF.<br>A string of numbers very similar to the Instrument IP address (e.g. 192.168.76.1.) that is the address of the computer used by your LAN to access the Internet. |
| **SUBNET MASK** | 0.0.0.0 | Can only be edited when DHCP is set to OFF.<br>Also a string of four packets of 1 to 3 numbers each (e.g. 255.255.252.0) that identifies the LAN to which the device is connected.<br>All addressable devices and computers on a LAN must have the same subnet mask. Any transmissions sent to devices with different subnets are assumed to be outside of the LAN and are routed through the gateway computer onto the Internet. |
| **TCP PORT[1]** | 3000 | This number defines the terminal control port by which the instrument is addressed by terminal emulation software, such as Internet or Teledyne API's APICOM. |
| **HOST NAME** | [initially blank] | The name by which your analyzer will appear when addressed from other computers on the LAN or via the Internet. To assign or change, see Section 7.5.2.1. |
| [1] Do not change the setting for this property unless instructed to by Teledyne API's Technical Support personnel. | | |

## 7.5.2. CONFIGURING ETHERNET COMMUNICATION USING DYNAMIC HOST CONFIGURATION PROTOCOL (DHCP)

The default Ethernet setting is DHCP.

1. Consult with your network administrator to affirm that your network server is running DHCP.
2. Access the Communications Menu (SETUP>MORE>COMM, see Figure 6-2).
3. Enter the INET menu and follow the setup sequence as follows:

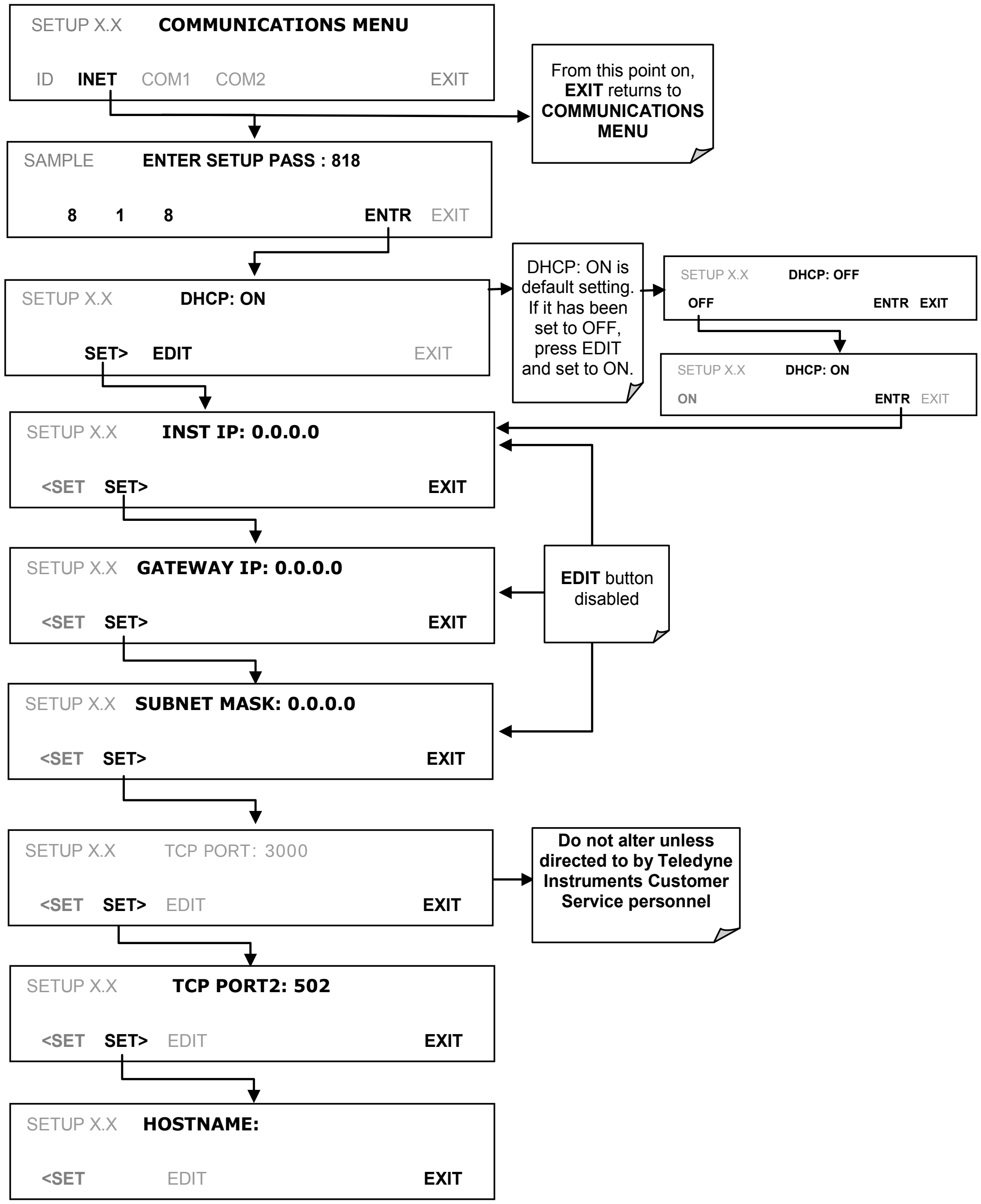


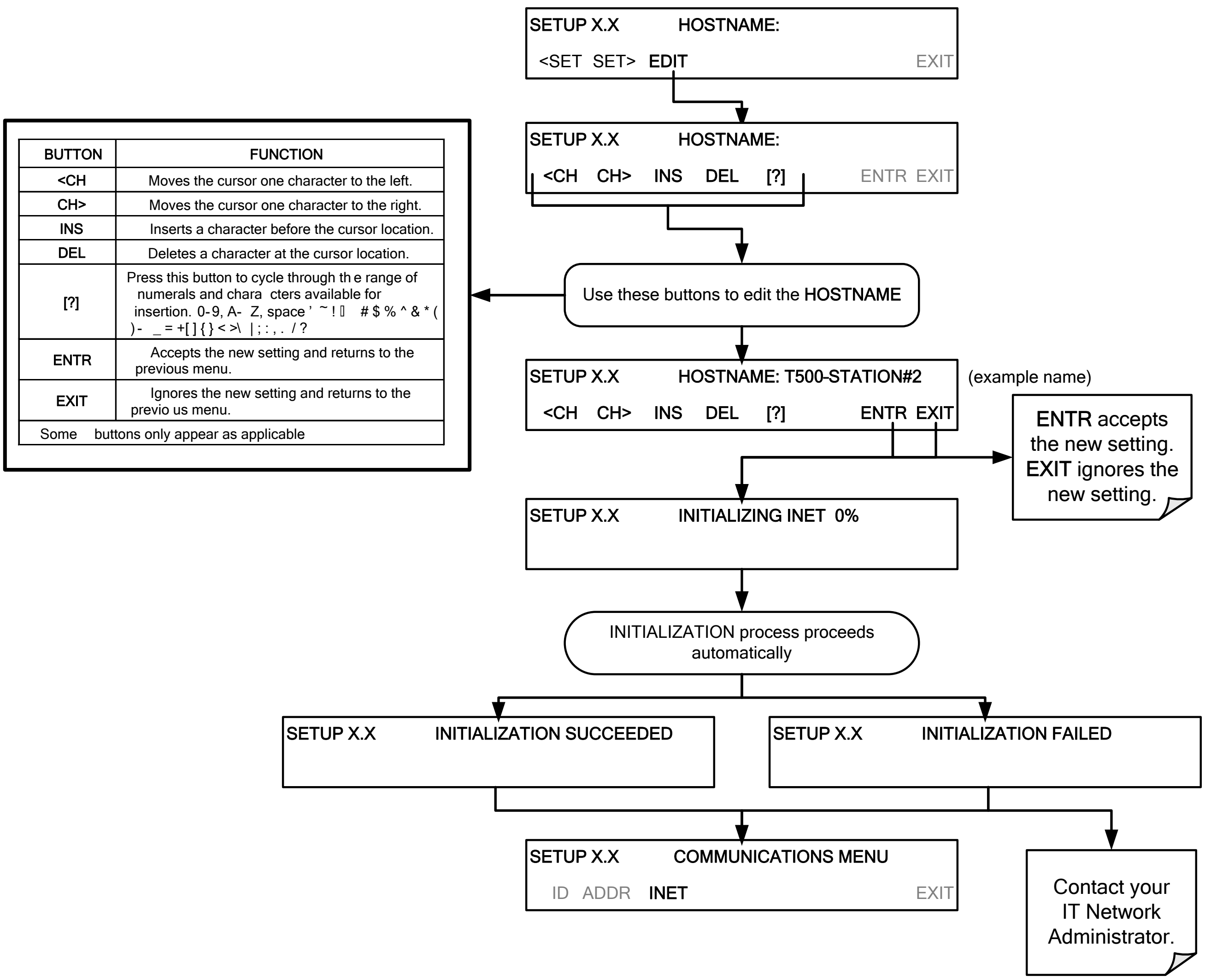

**Figure 7-2: COMM – LAN / Internet Automatic Configuration (DHCP)**

**Note**

**If the gateway IP, instrument IP and the subnet mask are all zeroes (i.e., "0.0.0.0"), the DCHP was not successful in which case you may have to configure the analyzer's Ethernet properties manually. See your network administrator.**

### 7.5.2.1. **CHANGING THE ANALYZER'S HOSTNAME**

The **HOSTNAME** is the name by which the analyzer appears on your network. The initial default Hostname is blank. To assign or change this name (particularly if you have more than one T500U analyzer on your network, where each must have a different Hostname), enter the SETUP>COMM>INET men and scroll to the HOSTNAME menu as in Figure 7-2; make the changes as follows:

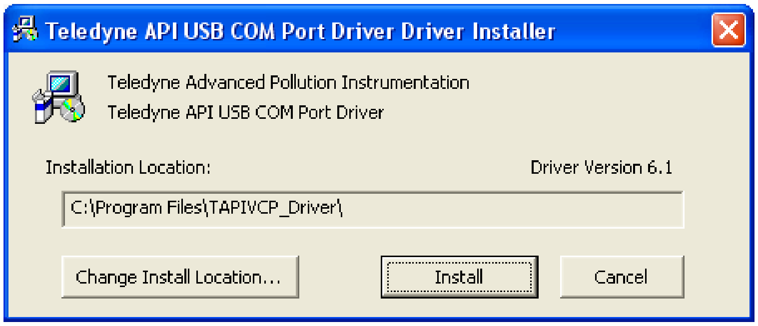



| BUTTON | FUNCTION |
|---|---|
| <CH | Moves the cursor one character to the left. |
| CH> | Moves the cursor one character to the right. |
| INS | Inserts a character before the cursor location. |
| DEL | Deletes a character at the cursor location. |
| [?] | Press this button to cycle through the range of numerals and characters available for insertion. 0-9, A- Z, space ' ~ ! # $ % ^ & * ( ) - _ = +[ ] { } < >\ \| ; : , . / ? |
| ENTR | Accepts the new setting and returns to the previous menu. |
| EXIT | Ignores the new setting and returns to the previous menu. |
| Some buttons only appear as applicable | |

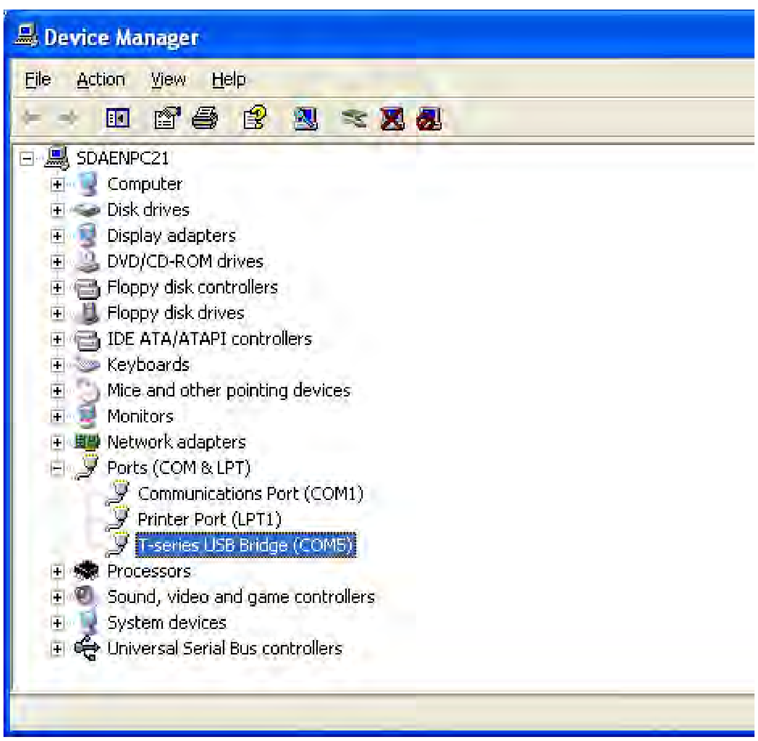
# 7.6. USB PORT FOR REMOTE ACCESS

The analyzer can be operated through a personal computer by downloading the TAPI USB driver and directly connecting their respective USB ports.

1. Install the Teledyne T-Series USB driver on your computer, downloadable from the Teledyne API website under Help Center>Software Downloads (www.teledyne-api.com/software).
2. Run the installer file: "TAPIVCPInstaller.exe"




3. Connect the USB cable between the USB ports on your personal computer and your analyzer. The USB cable should be a Type A – Type B cable, commonly used as a USB printer cable.
4. Determine the Windows XP Com Port number that was automatically assigned to the USB connection. (Start>Control Panel>System>Hardware>Device Manager). This is the com port that should be set in the communications software, such as APICOM or Hyperterminal.




Refer to the Quick Start (*Direct Cable Connection*) section of the Teledyne APICOM Manual, PN 07463.

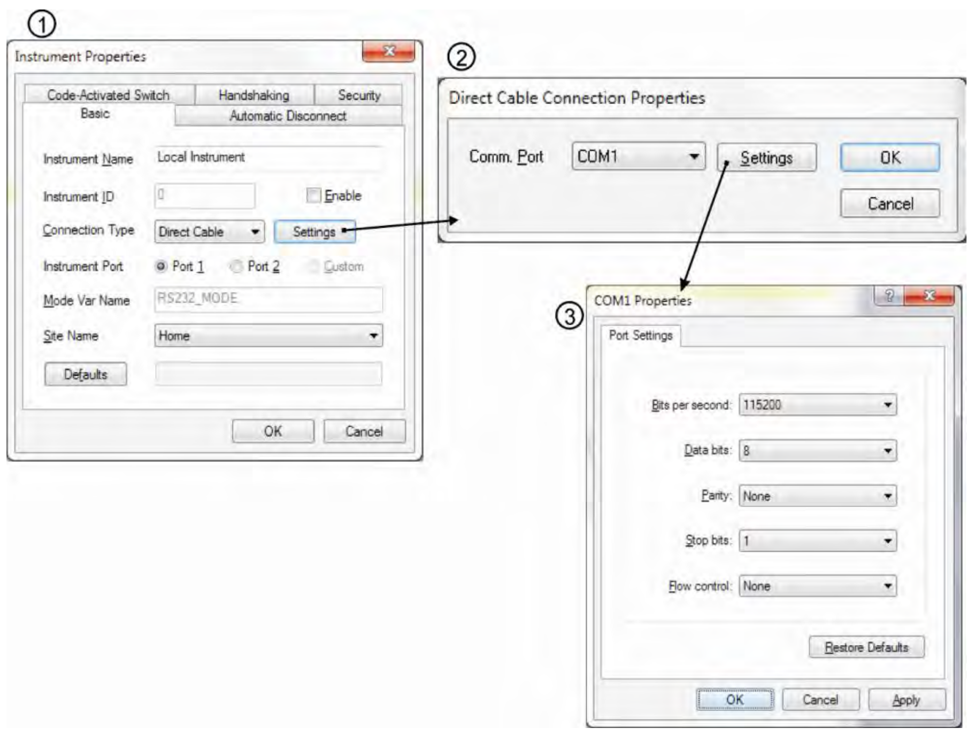
5. In the instrument's SETUP>MORE>COMM>COM2 menu, make the following settings:

   Baud Rate: 115200

   COM2 Mode Settings:

| | |
|---|---|
| Quiet Mode | ON |
| Computer Mode | ON |
| MODBUS RTU | OFF |
| MODBUS ASCII | OFF |
| E,8,1 MODE | OFF |
| E,7,1 MODE | OFF |
| RS-485 MODE | OFF |
| SECURITY MODE | OFF |
| MULTIDROP MODE | OFF |
| ENABLE MODEM | OFF |
| ERROR CHECKING | ON |
| XON/XOFF HANDSHAKE | OFF |
| HARDWARE HANDSHAKE | OFF |
| HARDWARE FIFO | ON |
| COMMAND PROMPT | OFF |

6. Next, configure your communications software, such as APICOM. Use the COM port determined in Step 4 and the baud rate set in Step 5. The figures below show how these parameters would be configured in the Instrument Properties window in APICOM when configuring a new instrument. See the APICOM manual (PN 07463) for more details.




**Note**

**Using the USB port disallows use of the rear panel COM2 port except for multidrop communication.**

# 7.7. COMMUNICATIONS PROTOCOLS

Communication protocols include Hessen and MODBUS.

## 7.7.1. HESSEN

The Hessen protocol is a multidrop protocol, in which several remote instruments are connected via a common communications channel to a host computer. The remote instruments are regarded as slaves of the host computer. The remote instruments are unaware that they are connected to a multidrop bus and never initiate Hessen protocol messages. They only respond to commands from the host computer and only when they receive a command 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. Teledyne API's implementation supports both of these principal features.

The Hessen protocol is not tightly defined; therefore, while Teledyne API's application is completely compatible with the protocol itself, it may be different from implementations by other companies.

### 7.7.1.1. HESSEN COM PORT CONFIGURATION

Hessen protocol requires the communication parameters of the T500U's COM ports to be set differently than the standard configuration as shown in the table below.

**Table 7-4: RS-232 Communication Parameters for Hessen Protocol**

| PARAMETER | STANDARD | HESSEN |
|---|---|---|
| Baud Rate | 300 – 19200 | 1200 |
| Data Bits | 8 | 7 |
| Stop Bits | 1 | 2 |
| Parity | None | Even |
| Duplex | Full | Half |

To change the baud rate of the T500U's COM ports, See Section 7.2.2.

To change the remaining COM port parameters listed in the table above, see Section 7.2.1, Table 7-1.

**Note**

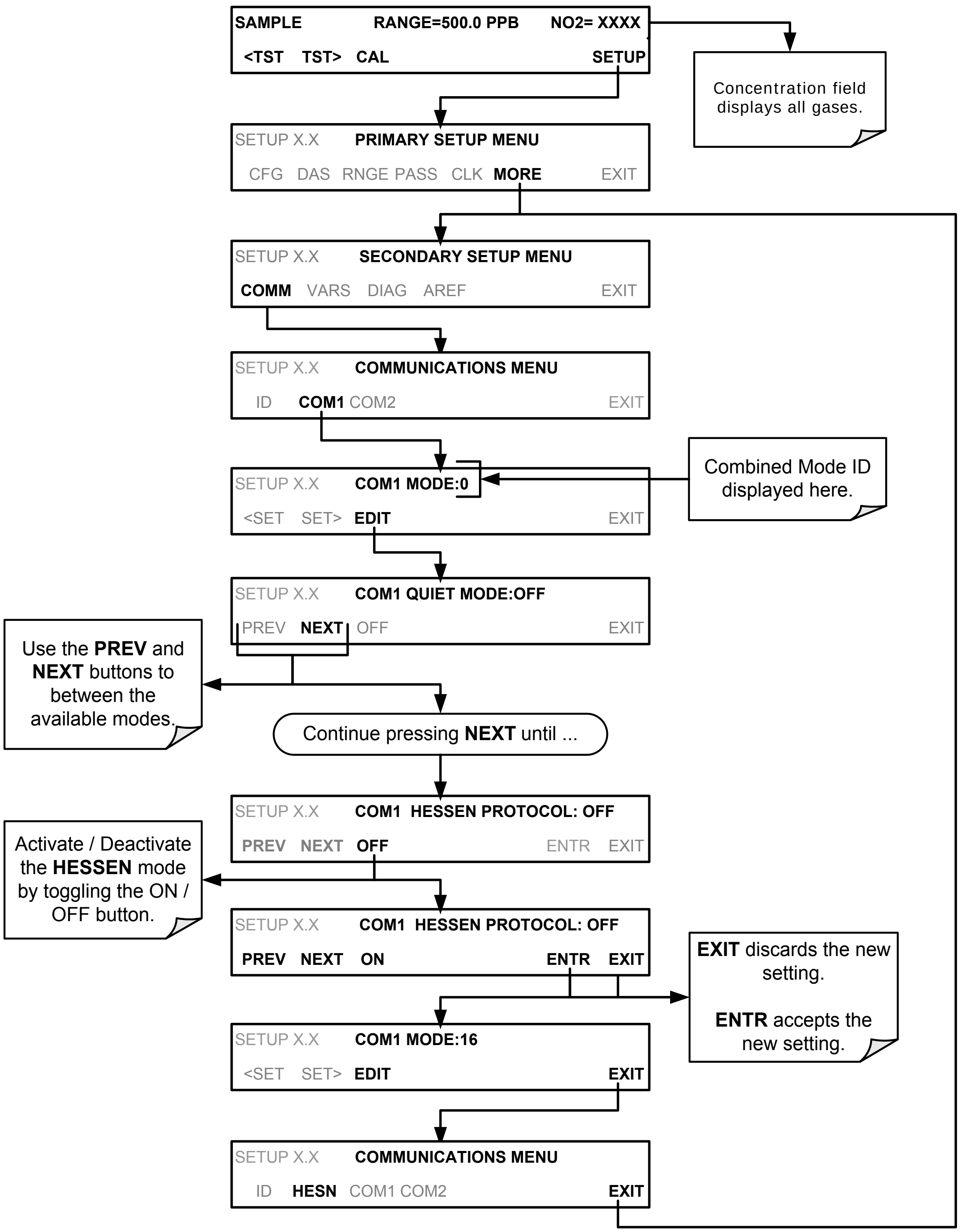
**Ensure that the communication parameters of the host computer are also properly set.**

**Also, the instrument software has a 200 ms latency period before it responds to commands issued by the host computer. This latency should present no problems, but you should be aware of it and only issue commands to the instrument at an appropriate pace.**

### 7.7.1.2. ACTIVATING HESSEN PROTOCOL

Once the COM port has been properly configured, the next step is to activate the Hessen mode for COM ports and configure the communication parameters for the port(s) appropriately.

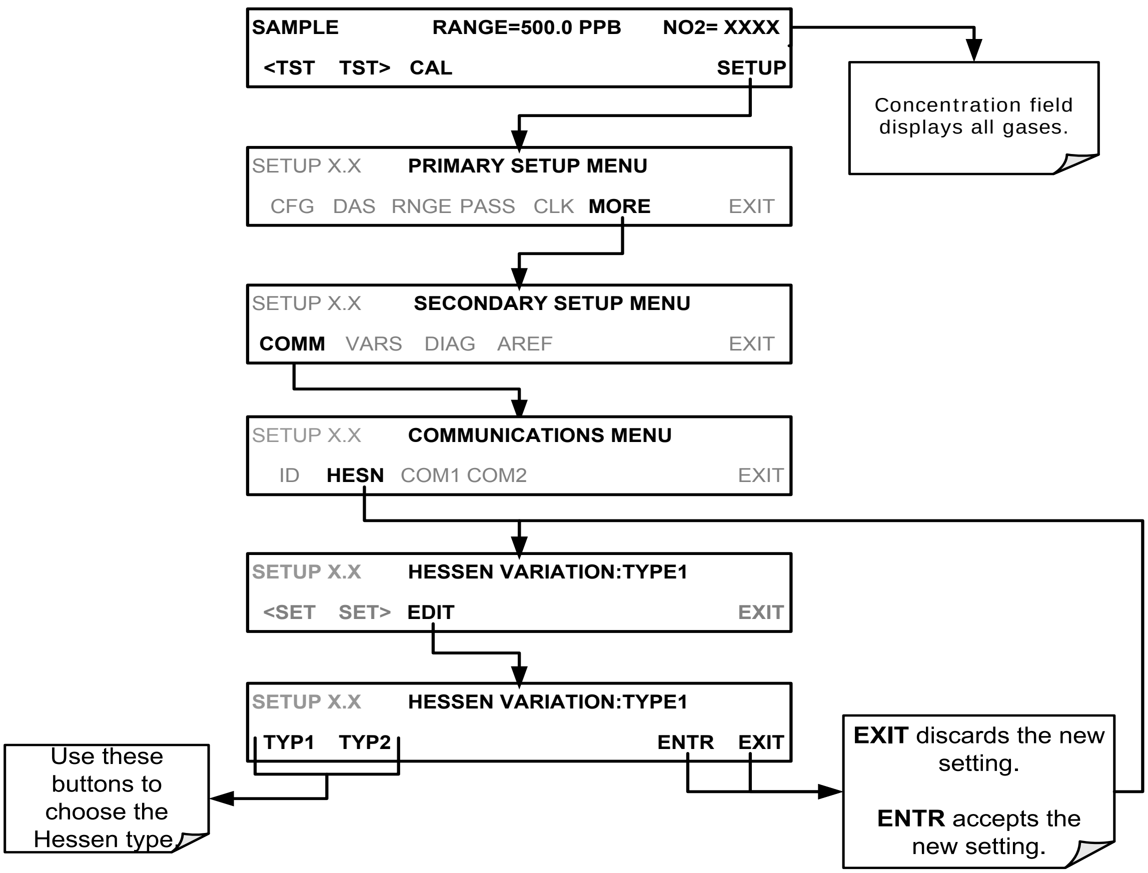
To activate the Hessen Protocol, press:



### 7.7.1.3. SELECTING A HESSEN PROTOCOL TYPE

Currently there are two versions of Hessen Protocol in use. The original implementation, referred to as **TYPE 1**, and a more recently released version, **TYPE 2** that has more flexibility when operating with instruments that can measure more than one type of gas. For more specific information about the difference between **TYPE 1** and **TYPE 2** download the *Manual Addendum for Hessen Protocol* from the Teledyne API's web site: http://www.teledyne-api.com/manuals/.

To select a Hessen Protocol Type press:




**NOTE**

**While Hessen Protocol Mode can be activated independently for COM1 and COM2, the TYPE selection affects both ports.**

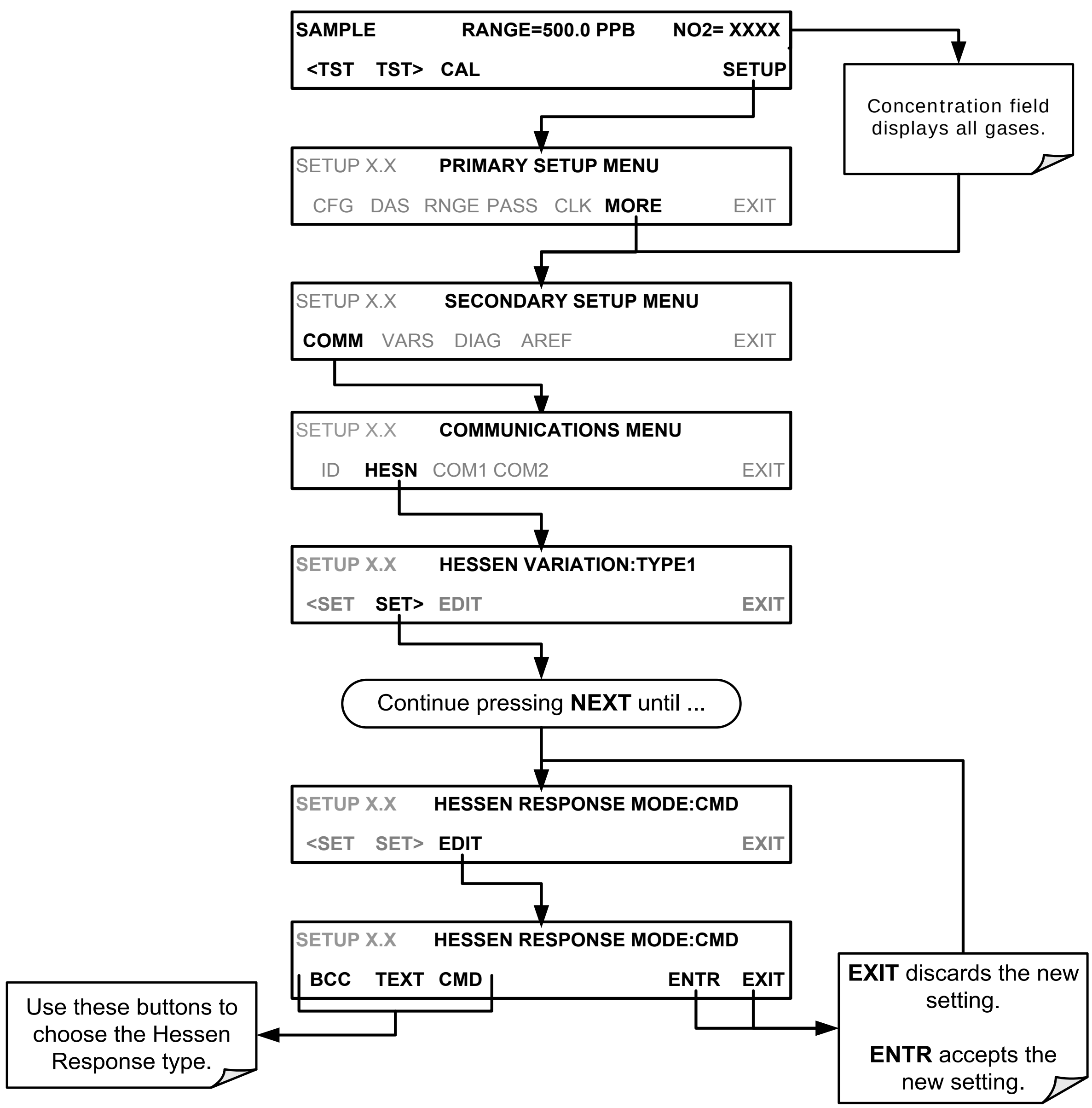
### 7.7.1.4. SETTING THE HESSION PROTOCOL RESPONSE MODE

The Teledyne API's implementation of Hessen Protocol allows the user to choose one of several different modes of response for the analyzer.

**Table 7-5: Teledyne API's Hessen Protocol Response Modes**

| MODE ID | MODE DESCRIPTION |
|---|---|
| **CMD** | This is the Default Setting. Reponses from the instrument are encoded as the traditional command format. Style and format of responses depend on exact coding of the initiating command. |
| **BCC** | Responses from the instrument are always delimited with <STX> (at the beginning of the response, <ETX> (at the end of the response followed by a 2 digit Block Check Code (checksum), regardless of the command encoding. |
| **TEXT** | Responses from the instrument are always delimited with <CR> at the beginning and the end of the string, regardless of the command encoding. |

To Select a Hessen response mode, press:



### 7.7.1.5. HESSEN PROTOCOL GAS LIST ENTRY FORMAT AND DEFINITIONS

The T500U analyzer keeps a list of available gas types. Each entry in this list is of the following format.

**[GAS TYPE],[RANGE],[GAS ID],[REPORTED]**

WHERE:

**GAS TYPE** The type of gas to be reported (the T500U has only one gas type: $NO_2$).

**RANGE** The concentration range for this gas. This feature permits the user to select which concentration range will be used. The T500U analyzer has two ranges: **RANGE1** or LOW & **RANGE2** or HIGH (see Section 6.3).

1. 0 - The HESSEN protocol to use whatever range is currently active.
2. 1 - The HESSEN protocol will always use RANGE1 for this gas.
3. 2 - The HESSEN protocol will always use RANGE2 for this gas.
4. 3 - Not applicable to the T500U analyzer.

**GAS ID** An identification number assigned to a specific gas. The T500U analyzer measures only $NO_2$, which has the following ID number:

$NO_2$ 213

**REPORT** States whether this list entry is to be reported or not reported whenever this gas type or instrument is polled by the HESSEN network. If the list entry is not to be reported this field will be blank. It's default gas list consists of only reads:

**NO2, 0, 213, REPORTED**

These default settings cause the instrument to report the concentration value of the currently active range. If you wish to have just concentration value stored for a specific range, this list entry should be edited or additional entries should be added to the list.

### 7.7.1.6. **SETTING HESSEN PROTOCOL STATUS FLAGS**

Teledyne API's’ implementation of Hessen protocols includes a set of 16 status bits that the instrument includes in responses to inform the host computer of its condition. This status flag includes an 8-bit set for Operational status follows by another 8-bit set for Failure status. Each 8-bit status message is formatted as a 2-digit hexadecimal number. Each bit can be assigned to one operational or warning message flag. The default settings for these bit/flags are:

**Table 7-6: Default Hessen Status Flag Assignments**

| STATUS FLAG NAME | DEFAULT BIT ASSIGNMENT HEX | BITS |
|---|---|---|
| **OPERATIONAL FLAGS (8 BITS)** | | |
| In MANUAL Calibration Mode | x02 | 0000 0010 |
| In ZERO Calibration Mode | x04 | 0000 0100 |
| In SPAN Calibration Mode | x08 | 0000 1000 |
| INVALID CONC | x80 | 1000 0000 |
| SPARE/UNUSED | x01 | 0000 0001 |
| **UNITS OF MEASURE FLAGS (ONLY BITS 5 AND 6 OF THE OPERATIONAL FLAG)** | | |
| UGM | | 00 |
| MGM | | 01 |
| PPB | | 10 |
| PPM | | 11 |
| **WARNING FLAGS (8 BITS)** | | |
| ANY PRESS WARN | x04 | 0000 0100 |
| SAMPLE TEMP WARNING | x08 | 0000 1000 |
| INTERNAL PUMP OVERRIDE SET TO OFF | x10 | 0001 0000 |
| IZS TEMP WARNING[1] | x20 | 0010 0000 |
| BENCH LED DISABLED | x40 | 0100 0000 |
| OVEN TEMP WARNING | x80 | 1000 0000 |

| **UNASSIGNED FLAGS** | |
|---|---|
| MANIFOLD TEMPERATURE[2] | FRONT PANEL COMMUNICATION WARNING |
| BOX TEMP WARNING | ANALOG CALIBRATION WARNING |
| SYSTEM RESET | DYNAMIC ZERO WARNING |
| RELAY BOARD WARNING | DYNAMIC SPAN WARNING |
| REAR BOARD NOT DETECTED | IN MULTI-POINT CALIBRATION MODE |
| AUTOREF WARNING | |

1 Only applicable if the optional internal span gas generator is installed.

2 Only applicable if the T500U is equipped with the optional manifold.

It is possible to assign more than one flag to the same Hessen status bit. This allows the grouping of similar flags, such as all temperature warnings, under the same status bit.

Be careful not to assign conflicting flags to the same bit as each status bit will be triggered if any of the assigned flags is active.

## 7.7.2. **MODBUS**

This section provides MODBUS communications protocol setup instructions; see Appendix A for MODBUS registers. This set of instructions assumes that the user is familiar with MODBUS communications, and provides minimal information to get started. For additional instruction, please refer to the Teledyne API MODBUS manual, PN 06276, downloadable from our website at http://www.teledyne-api.com/software/apicom/. Also refer to www.modbus.org for MODBUS communication protocols.

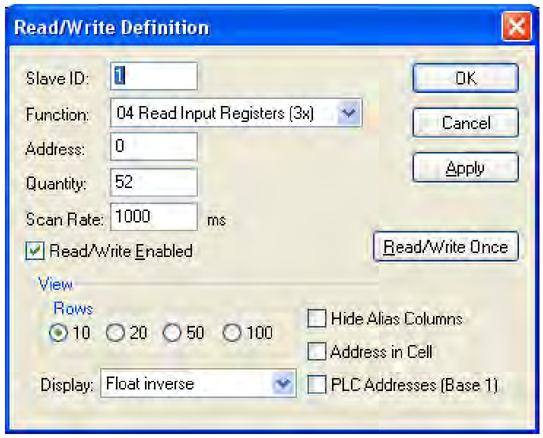
Minimum Requirements

- Instrument firmware with MODBUS capabilities installed.
- MODBUS-compatible software (TAPI uses MODBUS Poll for testing; see www.modbustools.com)
- Personal computer
- Communications cable (Ethernet or USB or RS232)
- Possibly a null modem adapter or cable

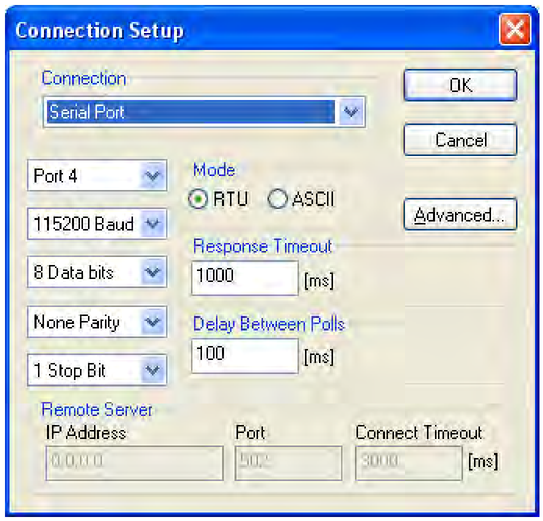
**Table 7-7. MODBUS Setup Instructions**

| **Actions** | |
|---|---|
| Set Com Mode parameters | |
| Comm | Ethernet: Using the front panel menu, go to SETUP – MORE – COMM – INET; scroll through the INET submenu until you reach TCP PORT 2 (the standard setting is 502), then continue to TCP PORT 2 MODBUS TCP/IP; press EDIT and toggle the menu button to change the setting to ON, then press ENTR. (Change Machine ID if needed: see "Slave ID").<br>USB/RS232: Using the front panel menu, go to SETUP – MORE – COMM – COM2 – EDIT; scroll through the COM2 EDIT submenu until the display shows COM2 MODBUS RTU: OFF (press OFF to change the setting to ON. Scroll NEXT to COM2 MODBUS ASCII and ensure it is set to OFF. Press ENTR to keep the new settings. (If RTU is not available with your communications equipment, set the COM2 MODBUS ASCII setting to ON and ensure that COM2 MODBUS RTU is set to OFF. Press ENTR to keep the new settings). |
| Slave ID | If your analyzer is connected to a network with at least one other analyzer of the same model, a unique Slave ID must be assigned to each. Using the front panel menu, go to SETUP – MORE – COMM – ID. The MACHINE ID default is the same as the model number. Toggle the menu buttons to change the ID. |
| Reboot analyzer | For the settings to take effect, power down the analyzer, wait 5 seconds, and power up again. |
| Make appropriate cable connections | Connect your analyzer via either:<br>• Ethernet or USB port to a PC (this may require a USB-to-RS232 adapter for your PC; if so, also install the software driver from the CD supplied with the adapter, and reboot the computer if required), or<br>• COM2 port to a null modem (this may require a null modem adapter or cable). |
| Specify MODBUS software settings<br>(examples used here are for MODBUS Poll software) | 1. Click Setup / [Read / Write Definition] /.<br>A. In the Read/Write Definition window (see example that follows) select a **Function** (what you wish to read from the analyzer).<br>B. Input **Quantity** (based on your firmware's register map).<br>C. In the View section of the Read/Write Definition window select a **Display** (typically Float Inverse).<br>D. Click **OK**.<br>2. Next, click Connection/Connect.<br>A. In the Connection Setup window (see example that follows), select the options based on your computer.<br>B. Press **OK**. |
| Read the Modbus Poll Register | Use the Register Map to find the test parameter names for the values displayed (see example that follows If desired, assign an alias for each. |

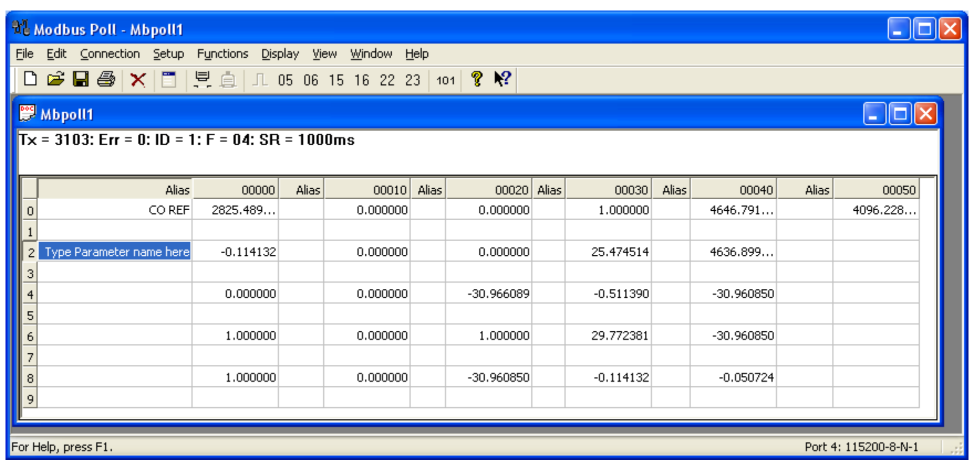
Example Read/Write Definition window:




Example Connection Setup window:




Example MODBUS Poll window:



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# 8. DATA ACQUISITION SYSTEM (DAS) AND APICOM

The internal data acquisition system (DAS) enables the analyzer to store concentration and calibration data as well as a host of diagnostic parameters. This feature can store a large number of data points covering days, weeks or months of valuable measurements, depending on individual configurations. The data records 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 electronic spreadsheets).

The DAS permits users to access stored data through the instrument's front panel or remotely through its communication ports. To support the DAS functionality, Teledyne API offers APICOM, a program that provides a visual interface for remote or local setup, configuration and data retrieval of the DAS (APICOM DAS Manual, PN 07463, which can be downloaded from our website at http://www.teledyne-api.com under Help Center > Product Manuals in the Special Manuals section).

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**DAS operation is suspended whenever its configuration is edited using the analyzer's front panel and therefore data may be lost. To prevent such data loss, it is recommended to use the APICOM graphical user interface for DAS changes (Section 8.2.1).**

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

**Note**

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

The principal use of the DAS 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.

The green **SAMPLE LED** on the instrument front panel not only indicates the analyzer status, but also indicates certain aspects of the DAS 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. DAS channels can be enabled or disabled for this period. Concentration data are typically disabled whereas diagnostic should be collected.

# 8.1. DAS STRUCTURE

The DAS is designed around the feature of a "record", a single data point. The types of data captured in a record are defined by two properties:

- **PARAMETER** type that defines the kind of data to be stored (e.g. the average of $NO_2$ concentrations measured with three digits of precision). See Section 8.1.3.3.
- A **TRIGGER** event that defines when the record is made (e.g. timer; every time a calibration is performed, etc.). See Section 8.1.3.2.

The specific **PARAMETERS** and **TRIGGER** events that describe an individual record are defined in a construct called a **DATA CHANNEL** (see Section 8.1.3).

## 8.1.1. DAS CHANNELS

Users may create up to 20 data channels and each channel can contain a triggering event and one or more parameters. For each channel, the following are selected:

- one triggering event
- up to 50 data parameters, which can be the shared between channels.
- several other properties that define the structure of the channel and allow the user to make operational decisions regarding the channel.

**Table 8-1: DAS Data Channel Properties**

| PROPERTY | DESCRIPTION | DEFAULT SETTING | SETTING RANGE |
|---|---|---|---|
| **NAME** | The name of the data channel. | **"NONE"** | Up to 6 letters or digits[1]. |
| **TRIGGERING EVENT** | The event that triggers the data channel to measure and store the datum. | **ATIMER** | Any available event (see Appendix A, DAS Trigger Events). |
| **NUMBER AND LIST OF PARAMETERS** | A user-configurable list of data types to be recorded in any given channel. | **1** | Any available parameter (see Appendix A, DAS Parameters). |
| **REPORT PERIOD** | The amount of time between each channel data point. | **000:01:00** *(1 hour)* | 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 limit is exceeded, the oldest data is over-written. | **100** | Limited by available storage space, which depends on DAS configuration. |
| **RS-232 REPORT** | Enables the analyzer to automatically report channel values to the RS-232 ports. | **OFF** | OFF or ON |
| **CHANNEL ENABLED** | Enables or disables the channel. Allows a channel to be temporarily turned off without deleting it. | **ON** | OFF or ON |
| **CAL HOLD OFF** | Disables sampling of data parameters while instrument is in calibration mode[2]. | **OFF** | OFF or ON |

[1] More with APICOM, but only the first six are displayed on the front panel).

[2] When enabled records are not recorded until the DAS_HOLD OFF period is passed after calibration mode. DAS_HOLD OFF SET in the **VARS** menu (see Section 6.7).

### 8.1.1.1. DEFAULT DAS CHANNELS

A set of default Data Channels has been included in the analyzer's software for logging $NO_2$ concentrations as well as certain predictive diagnostic data. Table 8-2 describes these channels for the software revision shipped with the T500U at the time of this writing. Figure 8-1 shows the APICOM interface with the default configuration.

**Table 8-2: T500U Default DAS Channels**

| Channel | Description |
|---|---|
| **CONC** | Samples $NO_2$ concentration at one minute intervals and stores an average every hour with a time and date stamp. Readings during calibration and calibration hold off are not included in the data.<br>By default, the last 800 hourly averages are stored. |
| **PNUMTC** | Collects sample flow and sample pressure data at five minute intervals and stores an average once a day with a time and date stamp. This data is useful for monitoring the condition of the pump, the flow control (sample flow) and the sample filter (clogging indicated by a drop in sample pressure) over time to predict when maintenance will be required.<br>By default, the last 360 daily averages (about 1 year) are stored. |
| **CALDAT** | Logs new slope and offset of $NO_2$ measurements every time a zero or span calibration is performed and the result changes the value of the slope (triggering event: **SLPCHG**). The $NO_2$ stability (to evaluate if the calibration value was stable) is also stored.<br>This data channel will store data from the last 200 calibrations and can be used to document analyzer calibration and is useful for detect trends in slope and offset (instrument response) when performing predictive diagnostics as part of a regular maintenance schedule (Section 11.1).<br>The CALDAT channel collects data based on events (e.g. a calibration operation) rather than a timed interval and therefore does not represent any specific length of time. 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).<br>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.<br>The **STABIL** parameter documents if the analyzer response was stable at the point of the calibration check reading. The last 200 data points are retained. |
| **DIAG** | Daily averages of temperature zones, flow and pressure data as well as some other diagnostic parameters.<br>This data is useful for predictive diagnostics and maintenance of the T500U. |
| **HIRES** | Records one-minute, instantaneous data of all active parameters in the T500U. Short-term trends as well as signal noise levels can be detected and documented.<br>The last 1500 data points are stored. Readings during calibration and the calibration hold off period are included in the averages. |

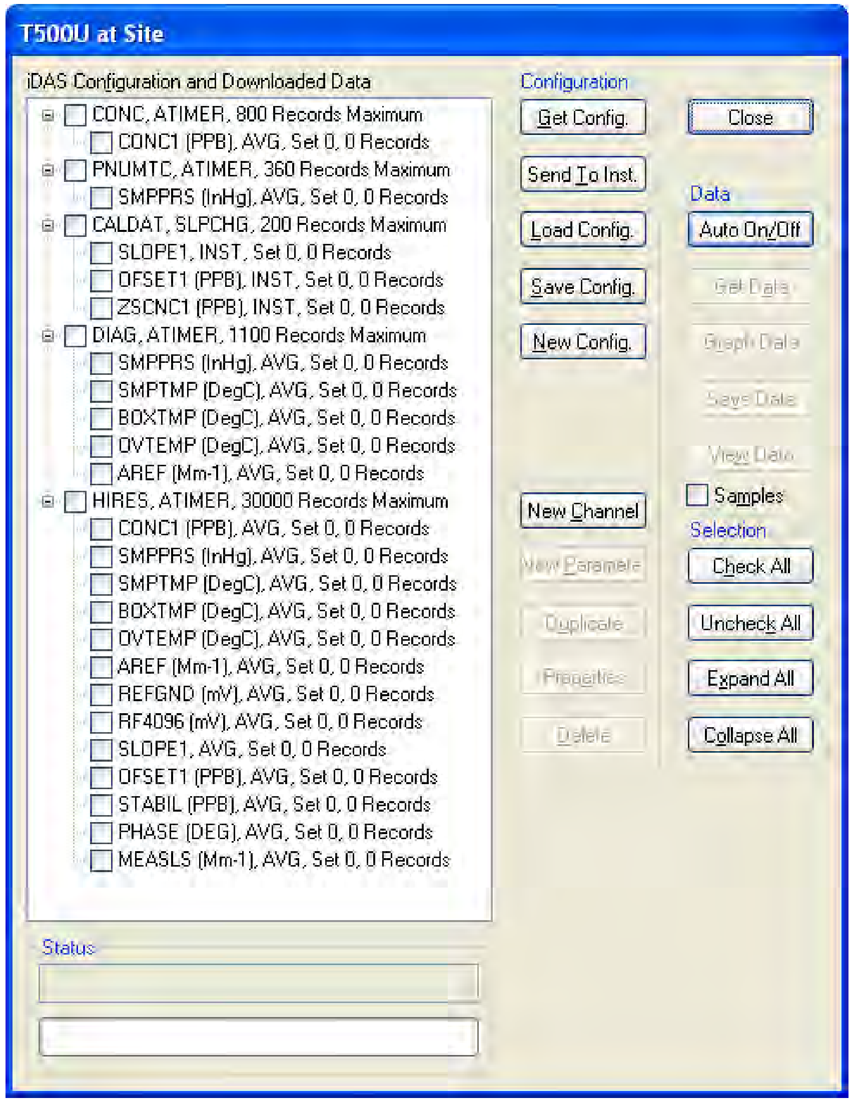



**Figure 8-1: Example Default DAS Configuration in APICOM** (Section 8.2.1) **Interface**

These default data channels can be used as they are, or they can be customized (Section 8.1.3) from the front panel to fit a specific application. They can also be deleted to make room for custom user-programmed Data Channels.

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Sending a DAS 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 DAS configuration before uploading new settings.**

### 8.1.1.2. DAS CONFIGURATION LIMITS

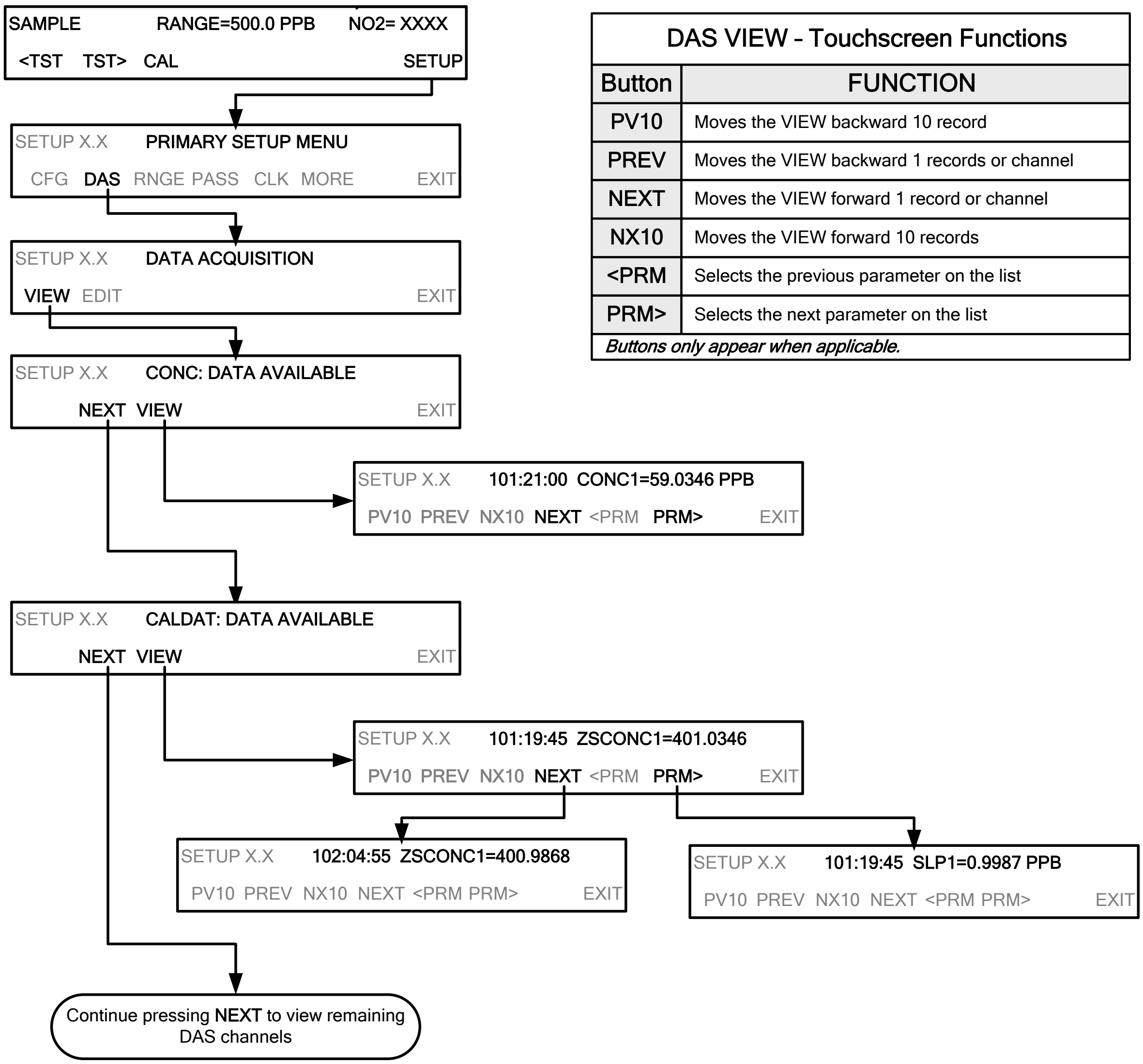
The number of DAS objects is limited by the instrument's finite storage capacity. For information regarding the maximum number of channels, parameters, and records and how to calculate the file size for each data channel, refer to the APICOM DAS manual.

## 8.1.2. **VIEWING DAS DATA AND SETTINGS**

DAS data and settings can be viewed on the front panel through the following menu sequence.

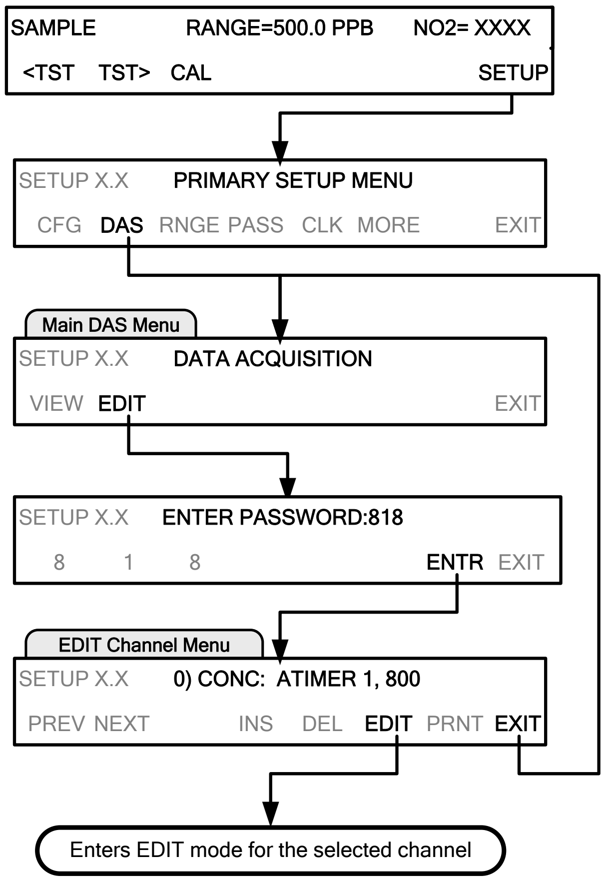
| DAS VIEW - Touchscreen Functions | |
|---|---|
| Button | FUNCTION |
| PV10 | Moves the VIEW backward 10 record |
| PREV | Moves the VIEW backward 1 records or channel |
| NEXT | Moves the VIEW forward 1 record or channel |
| NX10 | Moves the VIEW forward 10 records |
| <PRM | Selects the previous parameter on the list |
| PRM> | Selects the next parameter on the list |

*Buttons only appear when applicable.*



## 8.1.3. **EDITING DAS DATA CHANNELS**

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




| DAS EDIT – Touchscreen Button Functions | |
|---|---|
| **Button** | **FUNCTION** |
| PREV | Selects the previous data channel in the list |
| NEXT | Selects the next data channel in the list |
| INS | Inserts a new data channel into the list BEFORE the selected channel |
| DEL | Deletes the currently selected data channel |
| EDIT | Enters EDIT mode |
| PRINT | Exports the configuration of all data channels to the RS-232 interface |
| *Buttons only appear when applicable.* | |

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

For example, the display line:

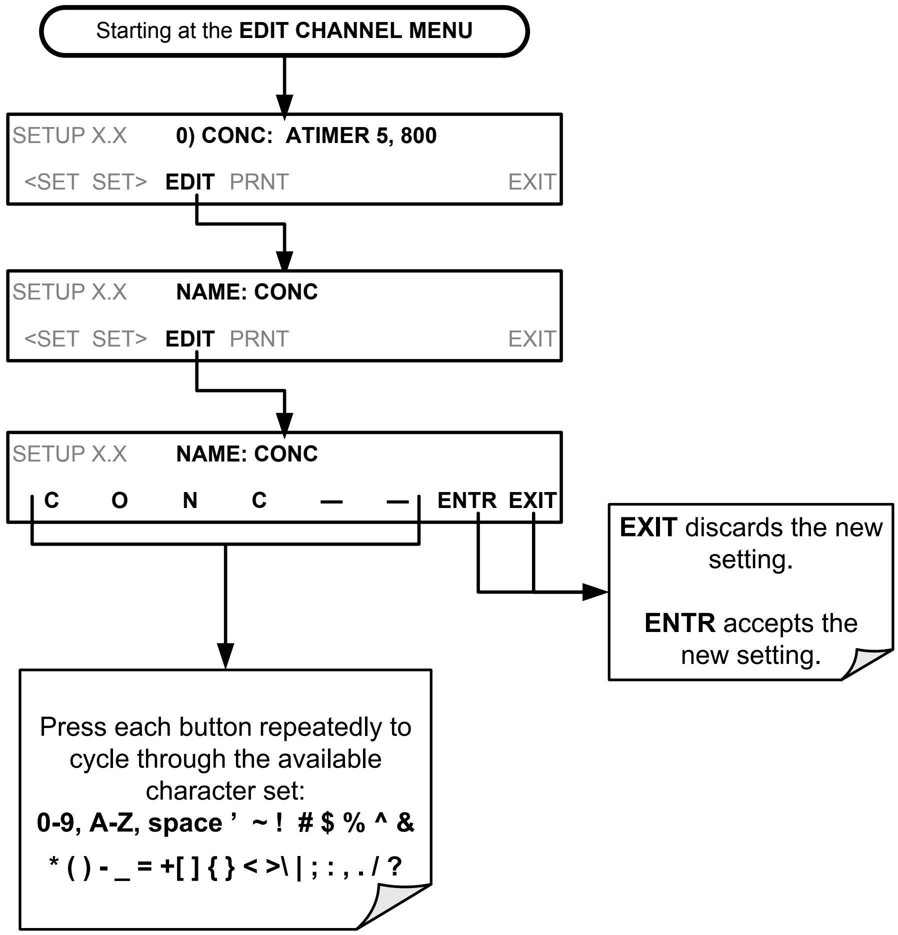
**0) CONC: ATIMER, 1, 800**

Translates to the following configuration:

**Channel No.:** 0
**NAME: CONC**
**TRIGGER EVENT: ATIMER**
**PARAMETERS:** Five parameters are included in this channel
**EVENT:** This channel is set up to store 800 records.

### 8.1.3.1. EDITING DAS DATA CHANNEL NAMES

To edit the name of a DAS data channel, follow the instruction shown in Section 8.1.3 then press:



### 8.1.3.2. EDITING DAS TRIGGERING EVENTS

Triggering events define when and how the DAS records a measurement of any given data channel. Triggering events are firmware-specific; they are listed Appendix A of this manual. The most commonly used 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**, and **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, e.g., for the new slope and offset (concentration response) values at the end of a calibration. Zero and slope values are useful for monitoring response drift and documenting when the instrument was calibrated.
- **WARNINGS:** Some data may be useful when stored if one of several warning messages appears such as **WSAMPPRESS** (sample pressure warning). This is helpful for troubleshooting by monitoring when a particular warning occurred.

**Note**

**A list of DAS Trigger Events can be found in Appendix A of this manual.**

### 8.1.3.3. EDITING DAS PARAMETERS

Data parameters are types of data that may be measured and stored by the DAS. For each Teledyne API's 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 T500U. DAS parameters include data such as $NO_2$ concentration measurements, temperatures of the various heaters placed around the analyzer, and pressure of the pneumatic subsystem and other diagnostic measurements, as well as calibration data such as stability, slope and offset.

Most data parameters have associated measurement units, such as mV, ppb, Mm-1, etc., although some parameters have no units (e.g. **SLOPE**). With the exception of concentration readings, none of these units of measure can be changed. To change the units of measure for concentration readings, see Section 6.3.3.4.

**Note**

**DAS does not keep track of the units (i.e., PPM or PPB) of each concentration value. Therefore, DAS data files may contain concentration data recorded in more than one type of unit if the units of measure were changed during data acquisition**

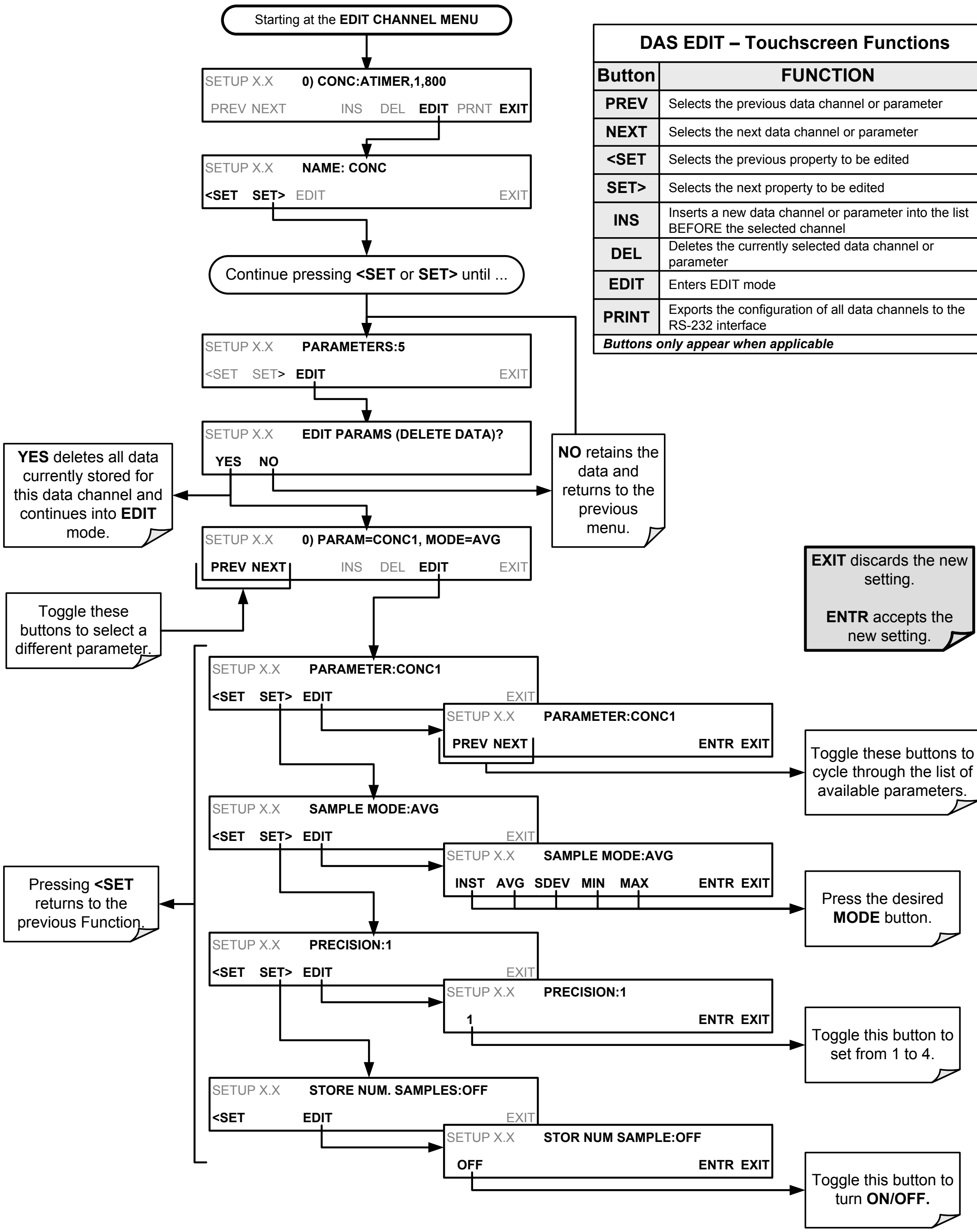
Each data parameter has user-configurable functions that define how the data are recorded which are listed in Table 8-3:

**Table 8-3: DAS Data Parameter Functions**

| FUNCTION | EFFECT |
|---|---|
| **PARAMETER** | Instrument specific parameter name. |
| **SAMPLE MODE** | **INST:** Records instantaneous reading.<br>**AVG:** Records average reading during reporting interval.<br>**SDEV:** Records the standard deviation of the data points recorded during the reporting interval.<br>**MIN:** Records minimum (instantaneous) reading during reporting interval.<br>**MAX:** Records maximum (instantaneous) reading during reporting interval. |
| **PRECISION** | **0 to 4:** Sets the number of digits to the right decimal point for each record.<br>Example: Setting **4**; **"399.9865 PPB"**<br>Setting **0**; **"400 PPB"** |
| **STORE NUM. SAMPLES** | **OFF:** Stores only the average (default).<br>**ON:** Stores the average and the number of samples in used to compute the value of the 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 in that channel. |

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 DAS can store only data of one format (number of parameter columns etc.) for any given channel. In addition, a DAS configuration can only be uploaded remotely as an entire set of channels. Hence, remote update of the DAS will always delete all current channels and stored data.

To modify, add or delete a parameter, follow the instruction shown in Section 8.1.3 then press:




**DAS EDIT – Touchscreen Functions**

| Button | FUNCTION |
|---|---|
| PREV | Selects the previous data channel or parameter |
| NEXT | Selects the next data channel or parameter |
| <SET | Selects the previous property to be edited |
| SET> | Selects the next property to be edited |
| INS | Inserts a new data channel or parameter into the list BEFORE the selected channel |
| DEL | Deletes the currently selected data channel or parameter |
| EDIT | Enters EDIT mode |
| PRINT | Exports the configuration of all data channels to the RS-232 interface |

***Buttons only appear when applicable***

**Note**

**When the STOR NUM. SAMPLES feature is turned on, the instrument will store the number of measurements that were used to compute the AVG, SDEV, MIN or MAX value but not the actual measurements themselves.**

### 8.1.3.4. EDITING SAMPLE PERIOD AND REPORT PERIOD

The DAS defines two principal time periods by which sample readings are taken and permanently recorded: Sample Period and Report Period.

- **SAMPLE PERIOD:** Determines how often DAS temporarily records a sample reading of the parameter in volatile memory (default is one minute), and generally cannot be accessed from the standard DAS front panel menu, but is available via the instruments communication ports by using APICOM or the analyzer's standard serial data protocol. **SAMPLE PERIOD** is only used when the DAS parameter's sample mode is set for AVG, SDEV, MIN or MAX
- **REPORT PERIOD**: Sets how often the sample readings stored in volatile memory are processed, (e.g., average, minimum or maximum are calculated) and the results stored permanently in the instrument's Disk-on-Module (DOM) as well as transmitted via the analyzer's communication ports. The Report Period may be set from the front panel. If the INST sample mode is selected, the instrument stores and reports an instantaneous reading of the selected parameter at the end of the chosen report period.

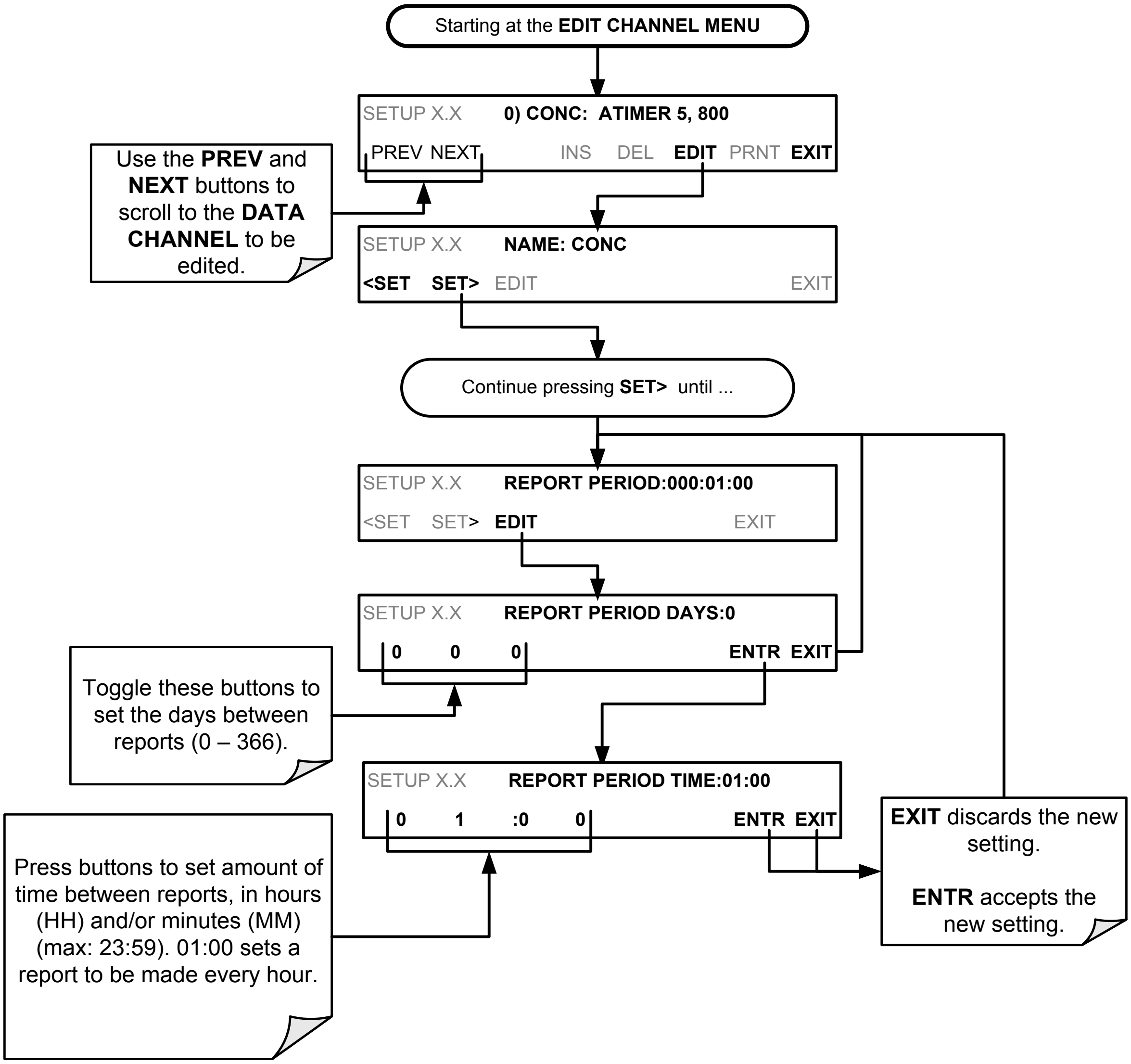
**Note**

**In AVG, SDEV, MIN or MAX sample modes (see Section 8.1.3.3), the settings for the Sample Period and the Report Period determine the number of data points used each time the parameters are calculated, stored and reported to the COM ports.**

**The actual sample readings are not stored past the end of the chosen report period.**

**When the STORE NUM SAMPLES feature is turned on, the instrument will store the number of measurements that were used to compute the AVG, SDEV, MIN or MAX value but not the actual measurements themselves.**

To define the **REPORT PERIOD**, follow the instruction shown in Section 8.1.3 then press:




The **SAMPLE PERIOD** and **REPORT PERIOD** intervals are synchronized to the beginning and end of the appropriate interval of the instruments internal clock.

- If **SAMPLE PERIOD** is set for one minute the first reading would occur at the beginning of the next full minute according to the instrument's internal clock.
- If the **REPORT PERIOD** is set for of one hour, the first report activity would occur at the beginning of the next full hour according to the instrument's internal clock.

EXAMPLE:

Given the above settings, if DAS parameters are activated at 7:57:35 the first sample would occur at 7:58 and the first report would be calculated at 8:00 consisting of data points for 7:58, 7:59 and 8:00.

During the next hour (from 8:01 to 9:00), the instrument will take a sample reading every minute and include 60 sample readings.

### 8.1.3.5. REPORT PERIODS IN PROGRESS WHEN INSTRUMENT IS POWERED OFF

If the instrument is powered off in the middle of a **REPORT PERIOD**, the samples accumulated during that period are lost. Once the instrument is turned back on, the DAS restarts taking samples and temporarily stores them in volatile memory as part of the **REPORT PERIOD** currently active at the time of restart. At the end of this **REPORT PERIOD,** only the sample readings taken since the instrument was turned back on will be included in any **AVG, SDEV, MIN** or **MAX** calculation.

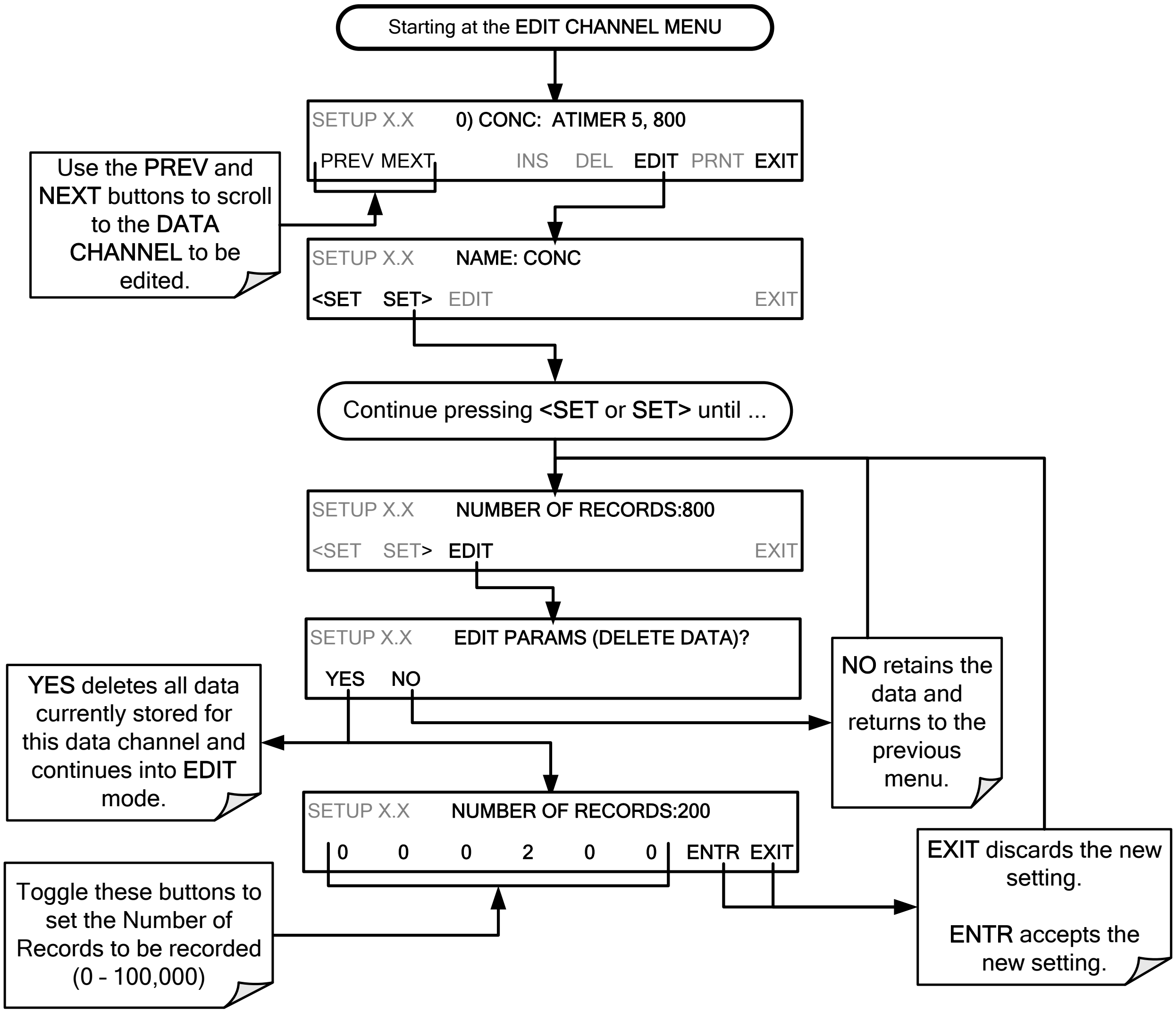
The **STORE NUM SAMPLES** feature will also report the number of sample readings taken since the instrument was restarted.

### 8.1.3.6. EDITING THE NUMBER OF RECORDS

The number of data records in the DAS is limited by its configuration. Every additional data channel, parameter, number of samples setting etc. will reduce the maximum amount of data points. In general, however, the maximum data capacity is divided among all channels (max: 20) and parameters (max: 50 per channel).

The DAS will check the amount of available data space and prevent the user from specifying too many records at any given point. (The **ENTR** button will disappear when trying to specify more records than space allows). This check for memory space may also make an upload of a DAS 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 to determine what the maximum number of records available is using the front panel interface or use trial-and-error in designing the DAS script or calculate the number of records using the DAS or APICOM manuals.

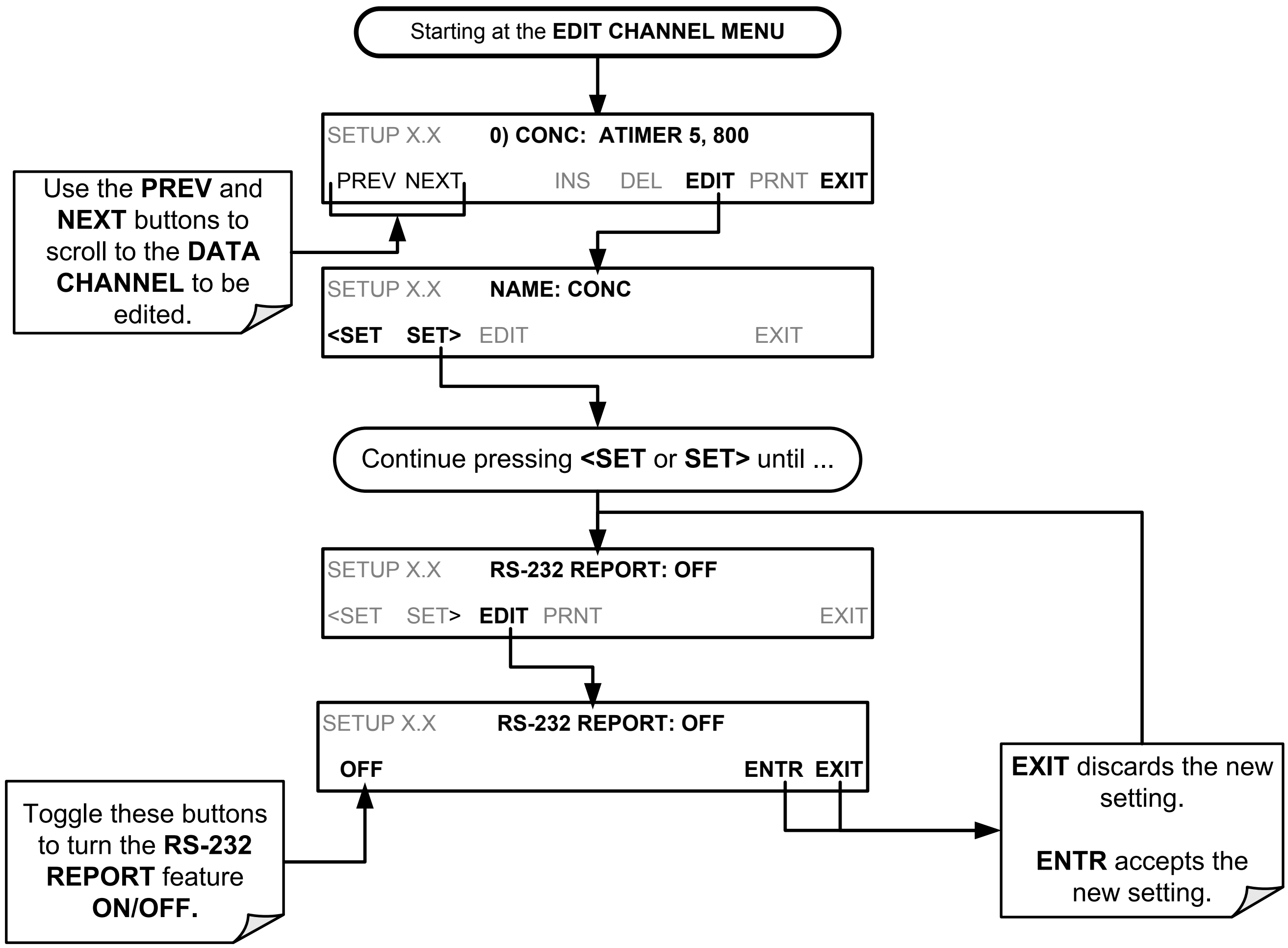
To set the **NUMBER OF RECORDS**, follow the instruction shown in Section 8.1.3 then press:



### 8.1.3.7. RS-232 REPORT FUNCTION

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

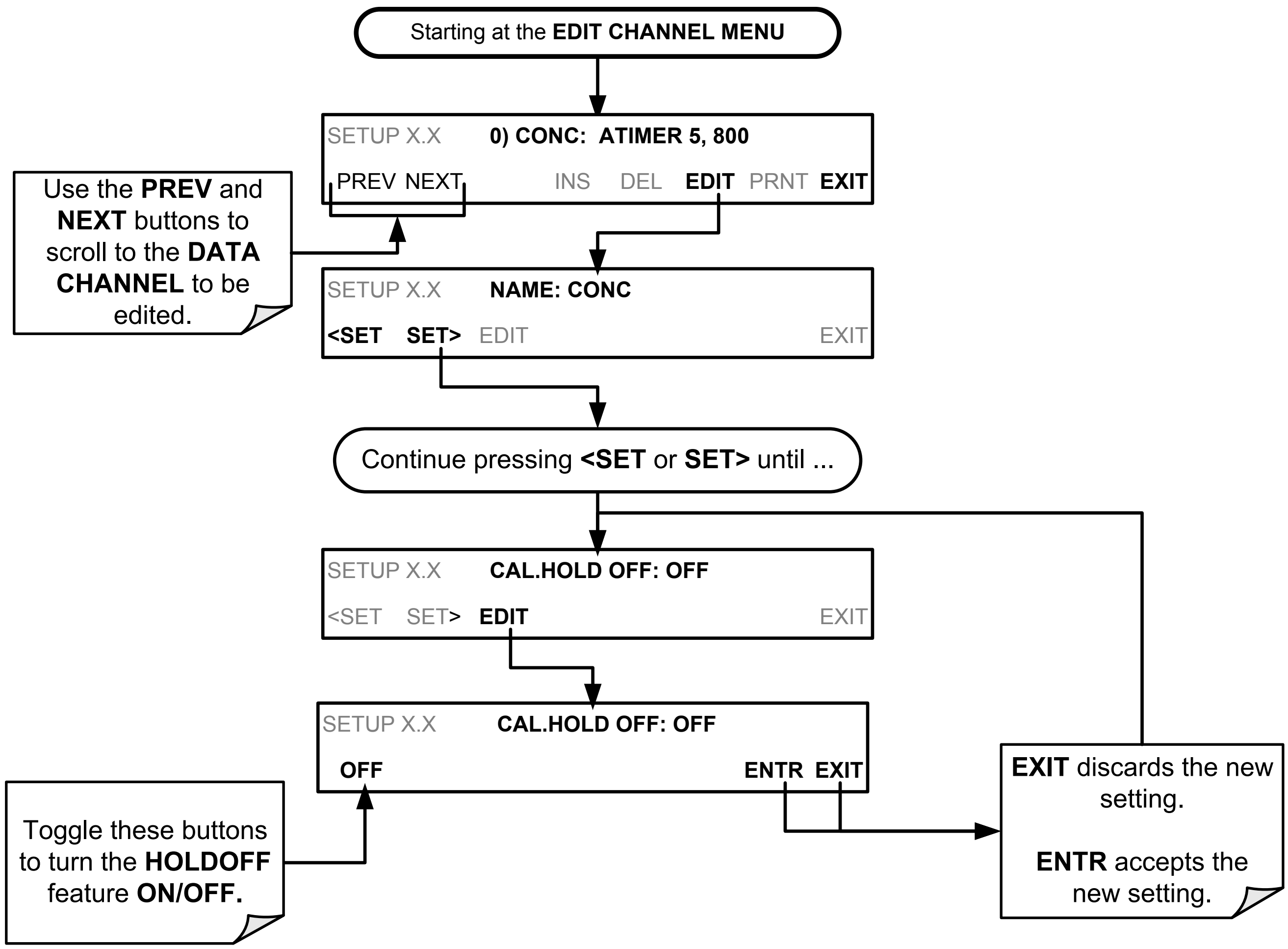
To enable automatic **COM port** reporting, follow the instruction shown in Section 8.1.3 then press:



### 8.1.3.8. HOLDOFF FEATURE

The DAS **HOLDOFF** feature prevents data collection during calibration operations.

To enable or disable the **HOLDOFF**, follow the instruction shown in Section 8.1.3 then press:




**HOLDOFF** also prevents DAS measurements from being made at certain times when the quality of the analyzer's $NO_2$ measurements may be suspect (e.g. while the instrument is warming up). In this case, the length of time that the **HOLDOFF** feature is active is determined by the value of the internal variable (**VARS**), **DAS_HOLDOFF.**

To set the length of the **DAS_HOLDOFF** period, go to the SETUP>MORE>VARS menu and at the DAS_HOLDOFF parameter (see Table 6-2), press the Edit button.

### 8.1.3.9. THE COMPACT REPORT FEATURE

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.

The **COMPACT DATA REPORT** generally cannot be accessed from the standard DAS front panel menu, but is available via the instrument's communication ports by using APICOM or the analyzer's standard serial data protocol.

### 8.1.3.10. THE STARTING DATE FEATURE

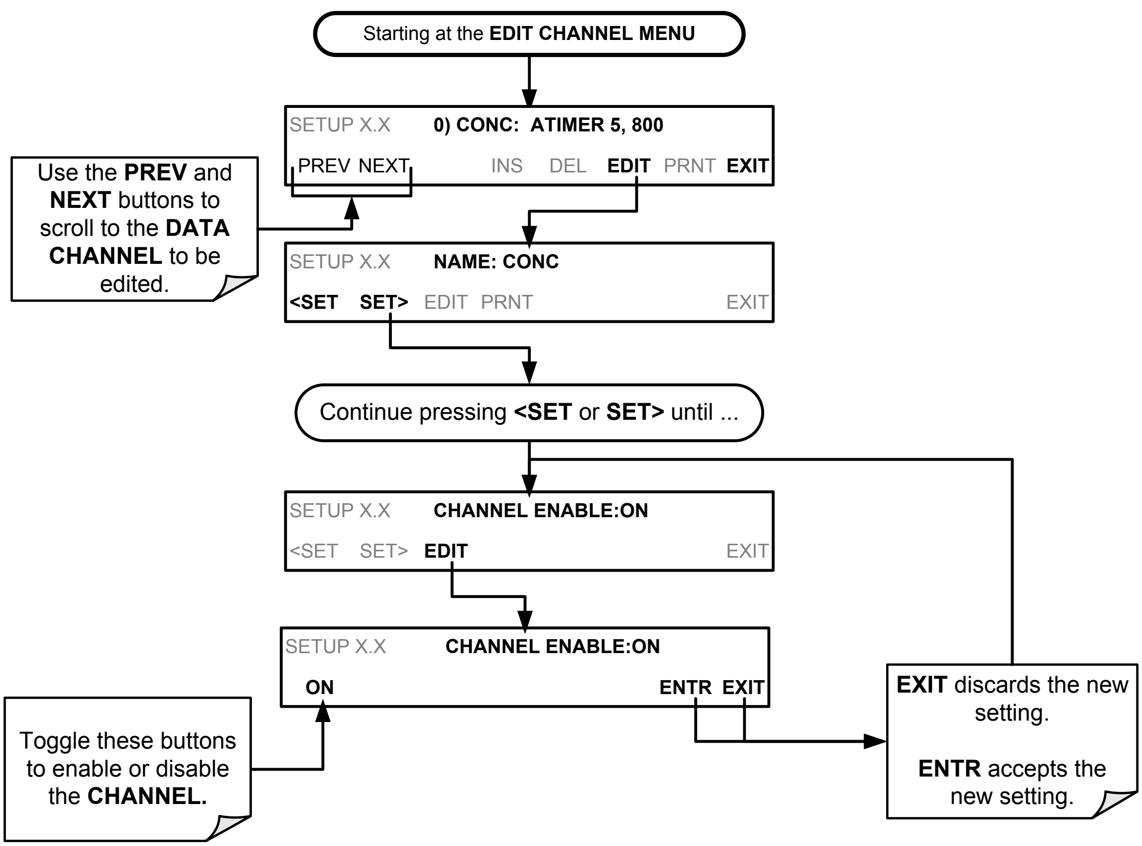
This option allows the user to specify a starting date for any given channel when the user wants to start data acquisition only after a certain time and date. If the **STARTING DATE** is in the past (the default condition), the DAS ignores this setting and begins recording data as defined by the **REPORT PERIOD** setting.

The **STARTING DATE** generally cannot be accessed from the standard DAS front panel menu, but is available via the instrument's communication ports by using APICOM or the analyzer's standard serial data protocol.

### 8.1.3.11. DISABLING/ENABLING DATA CHANNELS

Data channels can be temporarily disabled, which can reduce the read/write wear on the Disk-on-Module (DOM).

To disable a data channel, go to the DAS>EDIT menu as shown in Section 8.1.3 then continue as follows:



# 8.2. REMOTE DAS CONFIGURATION

The DAS can be configured and operated remotely via either the APICOM interface or a terminal emulation program. Once a DAS 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.

## 8.2.1. DAS CONFIGURATION VIA APICOM

Refer to the APICOM DAS user manual (Teledyne API's P/N 07463) for configuring DAS through the APICOM interface. (Download the APICOM software from our website at http://www.teledyne-api.com/software/apicom/).

## 8.2.2. DAS CONFIGURATION VIA TERMINAL EMULATION PROGRAMS

Although Teledyne API recommends the use of APICOM, the DAS can also be accessed and configured through a terminal emulation program such as HyperTerminal (see Figure 8-2 for example). It is best to start by downloading the default DAS 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.

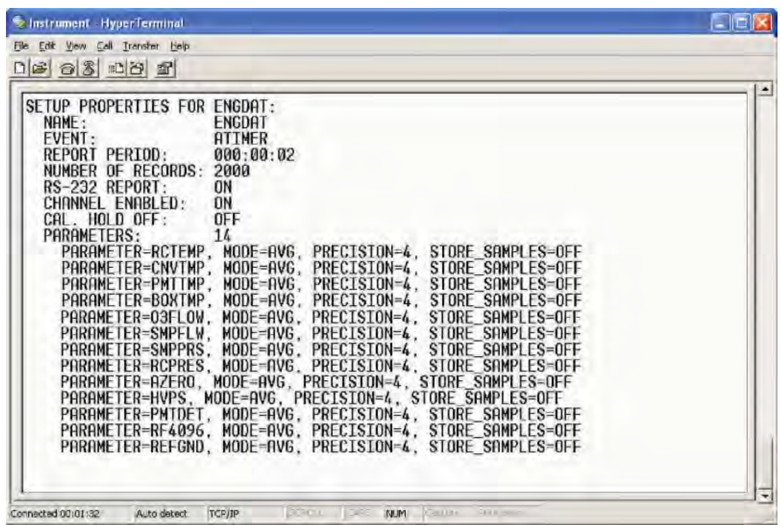



**Figure 8-2: DAS Configuration through a Terminal Emulation Program**

See Section 9.2.1 for configuration commands and their strict syntax. Commands can be pasted in from of an existing text file, which was first edited offline and then uploaded through a specific transfer procedure.

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Back up data and the original DAS configuration before editing the DAS. Although it is possible to edit DAS parameters of one channel through the front-panel without affecting other channels, uploading a DAS configuration script to the analyzer through its communication ports will erase all data, parameters and channels and replace them with the new DAS configuration.**

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# 9. REMOTE OPERATION

This section provides information needed when using external digital and serial I/O for remote operation. It assumes that the electrical connections have been made as described in Section 3.3.1.8.

The T500U can be remotely configured, calibrated or queried for stored data through the serial ports, via either **Computer mode** (using a personal computer) or **Interactive mode** (using a terminal emulation program).

## 9.1. COMPUTER MODE

Computer Mode is used when the analyzer is connected to a computer with a dedicated interface program such as APICOM, downloadable from our website at http://www.teledyne-api.com/software/apicom/.

## 9.2. INTERACTIVE MODE

Interactive mode is used with a terminal emulation programs or a "dumb" computer terminal.

### 9.2.1. REMOTE CONTROL VIA A TERMINAL EMULATION PROGRAM

Start a terminal emulation programs such as HyperTerminal. All configuration commands must be created following a strict syntax or be pasted in from a text file, which was edited offline and then uploaded through a specific transfer procedure. The commands that are used to operate the analyzer in this mode are listed in Table 9-1 and in Appendix A.

### 9.2.1.1. **HELP COMMANDS IN INTERACTIVE MODE**

**Table 9-1: 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 button. |
| **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. |

### 9.2.1.2. **COMMAND SYNTAX**

Commands are not case-sensitive and all arguments within one command (i.e. ID numbers, key words, 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 9-2 and Appendix A, Terminal Command Designators.

**[ID]** is the machine identification number (Section 6.6.1). 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 500.

**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 button on a computer).

**Table 9-2: Teledyne API's Serial I/O Command Types**

| COMMAND | COMMAND TYPE |
|---|---|
| **C** | Calibration |
| **D** | Diagnostic |
| **L** | Logon |
| **T** | Test measurement |
| **V** | Variable |
| **W** | Warning |

### 9.2.1.3. 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 key words 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. When using these commands, you must type the entire name of the item; you cannot abbreviate any names.

### 9.2.1.4. 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 7.2.1, Table 7-1).

Status reports include warning messages, calibration and diagnostic status messages. Refer to Appendix A-3, Warnings and Test Measurements, for a list of the possible messages, and this for information on controlling the instrument through the RS-232 interface.

### 9.2.1.5. 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 9-2. |
| 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, 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 troubleshooting and reference purposes. Terminal emulation programs such as HyperTerminal can capture these messages to text files for later review.

## 9.3. REMOTE ACCESS BY MODEM

The T500U 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 Teledyne API with P/N WR0000024).

Once the cable has been connected, check to ensure that:

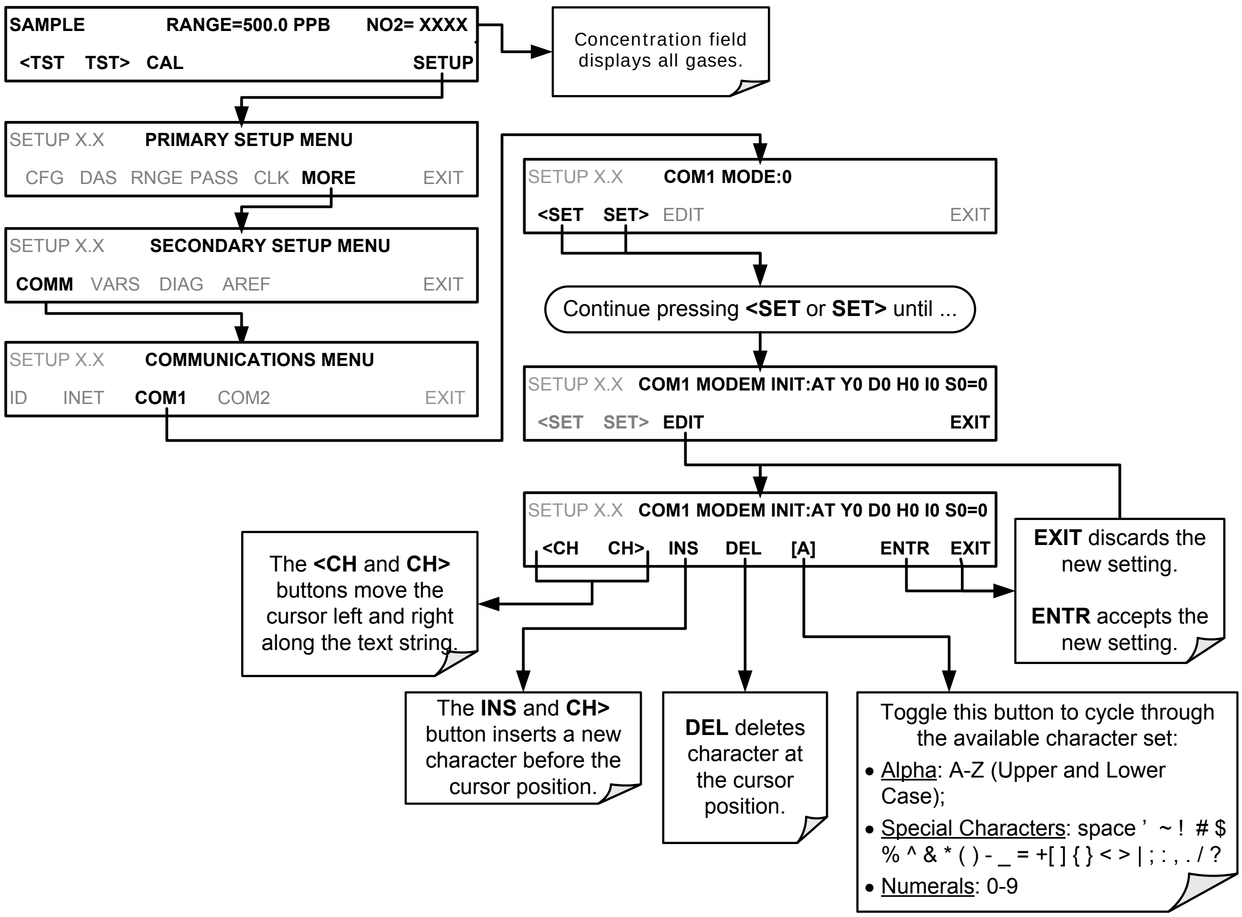
- The DTE-DCE is in the DCE position.
- The T500U COM port is set for a baud rate that is compatible with the modem,
- The Modem is designed to operate with an 8-bit word length with one stop bit.
- The **MODEM ENABLE** communication mode is turned **ON** (Mode 64, see Section 7.2.1).

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:

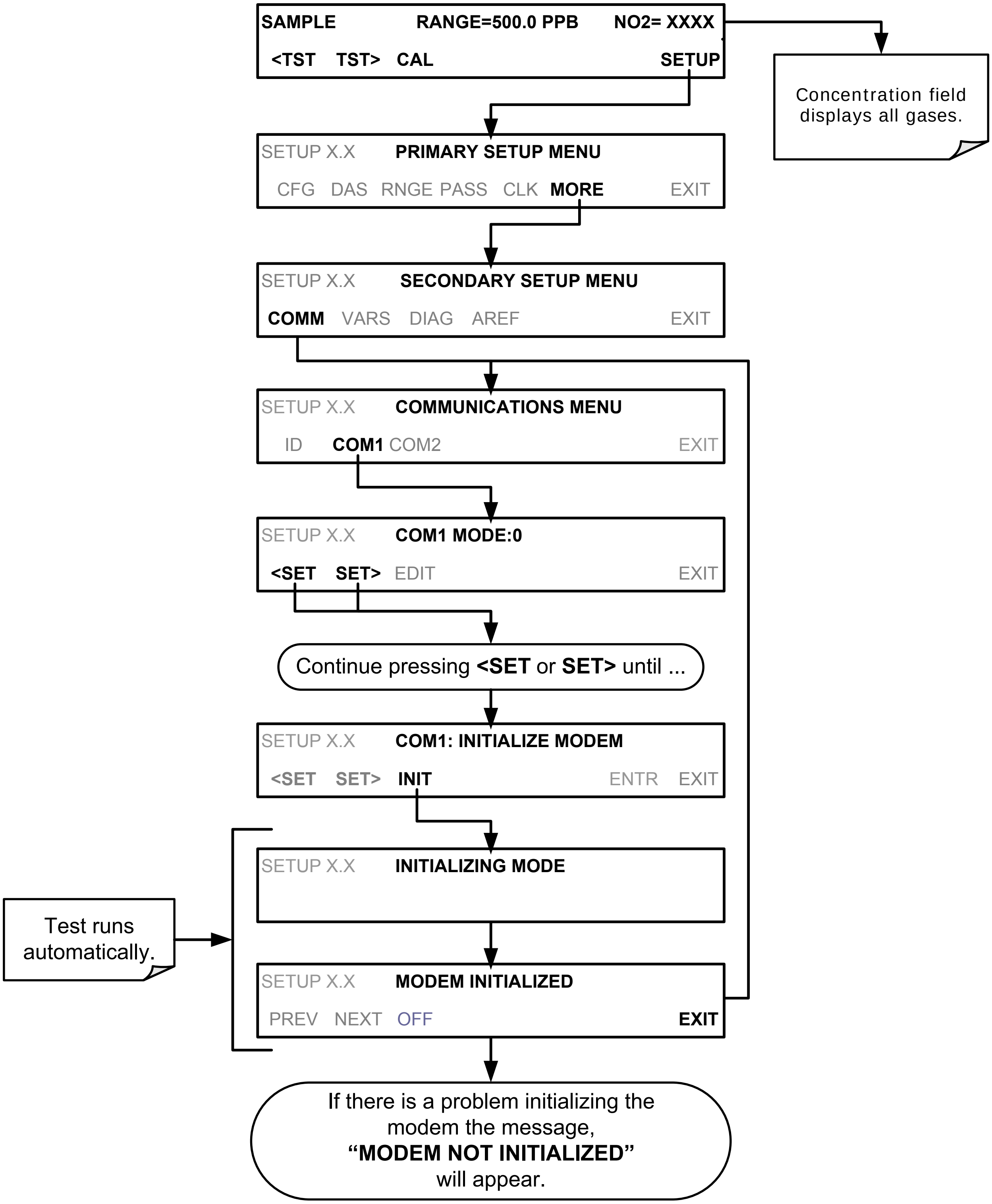
**AT Y0 D0 H0 I0 S0=0**

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

To edit this setting press:



To initialize the modem press:



# 9.4. PASSWORD SECURITY FOR SERIAL REMOTE COMMUNICATIONS

In order to provide security for remote access of the T500U, 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** (refer to Section 6.4). 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 T100 analyzer with **SECURITY MODE** feature enabled, type:

LOGON 940331

940331 is the default password. To change the default password, use the variable RS-232_PASS issued as follows:

V RS-232_PASS=NNNNNN

Where N is any numeral between 0 and 9.

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# 10. CALIBRATION

Calibration of the T500U Analyzer requires:

- Zero-air source
- Span gas source
- Teflon-type for all gas line materials
- A recording device such as a strip-chart recorder and/or data logger (optional)
- Exiting the calibration mode to sample mode, following a successful CALZ or CALS. The Auto Reference feature (Section 6.9) is disabled while in calibration mode.

For electronic documentation, the internal data acquisition system (DAS) can be used (Section 8).

This section discusses calibration gases, provides the basic method for manually checking the calibration, and for manually performing actual calibration of the T500U analyzer.

## 10.1. CALIBRATION GASES

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. A zero air generator such as the Teledyne API's Model 701 can be used. Please visit the company website for more information.

Span calibration gas is specifically mixed to match the chemical composition of the type of gas being measured at near full scale of the desired reporting range.

Alternatively, if a calibrator is available that is a trusted source of stable ozone, e.g., Teledyne API Model T700U with certified photometer, it is possible to use that $O_3$ output directly to obtain the $NO_2$ concentration.

### 10.1.1. SPAN GAS FOR MULTIPOINT CALIBRATION

Some applications, such as EPA monitoring, require a multipoint calibration where span gases of different concentrations are needed. We recommend using an $NO_2$ gas of higher concentration combined with a gas dilution calibrator such as a Teledyne API's Model T700. For more information see Section 3.3.2.1 and Section 12.

### 10.1.2. $NO_2$ PERMEATION TUBES

Teledyne API offers an optional internal span gas generator that utilizes an $NO_2$ permeation tube as a span gas source. The accuracy of these devices is only about ±5%.

Whereas this may be sufficient for quick, daily calibration checks, we recommend using certified $NO_2$ gases for accurate calibration.

**CAUTION!**

**Insufficient gas flow allows gas to build up to levels that will contaminate the instrument or present a safety hazard to personnel.**

**In units with a permeation tube option installed, either the tube must be removed and stored in sealed container (use original container that tube was shipped in) during periods of non-operation, or vacuum pump must be connected and powered on to maintain constant gas flow though the analyzer at all times.**

(See Figure 3-4 for location and Section 11.3.2 for instructions on how to remove the perm tube when the unit is not in operation).

# 10.2. 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 T500U.

- 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 T500U provides an internal data acquisition system (DAS), which is described in detail in Section 8.

APICOM, a remote control program, is also provided as a convenient and powerful tool for data handling, download, storage, quick check and plotting (see Sections 8.2.1, and the APICOM software manual downloadable from:

http://www.teledyne-api.com/manuals ).

# 10.3. MANUAL CALIBRATION CHECKS AND CALIBRATION OF THE T500U IN ITS BASE CONFIGURATION

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**ZERO/SPAN CALIBRATION CHECKS VS. ZERO/SPAN CALIBRATION**

**NEVER press the ENTR button if you are only *checking* calibration. Pressing the ENTR button during the following procedure resets the stored values for OFFSET and SLOPE and alters the instrument's Calibration. This should ONLY BE DONE during an actual calibration of the T500U.**

## 10.3.1. SETUP FOR BASIC CALIBRATION CHECKS AND CALIBRATION

Connect the sources of zero air and span gas as shown below in one of the following ways:

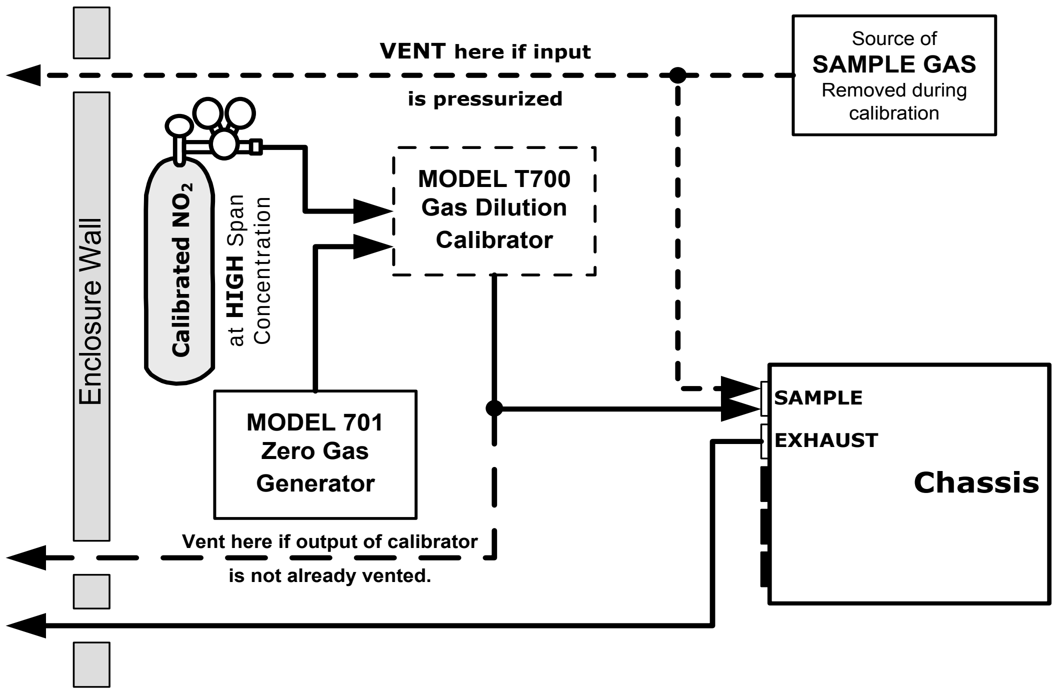
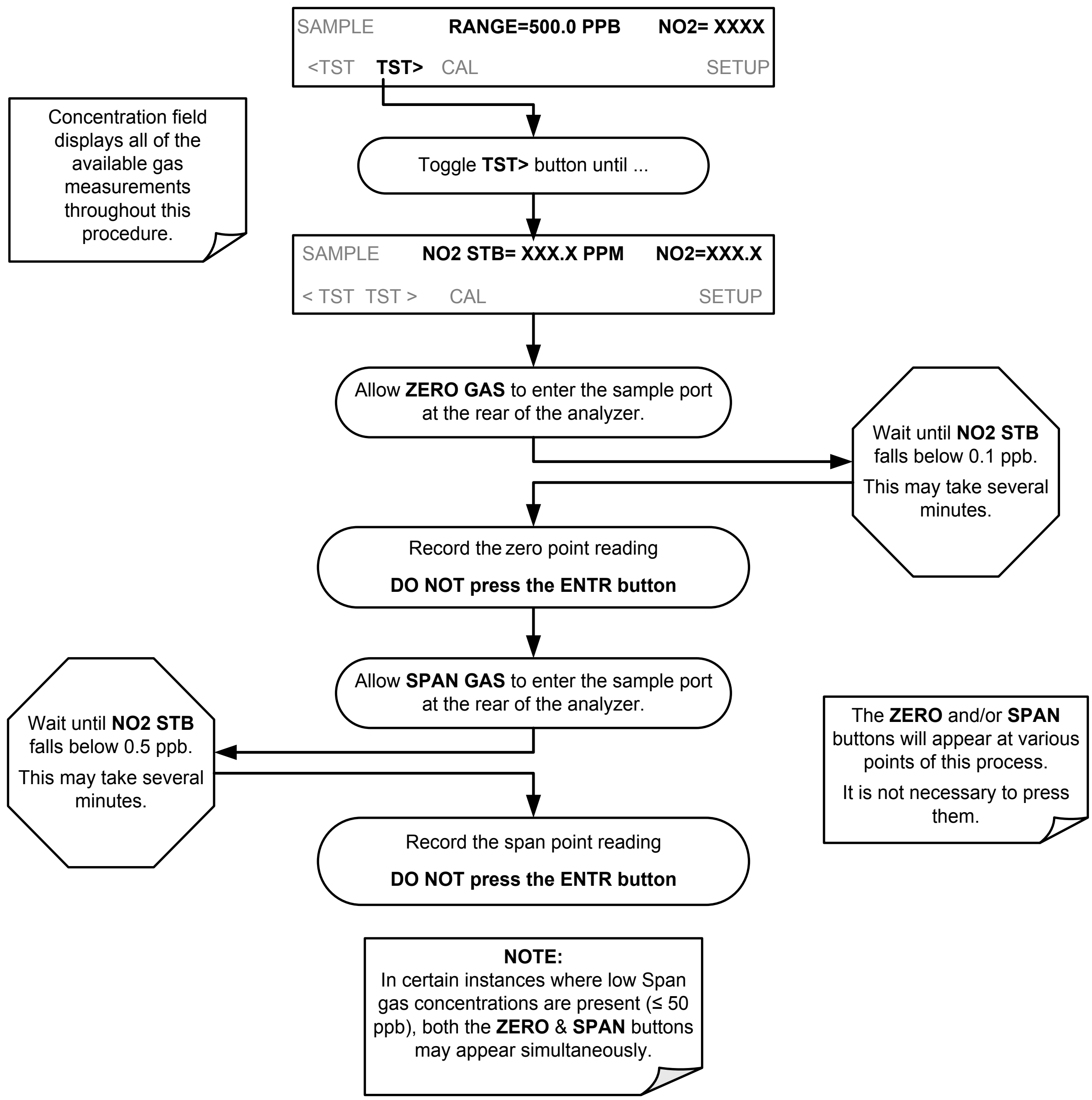



**Figure 10-1: Set up for Manual Calibrations/Checks in Base Configuration w/Gas Dilution Calibrator**

## 10.3.2. PERFORMING A BASIC MANUAL CALIBRATION CHECK




**Note** **If the ZERO or SPAN buttons are not displayed, the measurement made is outside the allowable range for a reliable calibration.**

## 10.3.3. PERFORMING A BASIC MANUAL CALIBRATION

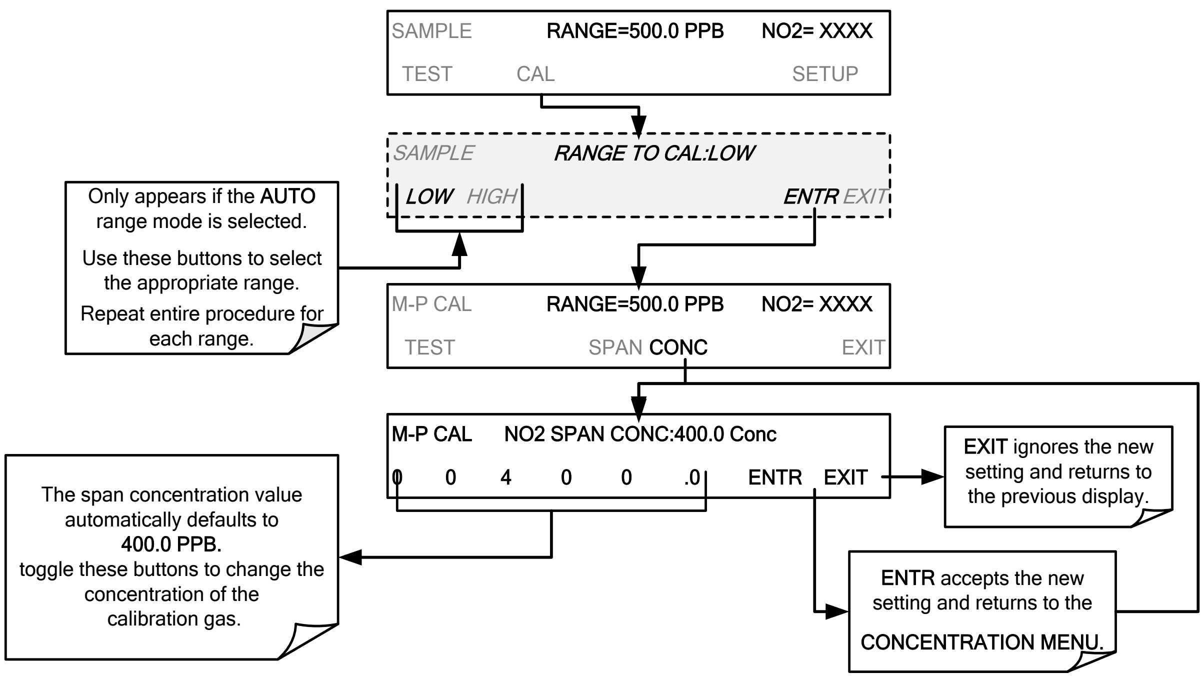
The following section describes the basic method for manually calibrating the T500U analyzer.

If the analyzer's reporting range is set for the **AUTO** range mode, a step will appear for selecting which range is to be calibrated (**Range 1** or **Range 2**, user-defined in the SETUP>RNGE>MODE>DUAL menu, Section 6.3.3.2). Each of these two ranges **MUST** be calibrated separately.

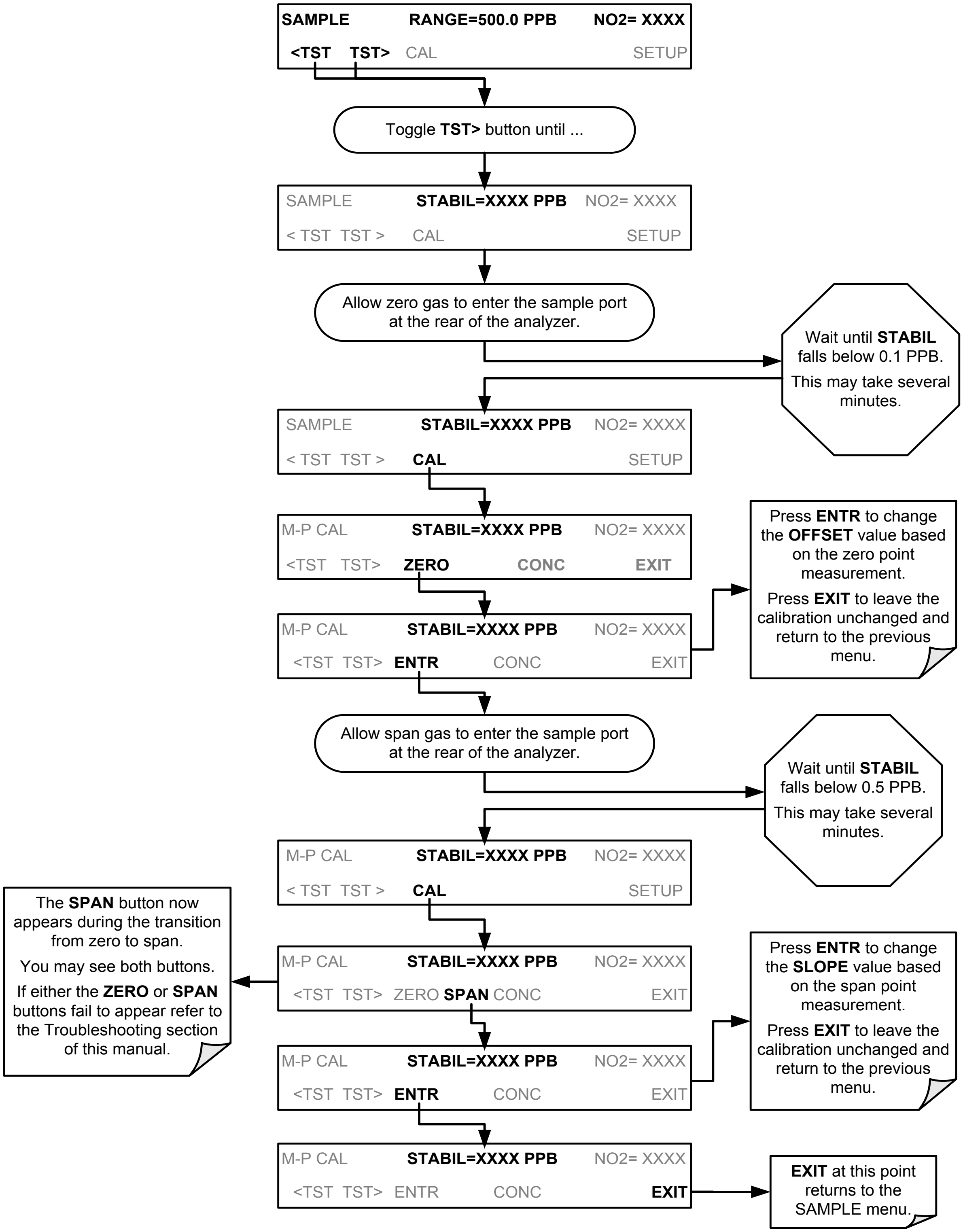
### 10.3.3.1. SETTING THE EXPECTED SPAN GAS CONCENTRATION

The span gas concentration should be 80% of range of concentration values likely to be encountered in your application. The default factory reporting range setting is 500 ppb and the default span gas concentration is 400.0 ppb.

To set the span gas concentration, press:



### 10.3.3.2. ZERO/SPAN POINT CALIBRATION PROCEDURE




**Note** **If the ZERO or SPAN buttons are not displayed, the measurement is out of the allowable range allowed for a reliable calibration.**

# 10.4. MANUAL CALIBRATION WITH THE INTERNAL SPAN GAS GENERATOR

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**The internal span gas generator's $NO_2$ permeation tube has a limited accuracy of about ±5%. It can be used to calibrate the analyzer. However, TAPI recommends using the permeation device for informal calibration *checks* (Section 10.4.3)**

## 10.4.1. PERFORMING "PRECISION" MANUAL CALIBRATION FOR INTERNAL SPAN GAS (IZS) GENERATOR OPTION

It is necessary to perform a precision calibration using more accurate zero and span gas standards prior to IZS span calibration or cal check.

To perform a precision calibration of the T500U, connect external sources of zero air and calibrated span gas (Section 10.1) and temporarily disconnect the sample gas source as shown below; then follow the procedures described in Section 10.3.3.

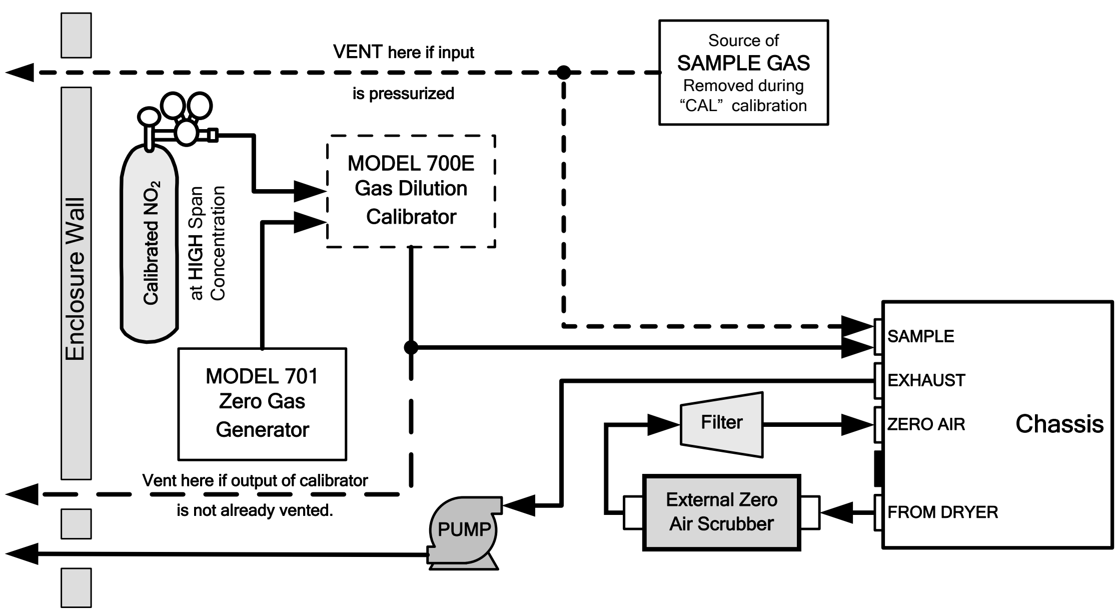



**Figure 10-2: Pneumatic Connections for T500U Precision Calibration when IZS Generator Present**

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**DO NOT USE THE CALZ or CALS buttons even though they will be visible, as this will cause the instrument to use the internal zero air and span gas.**

**Instead, press the CAL button. This will cause the analyzer to use**

**the external calibration gas sources.**

## 10.4.2. SETUP FOR CALIBRATION WITH THE INTERNAL SPAN GAS GENERATOR

Connect the sources of zero air and span gas as shown in Figure 10-3.

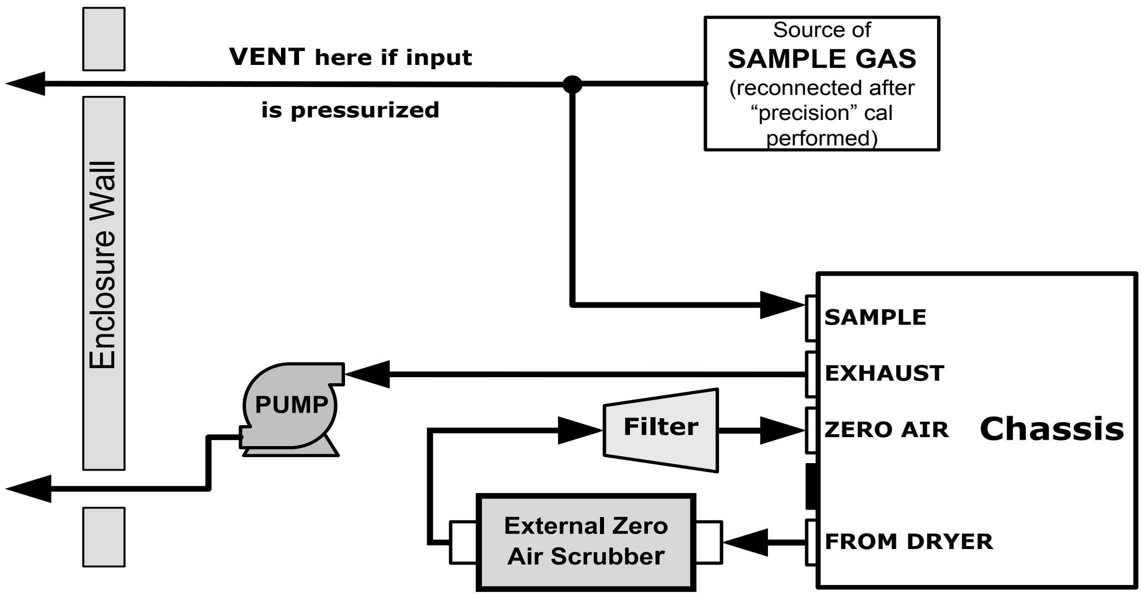
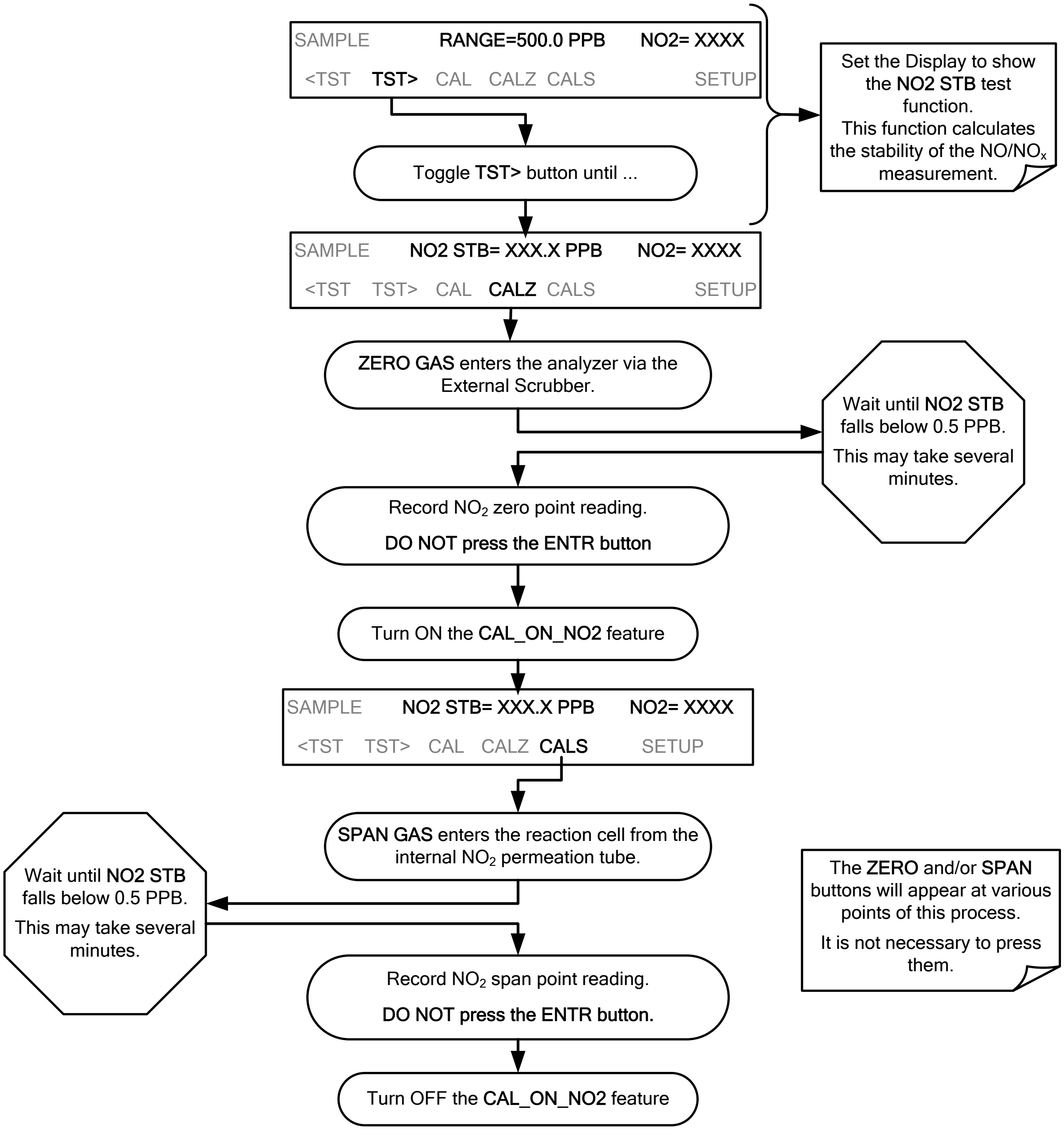



**Figure 10-3: Pneumatic Connections for Manual Calibration/Checks with the Internal Span Gas Generator**

## 10.4.3. PERFORMING A MANUAL CALIBRATION CHECK WITH THE INTERNAL SPAN GAS GENERATOR




**Note** **If the ZERO or SPAN buttons are not displayed, the measurement made is out of the allowable range for a reliable calibration. See Section 13.4.4 for troubleshooting tips.**

## 10.4.4. PERFORMING A MANUAL CALIBRATION WITH THE INTERNAL SPAN GAS GENERATOR

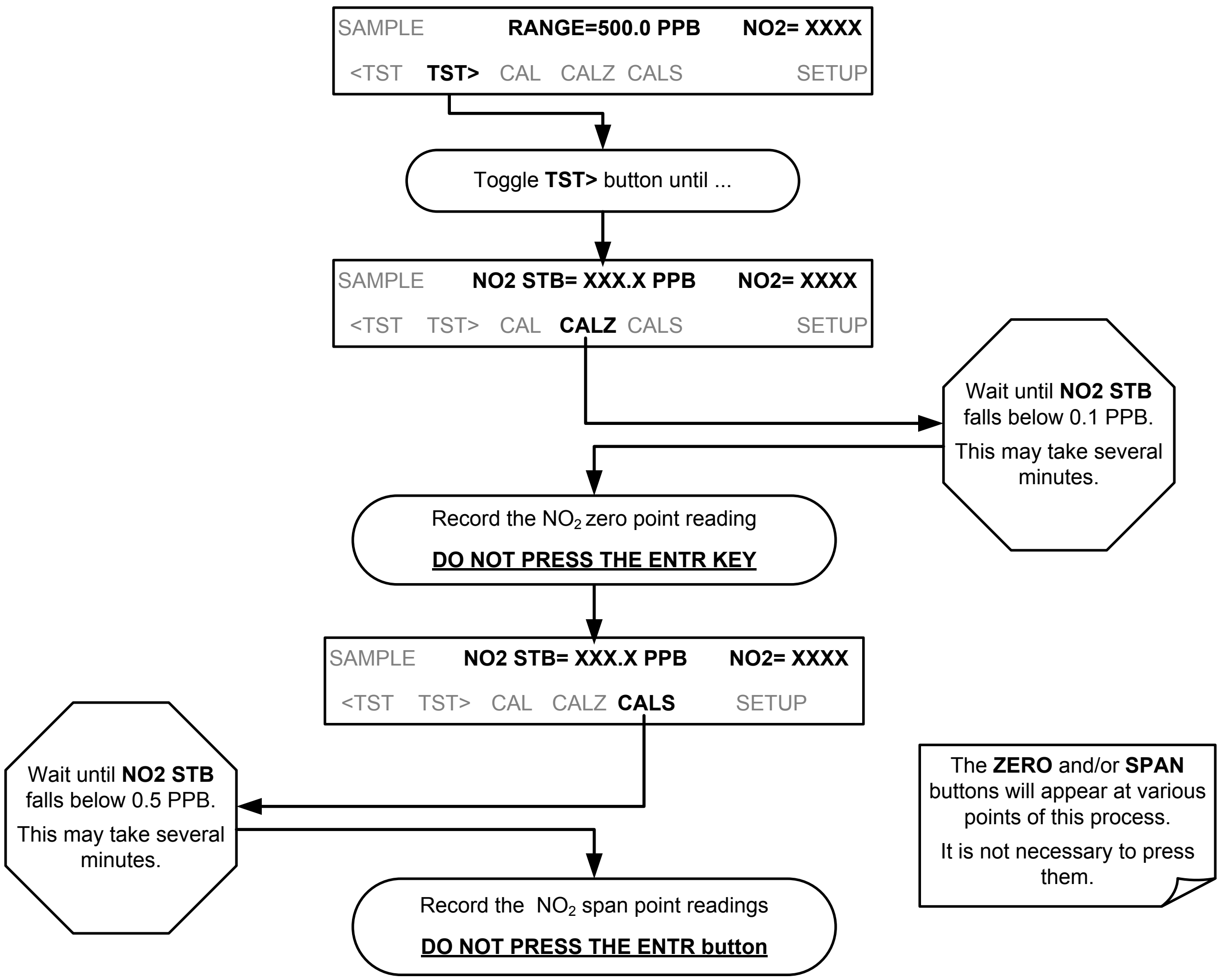
If the analyzer's reporting range is set for the **AUTO** range mode, a step will appear for selecting which range is to be calibrated (**LOW** or **HIGH**, user-selected in the SETUP>RNGE>MODE>DUAL menu, Section 6.3.3.2). Each of these two ranges *MUST be calibrated separately*.

### 10.4.4.1. SETTING THE EXPECTED SPAN GAS CONCENTRATION

When calibrating the instrument using the internal permeation tube as a span gas source, it is necessary to know, as close as possible, the concentration value of the gas being outputted by the tube. To determine this value:

1. Perform a precision calibration of the instrument as described in Section 10.4.1.
2. Perform a calibration check as described in Section 10.4.3.
   - Record the value displayed for $NO_2$ during the span check portion of the procedure.
   - This will be the concentration value used in subsequent calibrations using the internal span gas source.
   - It is a good idea to measure the permeation tube output once every 4 to 6 months.
3. Ensure that the reporting range span point is set for a value at least 10% higher than the measured value of the permeation tube output.

## 10.4.5. MANUAL CALIBRATION CHECKS WITH VALVE OPTIONS INSTALLED



## 10.4.6. **MANUAL CALIBRATION USING VALVE OPTIONS**

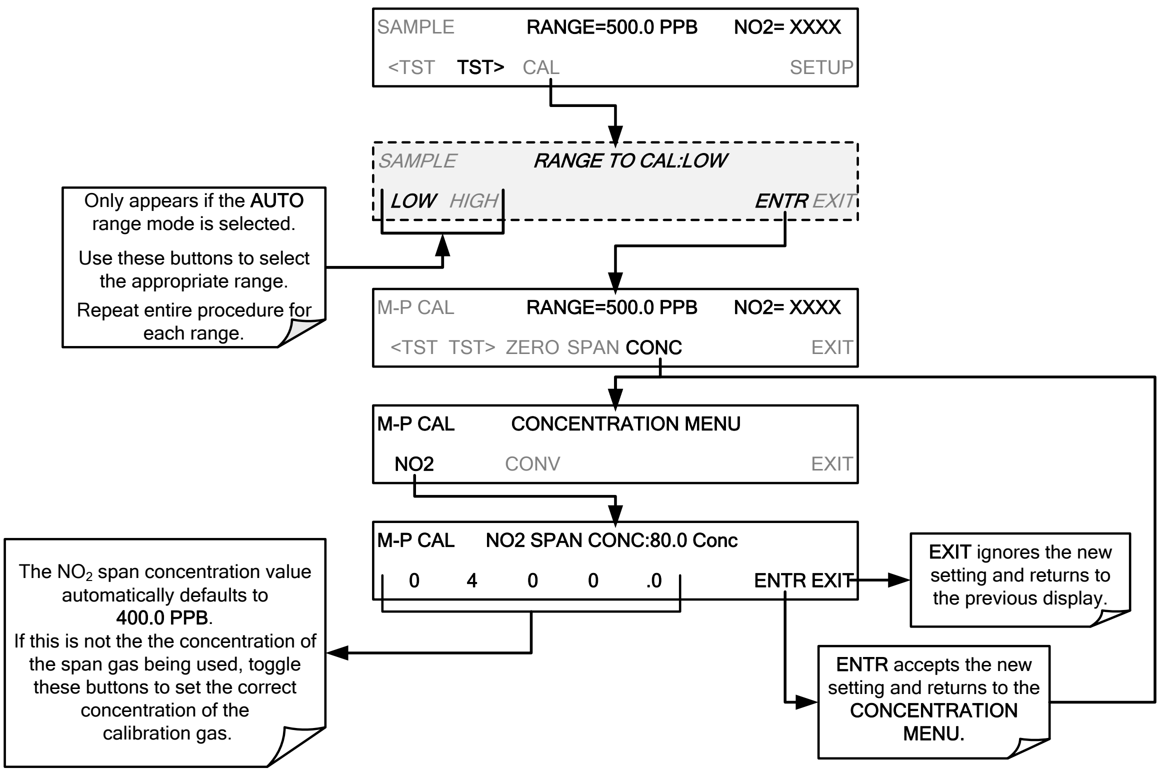
The following section describes the basic method for manually calibrating the T500U analyzer.

If the analyzer's reporting range is set for the **AUTO** range mode, a step will appear for selecting which range is to be calibrated (**LOW** or **HIGH**). Each of these two ranges ***MUST*** *be calibrated separately*.

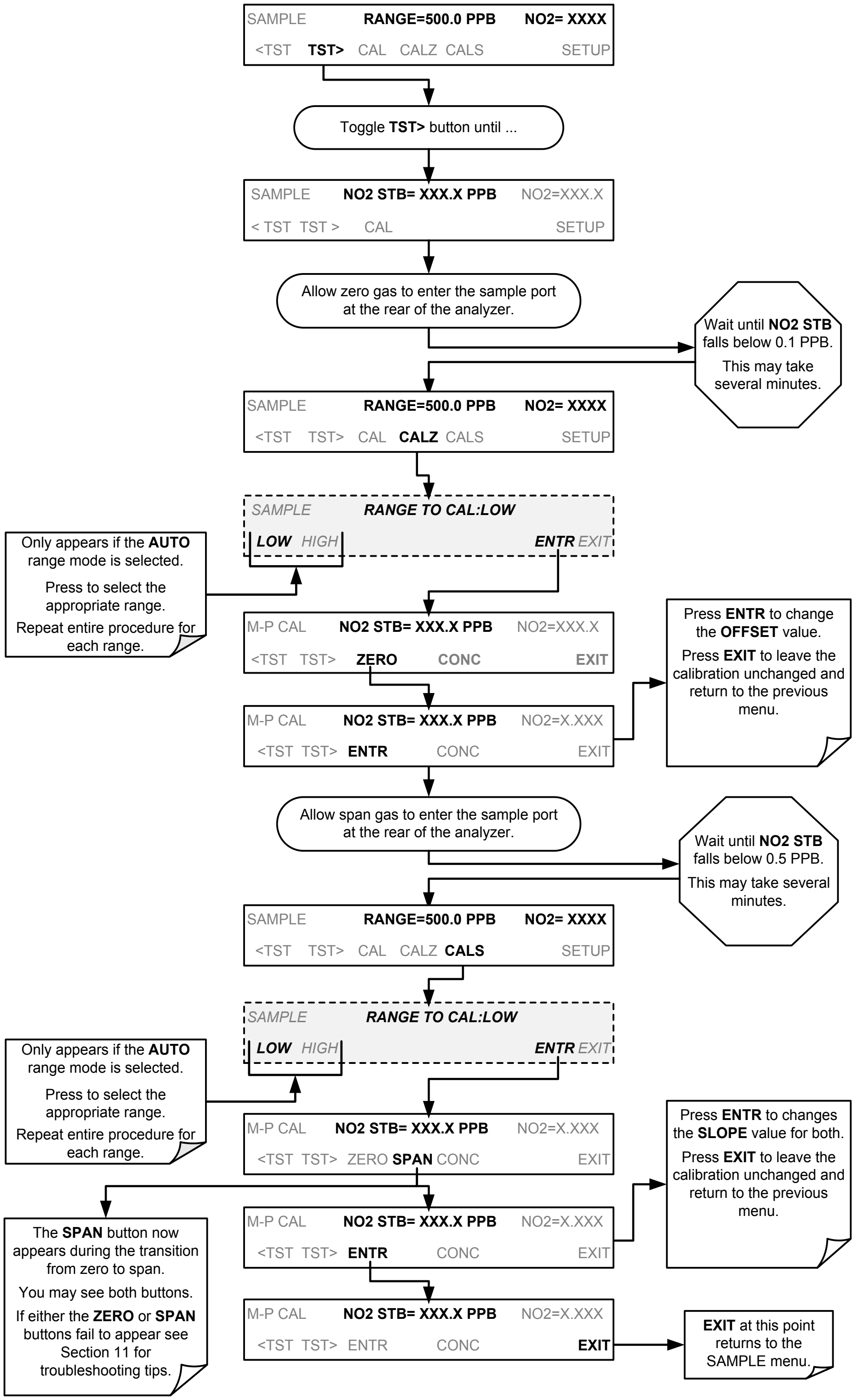
### 10.4.6.1. **SETTING THE EXPECTED SPAN GAS CONCENTRATION**

The $NO_2$ span gas concentration should be 80% of range of the concentration value likely to be encountered in your application. The default factory reporting range setting is 500 ppb and the default span gas concentration is 400.0 ppb.

To set the span gas concentration, press:



### 10.4.6.2. ZERO/SPAN POINT CALIBRATION PROCEDURE FOR VALVE OPTIONS




**Note** **If the ZERO or SPAN buttons are not displayed, the measurement made during is out of the range allowed for a reliable calibration.**

### 10.4.6.3. USE OF ZERO/SPAN VALVE WITH REMOTE CONTACT CLOSURE

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 are in Section 3.3.1.6.

When the contacts are closed for at least 5 seconds, the instrument switches into zero, low span or high span mode and the internal zero/span valves 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.

#### *Contact Closures and AutoCal's "CALIBRATE" Enabled*

If contact closures are being used in conjunction with the analyzer's AutoCalfeature (Section 10.5) and the AutoCal attribute "**CALIBRATE"** is enabled, the T500U 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.

#### *Contact Closures and AutoCal's "CALIBRATE" Disabled*

If the AutoCal attribute "**CALIBRATE"** is *disabled*, the instrument will return to **SAMPLE** mode, leaving the instrument's internal calibration variables unchanged.

## 10.5. AUTOMATIC ZERO/SPAN CAL/CHECK (AUTOCAL)

The AutoCal system allows unattended periodic operation of the Z**ERO/SPAN** valve options by using the T500U's internal time of day clock. AutoCal operates by executing **SEQUENCES** programmed by the user to initiate the various calibration modes of the analyzer and 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 10-1: AUTOCAL Modes**

| MODE NAME | ACTION |
|---|---|
| **DISABLED** | Disables the Sequence. |
| **ZERO** | Causes the Sequence to perform a Zero calibration/check. |
| **ZERO-SPAN** | Causes the Sequence to perform a Zero point calibration/check followed by a Span point calibration/check. |
| **SPAN** | Causes the Sequence to perform a Span concentration calibration/check only. |

For each mode, there are seven parameters that control operational details of the **SEQUENCE** as presented next in Table 10-2.

**Table 10-2: AutoCal Attribute Setup Parameters**

| ATTRIBUTE | ACTION |
|---|---|
| **TIMER ENABLED** | Turns on the Sequence timer. |
| **STARTING DATE** | Sequence will operate after Starting Date. |
| **STARTING TIME** | Time of day sequence will run. |
| **DELTA DAYS** | Number of days to skip between each Sequence execution.<br>• If set to 7, for example, the AutoCal feature will be enabled once every week on the same day. |
| **DELTA TIME** | Number of hours later each "Delta Days" Sequence is to be run.<br>• 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.<br>• 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** | Number of minutes the sequence operates.<br>• This parameter needs to be set such that there is enough time for the concentration signal to stabilize.<br>• The STB parameter shows if the analyzer response is stable at the end of the calibration.<br>• This parameter is logged with calibration values in the DAS. |
| **CALIBRATE** | Enable to do a calibration – Disable to do a cal check only. |
| **RANGE TO CAL** | LOW calibrates the low range, HIGH calibrates the high range. |

The following example sets sequence #2 to do a zero-span calibration every other day starting at 2:15PM on July 31, 2013, lasting 15 minutes, without calibration. This will start ½ hour later each iteration.

**Table 10-3: Example AutoCal 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 | 31 JUL 2013 | Start after July 31, 2013 |
| STARTING TIME | 14:15 | First Span starts at 2:15PM |
| DELTA DAYS | 2 | Do Sequence #2 every other day |
| DELTA TIME | 00:30 | Do Sequence #2 ½ -hr later each day |
| DURATION | 15.0 | Operate Span valve for 15 min |
| CALIBRATE | OFF | Calibrate at end of Sequence |

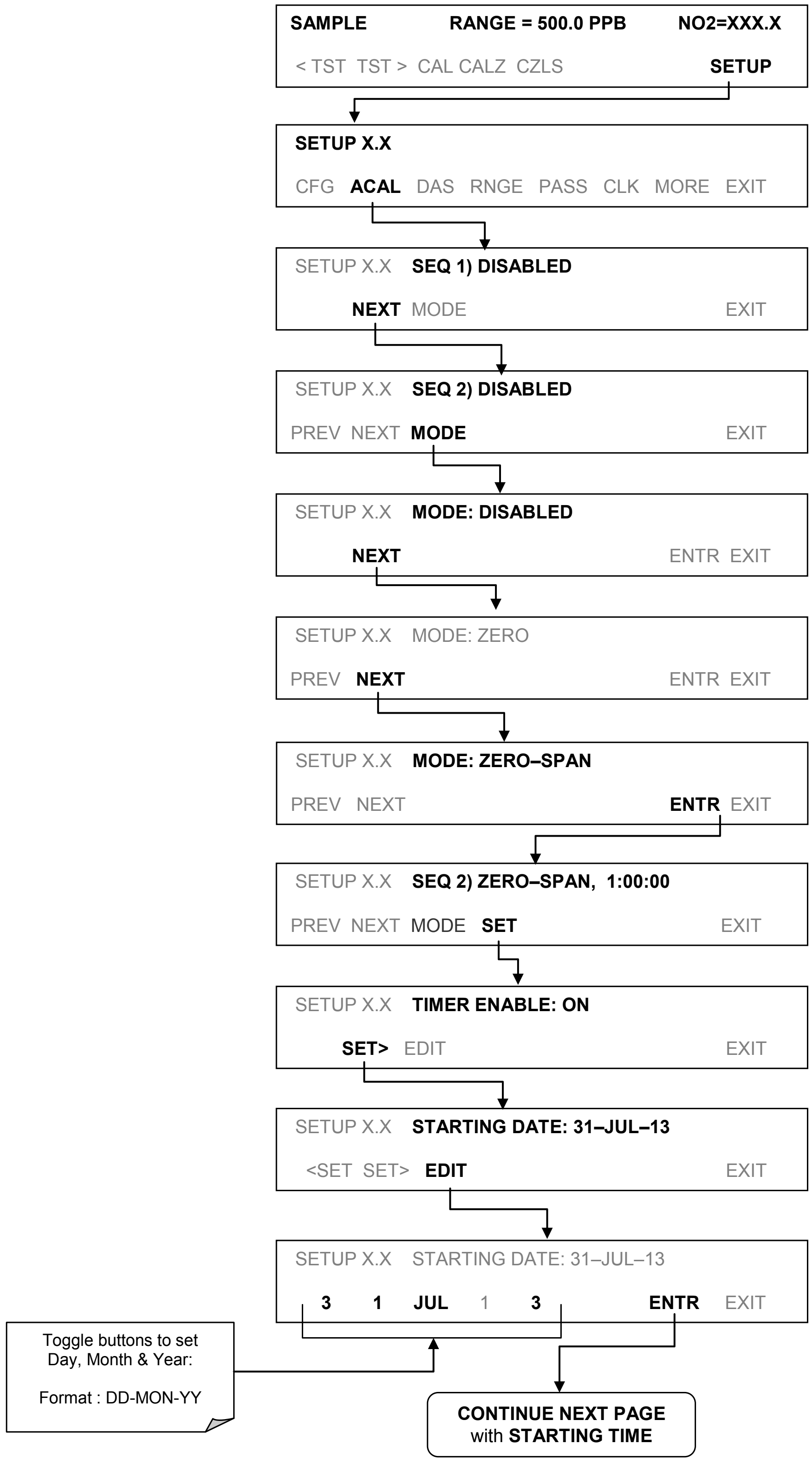
**IMPORTANT**

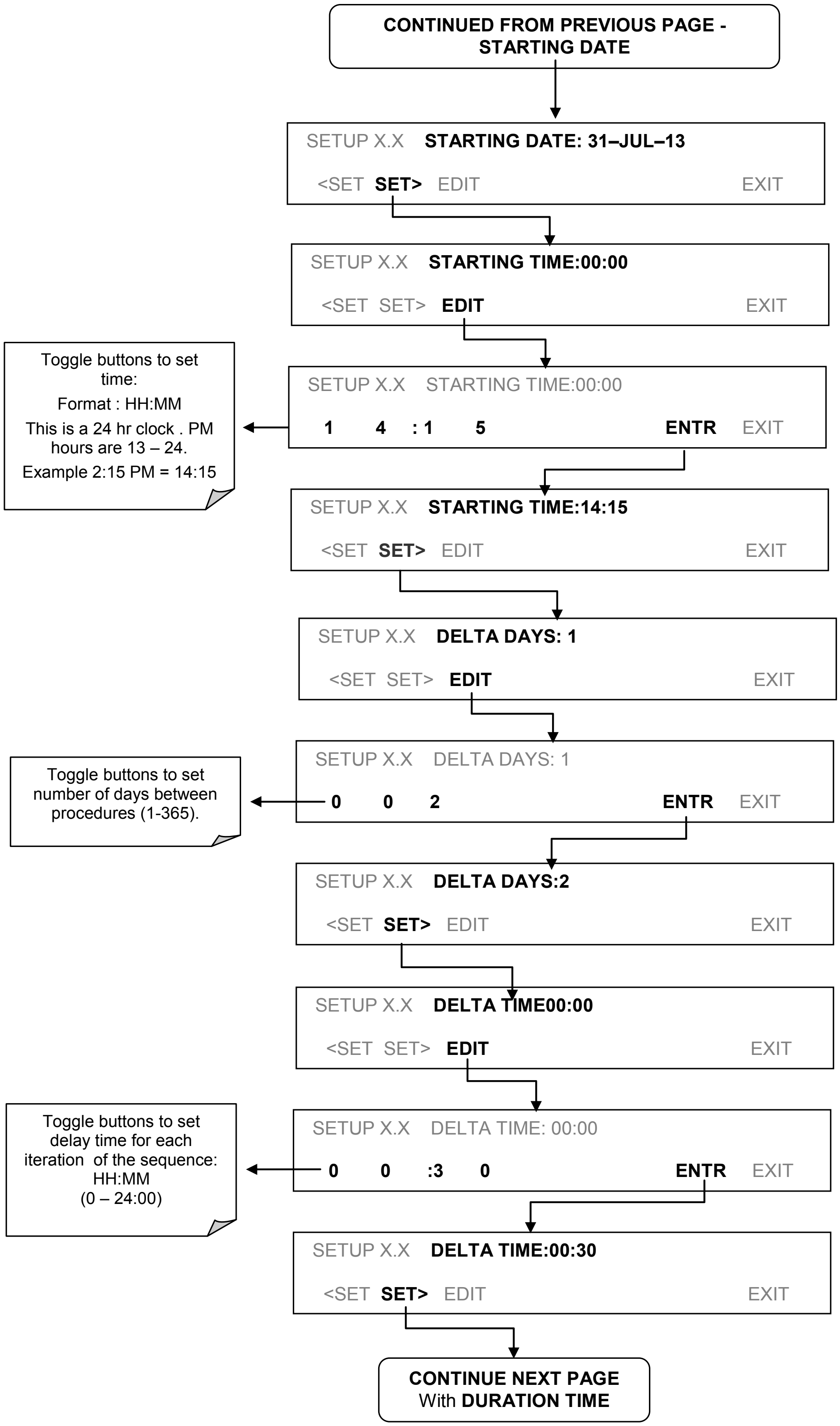
**IMPACT ON READINGS OR DATA**

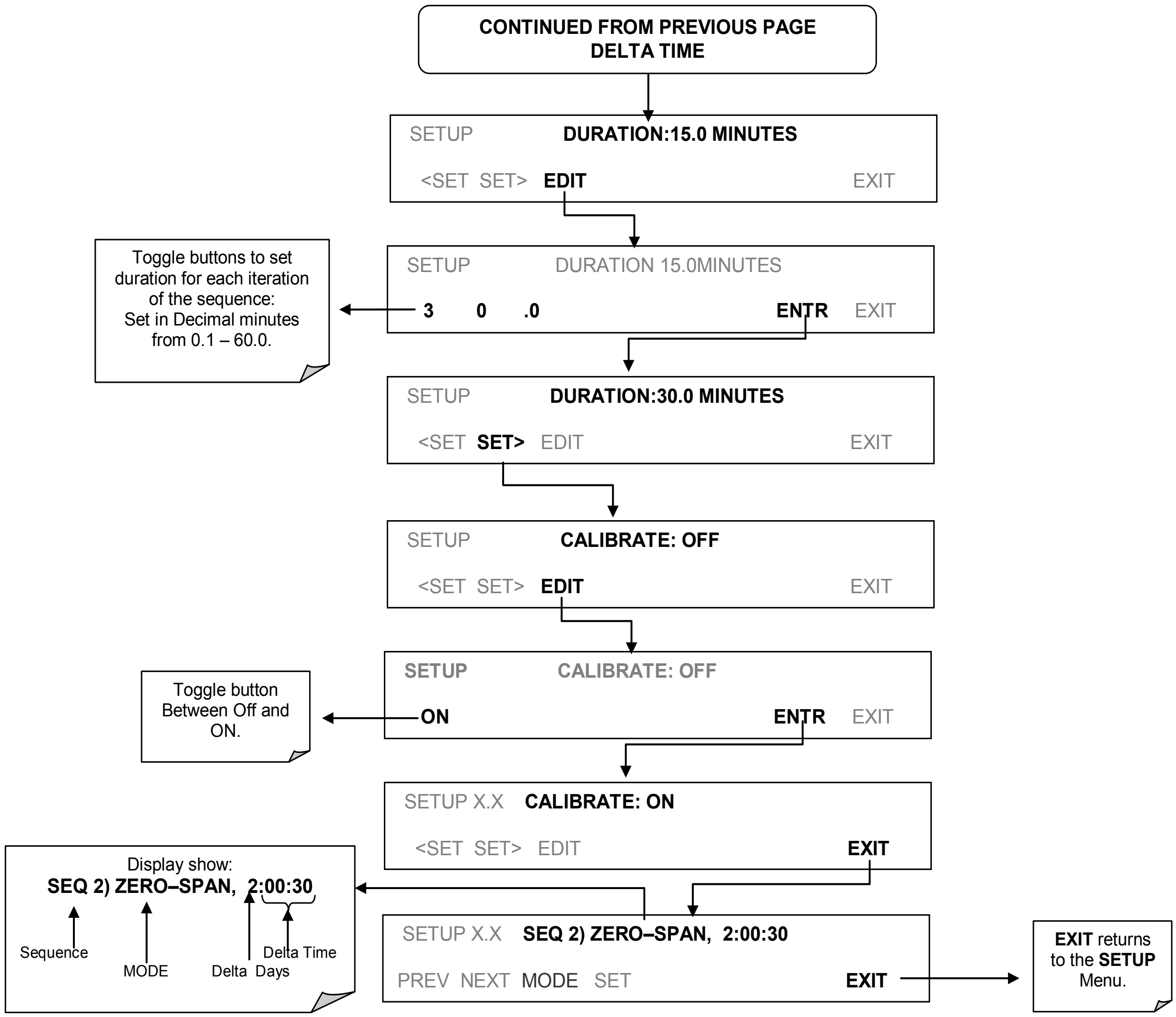
- The programmed STARTING_TIME must be a minimum of 5 minutes later than the real time clock for setting real time clock (see Section 6.5).
- Avoid setting two or more sequences at the same time of the day.
- Any new sequence that is initiated whether from a timer, the COM ports or the contact closure inputs will override any sequence that is in progress.
- The CALIBRATE attribute must always be set to OFF on analyzers with IZS Options installed and functioning.
- Calibrations should ONLY be performed using sources of Zero Air and Span Gas whose accuracy is traceable to EPA or NIST standards.

## 10.5.1. SETUP → ACAL: PROGRAMMING AND AUTO CAL SEQUENCE

To program the example sequence shown in Table 10-3, press:




CONTINUED FROM PREVIOUS PAGE - STARTING DATE
SETUP X.X STARTING DATE: 31–JUL–13
<SET SET> EDIT EXIT
SETUP X.X STARTING TIME:00:00
<SET SET> EDIT EXIT
Toggle buttons to set time:
Format : HH:MM
This is a 24 hr clock . PM hours are 13 – 24.
Example 2:15 PM = 14:15
SETUP X.X STARTING TIME:00:00
1 4 : 1 5 ENTR EXIT
SETUP X.X STARTING TIME:14:15
<SET SET> EDIT EXIT
SETUP X.X DELTA DAYS: 1
<SET SET> EDIT EXIT
Toggle buttons to set number of days between procedures (1-365).
SETUP X.X DELTA DAYS: 1
0 0 2 ENTR EXIT
SETUP X.X DELTA DAYS:2
<SET SET> EDIT EXIT
SETUP X.X DELTA TIME00:00
<SET SET> EDIT EXIT
Toggle buttons to set delay time for each iteration of the sequence: HH:MM (0 – 24:00)
SETUP X.X DELTA TIME: 00:00
0 0 :3 0 ENTR EXIT
SETUP X.X DELTA TIME:00:30
<SET SET> EDIT EXIT
CONTINUE NEXT PAGE With DURATION TIME




**lote**

**If at any time an unallowable entry is selected (Example: Delta Days > 367) the ENTR button will disappear from the display.**

# 10.6. CALIBRATION QUALITY ANALYSIS

Following calibration, evaluate the analyzer's calibration **SLOPE** and **OFFSET** parameters. Their values describe the linear response curve of the analyzer, indicating the quality of the calibration.

First, record the values of the SLOPE and OFFSET test functions (in SAMPLE Mode press the <TST TST> buttons, see Section 5.2), all of which are automatically stored in the DAS channel **CALDAT** for data analysis, documentation and archival.

Ensure that these values are within the limits listed in Table 10-4 and frequently compare them to those values on the *Final Test and Validation Data Sheet (P/N 07853)* that came attached to your manual, which should not be significantly different. If they are, refer to Section 13.1.2 in Troubleshooting and Service.

**Table 10-4: Calibration Data Quality Evaluation**

| Function | Minimum Value | Optimum Value | Maximum Value |
|---|---|---|---|
| SLOPE | -0.800 | 1.000 | 1.200 |
| OFFSET | -10 ppb | 0.0 ppb | 10.0 ppb |

# 11. MAINTENANCE

Although the T500U analyzer requires little service, a few simple procedures should be performed regularly to ensure that the T500U continues to operate accurately and reliably over its lifetime. In general, the exterior can be wiped down with a lightly damp cloth; avoid spraying anything directly onto any part of the analyzer.

Service and troubleshooting are covered in Section 13.

## 11.1. MAINTENANCE SCHEDULE

Table 11-1 shows a typical maintenance schedule for the T500U. Please note that in certain environments (i.e., dusty, very high ambient pollutant levels) some maintenance procedures may need to be performed more often than shown.

**WARNING – ELECTRICAL SHOCK HAZARD**

**Disconnect power before performing any of the following operations that require entry into the interior of the analyzer.**

**CAUTION – QUALIFIED PERSONNEL**

**These maintenance procedures must be performed by qualified technicians only.**

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**A span and zero calibration check (see CAL CHECK REQ'D Column of Table 11-1, T500U Maintenance Schedule) must be performed following some of the maintenance procedures.**

**To perform a CHECK of the instrument's Zero or Span Calibration, follow the calibration check steps in Section 10.4.**

**DO NOT press the ENTR button at the end of each operation. Pressing the ENTR button resets the stored values for OFFSET and SLOPE and alters the instrument's Calibration.**

**Alternately, use the Auto Cal feature described in Section 10.5 with the CALIBRATE attribute set to OFF.**

**Table 11-1: T500U Maintenance Schedule**

| ITEM | ACTION | FREQ | CAL CHECK REQ'D | DATE PERFORMED | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |
| TEST functions | Review and evaluate | Weekly | No | | | | | | | | | | |
| Particulate filter | Change particle filter | Yearly | No | | | | | | | | | | |
| Zero/span check | Evaluate offset and slope | Weekly | No | | | | | | | | | | |
| Zero/span calibration | Zero and span calibration | Every 3 months | Yes | | | | | | | | | | |
| Spectrometer mirrors | Contact Technical Support | As necessary due to excessive Measured Loss | Yes | | | | | | | | | | |
| Pneumatic sub-system | Check for leaks in gas flow paths | Annually or after repairs involving pneumatics | Yes if a leak is repaired | | | | | | | | | | |
| Internal Pump | Replace | Measured Flow less than 800 $cm^3$/min | Yes | | | | | | | | | | |

# 11.2. PREDICTIVE DIAGNOSTICS

Predictive diagnostic functions including failure warnings and alarms built into the analyzer's firmware allow the user to determine when repairs are necessary.

The Test Functions can also be used to predict failures by looking at how their values change over time. Initially it may be useful to compare the state of these Test Functions to the values recorded on the printed record of the *Final Test and Validation Data Sheet*, P/N 07853.

The following table can be used as a basis for taking action as these values change with time. The internal data acquisition system (DAS) is a convenient way to record and track these changes.

**Table 11-2: Predictive Uses for Test Functions**

| FUNCTION | EXPECTED | ACTUAL | INTERPRETATION & ACTION |
|---|---|---|---|
| **SAMP** (pressure) | Constant within atmospheric changes (Typically 2 InHg below ambient) | Fluctuating | Developing leak in pneumatic system. Check for leaks. |
| | | Slowly increasing | Developing leak in pneumatic system prior to the orifice. Check for leaks.<br>Sample pump requires replacement. Check flow rate. |
| | | Slowly decreasing | Flow path is clogging up. Replace sample filter. |
| **AREF** | Constant within ±100Mm-1 of check-out value | Significantly increasing | Developing AREF valve failure. Replace valve. |
| | | | Developing leak in pneumatic system. Check for leaks. |
| | | | Debris on mirrors. Replace charcoal scrubber. |
| **$NO_2$** (Concentration) | Constant for constant concentrations | Slowly decreasing signal for same concentration | Developing leak in pneumatic system. Check for leaks. |

**Note**

**It is recommended that the above test functions be checked weekly.**

# 11.3. MAINTENANCE PROCEDURES

The following procedures are to be performed periodically as part of the standard maintenance of the T500U.

## 11.3.1. REPLACING THE SAMPLE PARTICULATE FILTER

The particulate filter should be inspected often for signs of plugging or contamination.

To change the filter:

Turn OFF the analyzer to prevent drawing debris into the instrument.

Open the T500U's hinged front panel and disconnect the pneumatic fittings, using the appropriate wrenches, and remove the disposable sample filter.

**Note** **Flow enters filter at bottom and exits at top.**

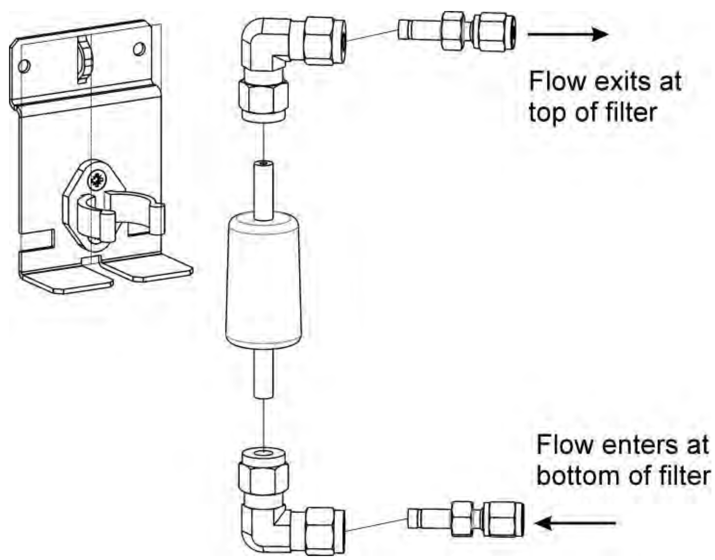



**Figure 11-1: Replacing the Sample Filter**

## 11.3.2. CHANGING THE INTERNAL SPAN GAS GENERATOR PERMEATION TUBE

1. Turn off the analyzer, unplug the power cord and remove the cover.
2. Locate the permeation tube oven next to the sample cell.
3. Remove the top layer of insulation if necessary.
4. Unscrew the black aluminum cover of the oven (3 screws) using a medium Phillips-head screw driver. (Leave the fittings and tubing connected to the cover).
5. Remove the old permeation tube and replace it with the new tube. (Ensure that the tube is placed into the larger of two holes and that the open permeation end of the tube (plastic) is facing up).
6. Re-attach the cover with three screws (Ensure that the three screws are tightened evenly).

7. Replace the analyzer cover, plug the power cord back in and turn on the analyzer.
8. Carry out a span check to see if the new permeation device works properly (see Section 10.3.2).
9. The permeation rate may need several days to stabilize.

**ATTENTION**

**COULD DAMAGE INSTRUMENT AND VOID WARRANTY**

**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.**

## 11.3.3. CHECKING FOR PNEUMATIC LEAKS

**CAUTION - TECHNICAL INFORMATION**

**Do not exceed 10 psi when pressurizing the system during either Sample Flow checks or Detailed Leak checks.**

### 11.3.3.1. DETAILED PRESSURE LEAK CHECK

Obtain a leak checker similar to Teledyne API's P/N 01960, which contains a small pump, shut-off valve, and pressure gauge to create both over-pressure. Alternatively, a tank of pressurized gas, with the two-stage regulator adjusted to $\leq$ 10 psi, a shutoff valve and a pressure gauge may be used.

**ATTENTION**

**COULD DAMAGE INSTRUMENT AND VOID WARRANTY**

**Once tube fittings have been wetted with soap solution under a pressurized system, do not apply or reapply vacuum as this will cause soap solution to be sucked into the instrument, contaminating inside surfaces.**

1. Turn OFF power to the instrument and remove the instrument cover.
2. Install a leak checker on the sample inlet at the rear panel.
3. CAP rear panel PORTS and cap the pump port.
   - If zero/span valves are installed, disconnect the tubing from the zero and span gas ports and cap the ports (Figure 3-3).
4. Pressurize the instrument with the leak checker, allowing enough time to fully pressurize the instrument.
   - Do not exceed 10 psi pressure.
5. Once the leak has been located and repaired, the leak-down rate of the indicated pressure should be less than 1 psi in 5 minutes after the pressure is turned off. Replace the instrument cover and restart the analyzer.
6. If the leak still cannot be found, check each tube connection (fittings, hose clamps) with soap bubble solution, looking for fine bubbles.

- Pressurize the instrument with the leak checker, allowing enough time to fully pressurize the instrument.
- Do not exceed 10 psi pressure.
- Wet the bench last with soap solution.
- Once the fittings have been wetted with soap solution, do not reapply vacuum as it will draw soap solution into the instrument and contaminate it.

7. Clean surfaces from soap solution, reconnect the sample and pump lines and replace the instrument cover.
8. Restart the analyzer.

#### 11.3.3.2. **PERFORMING A SAMPLE FLOW CHECK**

**IMPORTANT**

**IMPACT ON READINGS OR DATA**

**Use a calibrated flow meter capable of measuring flows between 0 and 1000 cm³/min to measure the gas flow rate though the analyzer.**

Sample flow checks are useful for monitoring the actual flow of the instrument. A decreasing sample flow may point to slowly clogging pneumatic paths, most likely the critical flow orifice or the sample filter. To perform a sample flow check:

1. Disconnect the sample inlet tubing from the rear panel SAMPLE port.
2. 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.
3. Check that the sample flow measured with the external flow meter is within specification.
4. If sample flow is out of specification, replace the sample filter, and if needed, replace the critical flow orifice.
5. If sample flow is still out of spec, call Technical Support.

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# 12. EPA PROTOCOL CALIBRATION

To ensure high quality, accurate measurements at all times, the T500U 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 that you obtain a copy of the publication Quality Assurance Handbook for Air Pollution Measurement Systems (abbreviated, Q.A. Handbook Volume II); USEPA Order Number: EPA454R98004; or NIST Order Number: PB99-129876.

This manual can be purchased from:

- EPA Technology Transfer Network (http://www.epa.gov/ttn/amtic)
- National Technical Information Service (NTIS, http://www.ntis.gov/)

Specific regulations regarding the use and operation of ambient $NO_x$ analyzers can be found in Section 12.1 Reference 1.

If the T500U is used for EPA compliance monitoring, it must be calibrated in accordance with EPA guidelines. The instrument(s) supplying the zero air and Span calibration gasses used must themselves be calibrated and that calibration must be traceable to an EPA/NIST primary standard.

## 12.1. REFERENCES RELATING TO $NO_2$ MONITORING

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.

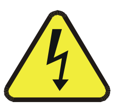
# 13. TROUBLESHOOTING AND SERVICE

This section contains a variety of methods for identifying the source of performance problems with the analyzer. Also included in this section are procedures that are used in repairing the instrument.

**Note:** **To support your understanding of the technical details of maintenance, Section 14, Principles of Operation, provides information about how the instrument works.**

**CAUTION**

**The operations outlined in this section must be performed by qualified maintenance personnel only.**



**WARNING**
**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 short or touch electric connections with metallic tools while operating inside the analyzer.**

**Use common sense when operating inside a running analyzer.**

**Note** **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).**

**Remove the locking screw located at the right-hand side of the front panel.**

# 13.1. GENERAL TROUBLESHOOTING

The T500U has been designed so that problems can be rapidly detected, evaluated and repaired. During operation, it 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 LEDs 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 PCA.
    - 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 PCA.
- Suspect a leak first!
    - Technical Support data indicate that the majority of all problems are eventually traced to leaks in the internal pneumatics of the analyzer or the diluent gas and source gases delivery systems (refer to Section 11.3.3).
- Check for gas flow problems such as clogged or blocked internal/external gas lines, damaged seals, punctured gas lines, a damaged / malfunctioning pumps, etc.

## 13.1.1. FAULT DIAGNOSIS WITH WARNING MESSAGES

The most common and/or serious instrument failures will result in a warning message being displayed on the front panel. Table 13-1 lists 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 sub-system (power supply, relay PCA motherboard) has failed rather than an indication of the specific failures referenced by the warnings.

The analyzer will alert the user that a Warning Message is active by flashing the FAULT LED and displaying the Warning message in the Param field along with the **CLR** button (press to clear Warning message). The **MSG** button displays if there is more than one warning in queue, or if you are in the TEST menu and have not yet cleared the message.

The following display/touch screen examples provide an illustration of each (top: Fault message with CLR button; bottom: MSG button to read and clear fault).

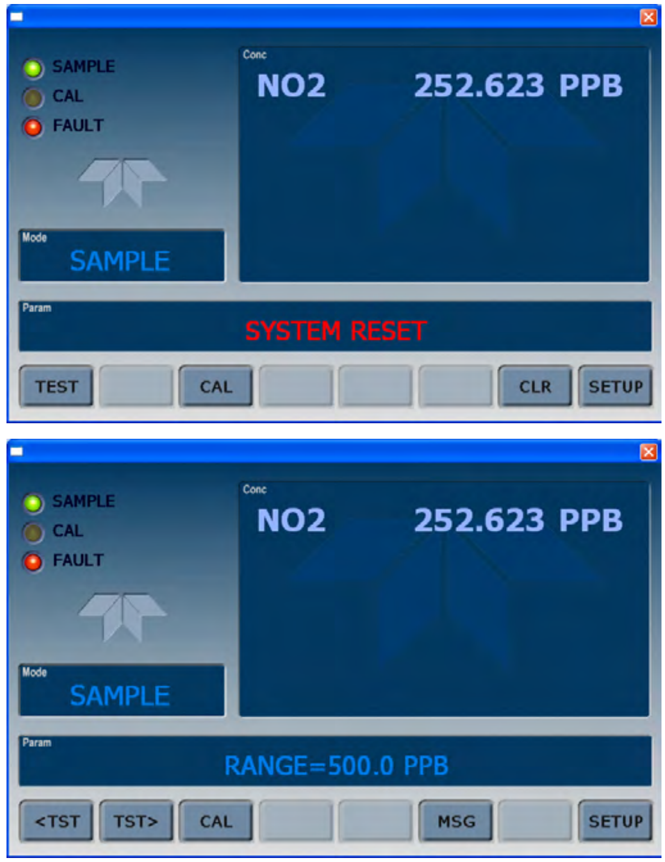



**Figure 13-1. CLR and MSG Menu Buttons**

The analyzer will also alert the user via the Serial I/O COM port(s).

To view or clear the various warning messages press:

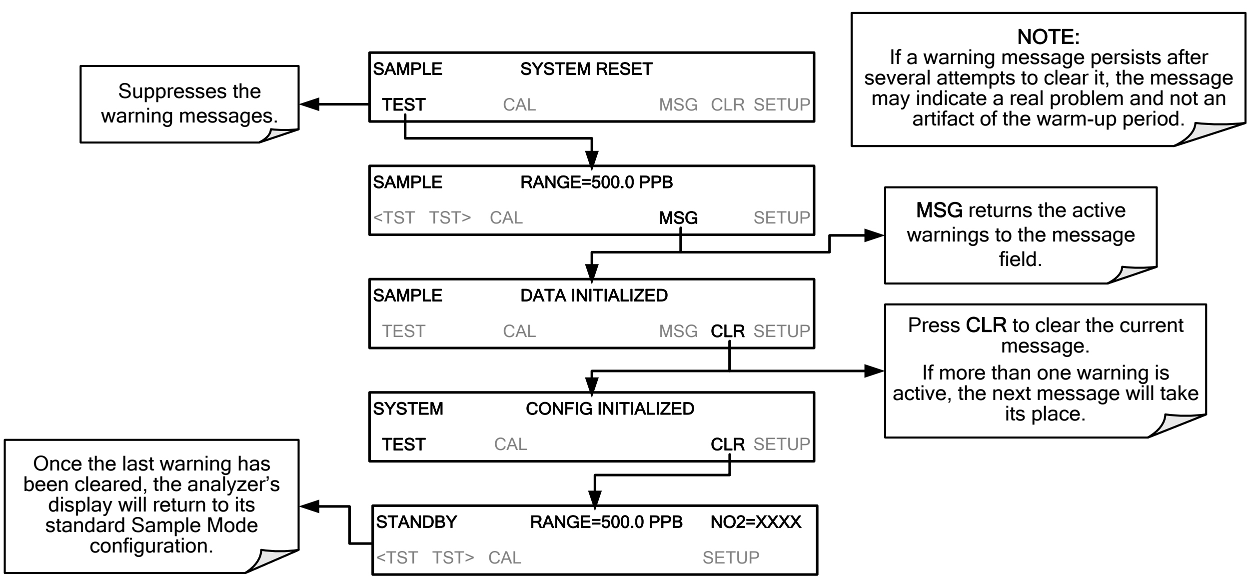


**Table 13-1: Front Panel Warning Messages**

| WARNING | FAULT CONDITION | POSSIBLE CAUSES |
|---|---|---|
| **AUTO REF WARNING** | Auto Ref value outside limit specified by AREF_LIMIT variable. | Drift in baseline loss due to large leak.<br>Sample filter bypassed. |
| **BOX TEMP WARNING** | Chassis temperature outside limits specified by BOX_SET variable | Box Temperature typically runs ~7°C warmer than ambient temperature<br>Poor/blocked ventilation to the analyzer<br>Stopped Exhaust-Fan<br>Ambient Temperature outside of specified range |
| **CANNOT DYN SPAN** | Dynamic Span operation failed. | Measured concentration value is too high or low<br>Concentration Slope value to high or too low |
| **CANNOT DYN ZERO** | Dynamic Zero operation failed. | Measured concentration value is too high<br>Concentration Offset value to high |
| **CONFIG INITIALIZED** | Configuration and Calibration data reset to original Factory state. | Failed Disk on Module<br>User erased data |
| **DATA INITIALIZED** | Data Storage in DAS was erased. | Failed Disk-on-Module<br>User cleared data. |
| **REAR BOARD NOT DET** | Motherboard not detected on power up. | This WARNING only appears on Serial I/O COM port(s) Front Panel Display will be frozen, blank or will not respond.<br>Failure of Motherboard |
| **RELAY BOARD WARN** | The CPU cannot communicate with the Relay Board. | $I^2C$ Bus failure<br>Failed Relay Board<br>Loose connectors/wiring |
| **SAMPLE PRESS WARN** | Sample pressure outside limits specified by SAMP_PRESS_SET variable | Leak<br>Malfunctioning valve<br>Malfunctioning pump<br>Clogged flow orifces |
| **SYSTEM RESET** | The computer has rebooted. | This message occurs at power on.<br>If it is confirmed that power has not been interrupted:<br>Failed +5 VDC power<br>Fatal Error caused software to restart<br>Loose connector/wiring |

**Note** **A failure of the analyzer's CPU, motherboard or power supplies can result in any or ALL of the above messages.**

## 13.1.2. FAULT DIAGNOSIS WITH TEST FUNCTIONS

In addition to being useful as predictive diagnostic tools, the test functions viewable from the analyzers front panel can be used to isolate and identify many operational problems when combined with a thorough understanding of the analyzer's principles of operation (see Section 14).

The acceptable ranges for these test functions are listed in the "Nominal Range" column of the analyzer *Final Test and Validation Data Sheet* (P/N 07853) shipped with the instrument. Values outside these acceptable ranges indicate a failure of one or more of the analyzer's subsystems. Functions whose values are still within acceptable ranges but have significantly changed from the measurement recorded on the factory data sheet may also indicate a failure.

**Note** **A value of "XXXX" displayed for any of these TEST functions indicates an OUT OF RANGE reading.**

**Note** **Sample Pressure measurements are represented in terms of ABSOLUTE pressure because this is the least ambiguous method reporting gas pressure.**

**Absolute atmospheric pressure is about 29.92 in-Hg-A at sea level. It decreases about 1 in-Hg per 1000 ft gain in altitude. A variety of factors such as air conditioning systems, passing storms, and air temperature, can also cause changes in the absolute atmospheric pressure.**

**Table 13-2: Test Functions - Indicated Failures**

| TEST FUNCTION | INDICATED FAILURE(S) |
|---|---|
| **SMP PRS (pressure)** | Leak; malfunctioning valve; malfunctioning pump; clogged flow orifices; sample inlet overpressure. |
| **SMP Temp** | Sample temperature out of range; broken thermistor. |
| **OVEN TEMP** | Oven temperature out of range; broken thermistor. |
| **BOX TEMP** | Environment out of temperature operating range; broken thermistor. |
| **MANIFOLD TEMP** | Manifold temperature out of range; broken thermistor. |
| **IZS TEMP** | IZS temperature out of range; broken thermistor. |

## 13.1.3. DIAG → SIGNAL I/O: USING THE DIAGNOSTIC SIGNAL I/O FUNCTION

The signal I/O diagnostic mode allows access to the digital and analog I/O in the analyzer. Some of the digital signals can be controlled through the touchscreen. These signals are useful for troubleshooting in three ways:

- The technician can view the raw, unprocessed signal level of the analyzer's critical inputs and outputs.
- Many of the components and functions that are normally under algorithmic control of the CPU can be manually exercised.
- The technician can directly control the signal level Analog and Digital Output signals.

This allows the technician to observe systematically the effect of directly controlling these signals on the operation of the analyzer. Following is 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.

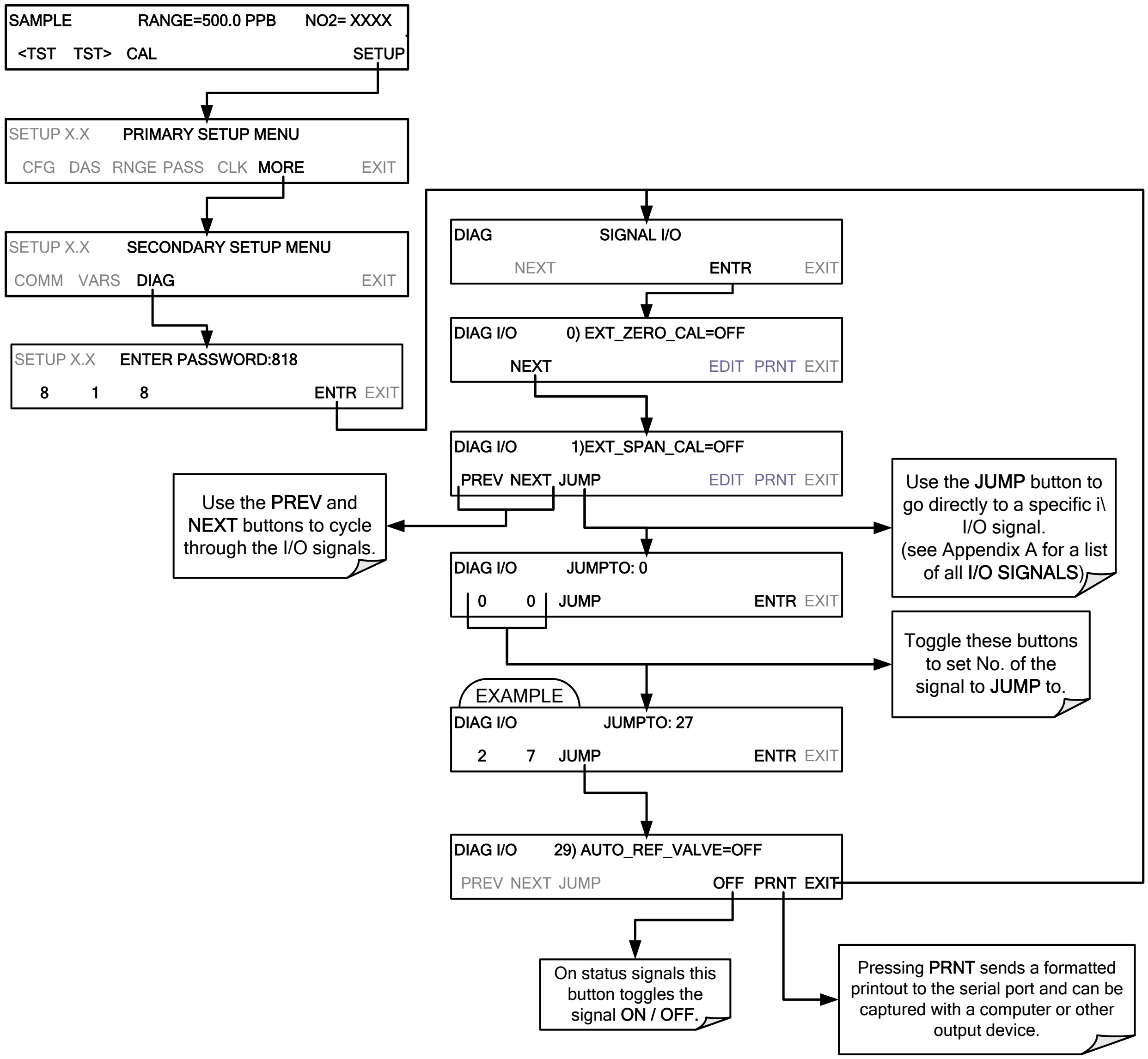



**Figure 13-2: Example of Signal I/O Function**

**Note**

**Any I/O signals changed while in the signal I/O menu will remain in effect ONLY until signal I/O menu is exited. The Analyzer regains control of these signals upon exit.**

**See Appendix A for a complete list of the parameters available for review under this menu.**

# 13.2. USING THE ANALOG OUTPUT TEST CHANNEL

The signals available for output over the T500U's analog output channel can also be used as diagnostic tools. See Section 6.8.2 for instruction on activating the analog output and selecting a function. See Table 13-1 for possible causes of extremely high or low readings.

# 13.3. USING THE INTERNAL ELECTRONIC STATUS LEDS

Several LEDs are located inside the instrument to assist in determining if the analyzer's CPU, $I^2C$ bus and Relay PCA are functioning properly.

## 13.3.1. CPU STATUS INDICATOR

DS5, a red LED, that is located on upper portion of the motherboard, just to the right of the CPU board, flashes when the CPU is running the main program loop. After power-up, approximately 30 – 60 seconds, DS5 should flash on and off. If characters are written to the front panel display but DS5 does not flash then the program files have become corrupted, contact Teledyne API's Technical Support Department (see Section 13.9) because it may be possible to recover operation of the analyzer. If after 30 – 60 seconds, neither DS5 is flashing nor have any characters been written to the front panel display then the CPU is bad and must be replaced.

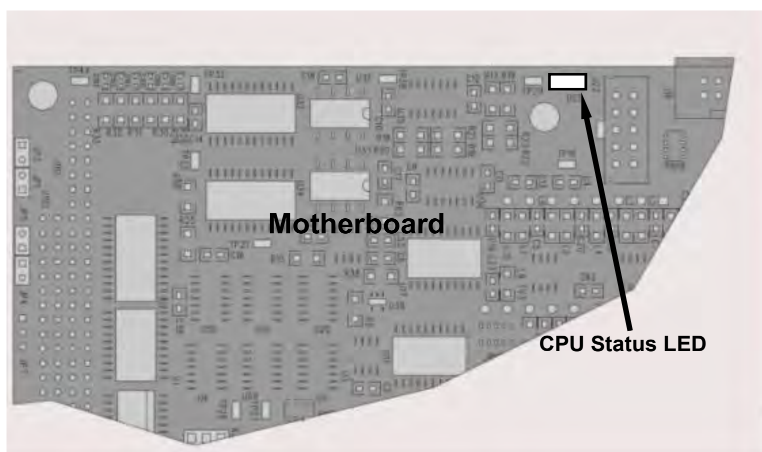



**Figure 13-3: CPU Status Indicator**

## 13.3.2. RELAY PCA STATUS LEDS

There are sixteen LEDs located on the Relay PCA. Some are not used on this model.

### 13.3.2.1. $I^2C$ BUS WATCHDOG STATUS LEDS

The most important is D1 (see Figure 13-4), which indicates the health of the $I^2C$ bus.

**Table 13-3: Relay PCA Watchdog LED Failure Indications**

| LED | Function | Fault Status | Indicated Failure(s) |
|---|---|---|---|
| D1<br>(Red) | $I^2C$ bus Health<br>(Watchdog Circuit) | Continuously ON<br>or<br>Continuously OFF | Failed/Halted CPU<br>Faulty Motherboard, Touchscreen or Relay PCA<br>Faulty Connectors/Wiring between Motherboard, Touchscreen or Relay PCA<br>Failed/Faulty +5 VDC Power Supply (PS1) |

If D1 is blinking, then the other LEDs can be used in conjunction with **DIAG** Menu Signal I/O to identify hardware failures of the relays and switches on the Relay PCA.

### 13.3.2.2. **RELAY PCA STATUS LEDS**

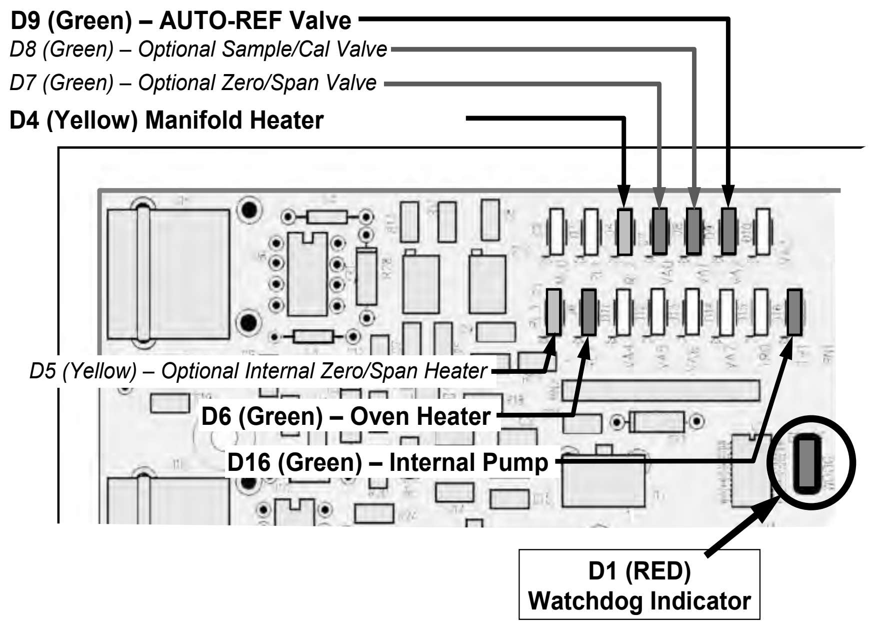



**Figure 13-4: Relay PCA Status LEDS Used for Troubleshooting**

**Table 13-4: Relay PCA Status LED Failure Indications**

| LED | COLOR | COMPONENT | FAULT STATUS | INDICATED FAILURE(S) |
|---|---|---|---|---|
| **LED ROW 1** | | | | |
| D2-D3 | spares | | | |
| D4 | Yellow | Manifold heater | Continuously ON or OFF | Heater broken, thermistor broken |
| D7 | Green | Internal Zero/Span (option) valve | Continuously ON or OFF | Valve broken or stuck, valve driver chip broken |
| D8 | Green | Sample/Cal valve (option) | Continuously ON or OFF | Valve broken or stuck, valve driver chip broken |
| D9 | Green | Auto-Ref valve | Continuously ON or OFF | Valve broken or stuck, valve driver chip broken |
| D10 | spare | | | |
| **LED ROW 2** | | | | |
| D5 | Yellow | Internal Zero/Span (option) heater | Continuously ON or OFF | Heater broken, thermocouple broken |
| D6 | Green | Oven heater | Continuously ON or OFF | Heater broken, thermistor broken |
| D11-15 | spares | | | |
| D16 | Green | Internal pump | Continuously ON or OFF | Not receiving power; relay board bad |

# 13.4. CALIBRATION PROBLEMS

This section describes possible causes of calibration problems.

## 13.4.1. NEGATIVE CONCENTRATIONS

A negative concentration value can be caused by calibration error: If the zero air were contaminated, and the analyzer was calibrated at “zero”, the analyzer may report a negative value when measuring air that contains little or no $NO_2$.

## 13.4.2. 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.

1. Confirm the lack of response by supplying or $NO_2$ span gas of about 80% of the range value to the analyzer.
2. Check the sample flow rate for proper value.
3. Check for disconnected cables to the sensor module.

## 13.4.3. UNSTABLE ZERO AND SPAN

Leaks in the T500U or in the external gas supply and vacuum systems are the most common source of unstable and non-repeatable concentration readings.

1. Check for leaks in the pneumatic systems as described in Section 11.3.3.
2. Consider pneumatic components in the gas delivery system outside the T500U 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.
3. Once the instrument passes a leak check, do a flow check (this chapter) to ensure that the instrument is supplied with adequate sample air.
4. Confirm the sample pressure, sample temperature, and sample flow readings are correct and steady.
5. Verify that the sample filter element is clean and does not need to be replaced.

## 13.4.4. INABILITY TO SPAN - NO SPAN BUTTON (CALS)

In general, the T500U will not display certain buttons 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** button 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.

1. Verify that the expected concentration is set properly to the actual span gas concentration in the CONC sub-menu.
2. Confirm that the span gas source is accurate.
   - This can be done by comparing the source with another calibrated analyzer, or by having the span gas source verified by an independent traceable photometer.
3. Check for leaks in the pneumatic systems as described in Section 11.3.3.
   - 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.
4. If the low-level, hardware calibration has drifted 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 (0.8-1.2 for slope, -10 to 10 for offsets.

## 13.4.5. INABILITY TO ZERO - NO ZERO BUTTON (CALZ)

In general, the T500U will not display certain buttons 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 button when carrying out a zero calibration, the actual gas concentration must be significantly different from the actual zero point (as per last calibration), which may be for any of several reasons.

- Confirm that there is a good source of zero air.
- Check to ensure that there is no ambient air leaking into the zero air line.
- Check for leaks in the pneumatic systems as described in Section 11.3.3.

## 13.4.6. **NON-LINEAR RESPONSE**

The T500U was factory calibrated to a high level of $NO_2$ and should be linear to within 1% of full scale. Common causes for non-linearity are:

- Leaks in the pneumatic system:
  - Leaks can add an offset signal to the ambient sample, zero air or span gas, whose concentration can fluctuate while a linearity test is being performed.
  - Check for leaks as described in Section 11.3.3.
- 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.
- Dilution air contains sample or span gas.
- Incoming concentrations may not be linear.
  - Check input bottles.
- 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.
  - Ensure to create and properly vent excess span gas.

## 13.4.7. **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 recalibrate 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 6.8.3.2 for a detailed description of this procedure.

# 13.5. OTHER PERFORMANCE PROBLEMS

Dynamic problems (i.e. problems that 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.

## 13.5.1. EXCESSIVE NOISE

Excessive noise levels under normal operation usually indicate leaks in the sample supply or the analyzer itself. Ensure that the sample or span gas supply is leak-free and carry out a detailed leak check as described earlier in this chapter.

Other sources of measurement noise may be related to cabling issues. Gain access to the instrument, when powered down, and reset the cable connectors.

## 13.5.2. SLOW RESPONSE

If the analyzer starts responding too slowly 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.
- Dirty or plugged flow restrictor. Check flows, pressures and, if necessary, change restrictor.
- Wrong materials in contact with sample - use glass, stainless steel or Teflon materials only.
- Insufficient time allowed for purging of lines upstream of the analyzer. Wait until stability is reached.
- Insufficient time allowed for $NO_2$ calibration gas source to become stable. Wait until stability is reached.

## 13.5.3. AREF WARNINGS

Auto Reference (AREF or AutoRef) warnings occur if the signal measured during an AREF cycle is higher than 1100 Mm-1 (Mega/meter, the units that are used to express AutoRef offset value). The AutoRef offset limit is set by the AREF_LIMIT variable, and the AutoRef warning level is set by the AREF_WARN variable.

**Note** **There will not be an AREF warning if the AREF feature was disabled due to prolonged time in CAL mode. Ensure the instrument is returned to SAMPLE mode as soon as a calibration has been completed.**

**Note** **The AREF warning displays the value of the Auto Reference reading when the warning occurs.**

If this value is higher than 1100 Mm-1, check that the Auto Reference valve is operating properly:

- In the **DIAG** menu go to **SIGNAL I/O>AUTO_REF_VALVE** 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.
- Check the power supply to the valve (12 V to the valve should turn on and off when measured with a voltmeter).

**Note** **It takes only a small leak across the ports of the valve to show excessive Auto Reference values when supplying high concentrations of span gas.**

If the Auto Reference valve is working properly, then the problem could be due to dirty mirrors. Please contact Technical Support to confirm this, prior to removing the optical bench, in order to rule out other possibilities (Section 13.9).

# 13.6. **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.

## 13.6.1. **AC MAIN POWER**

The T500U analyzer's electronic systems will operate with any of the specified power regimes. As long as system is connected to 100-120 VAC or 220-240 VAC at either 50 or 60 Hz it will turn on and after about 30 seconds show a front panel display.

- Internally, the status LEDs located on the Relay PCA, Motherboard and CPU should turn on as soon as the power is supplied.
- If they do not, check the circuit breaker built into the ON/OFF switch on the instruments front panel.
- If the instrument is equipped with an internal pump, it will begin to run. If it does not:
    - Verify that the pump connection is mated correctly.
    - Verify that there are no kinks in the tubing that would restrict pump operation.

**WARNING – ELECTRICAL SHOCK HAZARD**

**Should the AC power circuit breaker trip, investigate and correct the condition causing this situation before turning the analyzer back on.**

## 13.6.2. **DC POWER SUPPLY**

If you have determined that the analyzer's AC mains 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. The supplies can have two faults, namely no DC output, and noisy output.

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 PCA follow a standard color-coding scheme as defined in the following table.

**Table 13-5: DC Power Test Point and Wiring Color Codes**

| 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 | |

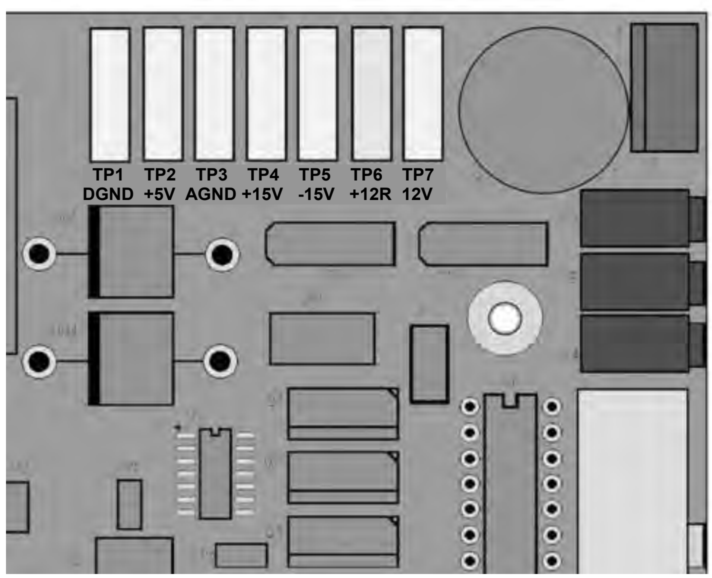



**Figure 13-5: Location of DC Power Test Points on Relay PCA**

A voltmeter should be used to verify that the DC voltages are correct per the values in the table below, and an oscilloscope, in AC mode, with band limiting turned on, can be used to evaluate if the supplies are producing excessive noise (> 100 mV p-p).

**Table 13-6: 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 | +4.85 | +5.25 |
| PS1 | +15 | AGND | 3 | +15 | 4 | +13.5 | +16.0 |
| PS1 | -15 | AGND | 3 | -15V | 5 | -13.5 | -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 |

## 13.6.3. $I^2C$ BUS

Operation of the $I^2C$ bus can be verified by observing the behavior of D1 on the relay PCA & D2 on the Valve Driver PCA. Assuming that the DC power supplies are operating properly, the $I^2C$ bus is operating properly if D1 on the relay PCA and D2 of the Valve Driver PCA are flashing

There is a problem with the $I^2C$ bus if both D1 on the relay PCA and D2 of the Valve Driver PCA are ON/OFF constantly.

## 13.6.4. LCD/DISPLAY MODULE

### *Touchscreen Interface*

Assuming that there are no wiring problems and that the DC power supplies are operating properly, the display screen should light and show the splash screen and other indications of its state as the CPU goes through its initialization process.

## 13.6.5. RELAY PCA

The Relay PCA can be most easily checked by observing the condition of the status LEDs on the Relay PCA (see Section 13.3.2), and using the **SIGNAL I/O** submenu under the **DIAG** menu (see Section 13.1.3) to toggle each LED **ON** or **OFF.**

If D1 on the Relay PCA is flashing and the status indicator for the output in question (Heater power, Valve Drive, etc.) toggles properly using the Signal I/O function, then the associated device (valve, heater, etc.) may be bad.

## 13.6.6. MOTHERBOARD

### 13.6.6.1. TEST CHANNEL / ANALOG OUTPUTS VOLTAGE

The **ANALOG OUTPUT** submenu, located under the **SETUP → MORE → DIAG** menu is used to verify that the T500U analyzer's three analog outputs are working properly. The test generates a signal on all three outputs simultaneously as shown in the following table:

**Table 13-7: Analog Output Test Function - Nominal Values Voltage Outputs**

| | | FULL SCALE OUTPUT OF VOLTAGE RANGE (see Section 6.8.3.1) | | | |
|---|---|---|---|---|---|
| | | **100MV** | **1V** | **5V** | **10V*** |
| **STEP** | **%** | **NOMINAL OUTPUT VOLTAGE** | | | |
| 1 | 0 | 0 | 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 |

*** For 10V output, increase the Analog Output Calibration Limits (AOUT CAL LIM in the DIAG>Analog I/O Config menu) to 4% (offset limit) and 20% (slope limit).**

For each of the steps the output should be within 1% of the nominal value listed except for the 0% step, which should be within 0mV ±2 to 3 mV. Ensure you take into account any offset that may have been programmed into channel (See Section 6.8.3.9).

If one or more of the steps fails to be within these ranges, it is likely that there has been a failure of the either or both of the Digital-to-Analog Converters (DACs) and their associated circuitry on the motherboard. To perform the test connect a voltmeter to the output in question and perform an analog output step test as follows:

### 13.6.6.2. A/D FUNCTIONS

The simplest method to check the operation of the A-to-D converter on the motherboard is to use the Signal I/O function under the **DIAG** menu to check the two A/D reference voltages and input signals that can be easily measured with a voltmeter.

Use the Signal I/O function (see Section 13.1.3 and Appendix A) to view the value of **REF_4096_MV** and **REF_GND**.

- If both are within 3 mV of nominal (4096 and 0), and are stable, ±0.2 mV, then the basic A/D is functioning properly. If not, then the motherboard is bad.

Choose a parameter in the Signal I/O function list (see Section 13.1.3) such as **EXT_ZERO_CAL**

- Compare this voltage at its origin (see the interconnect drawing and interconnect list in Appendix D) with the voltage displayed through the signal I/O function.
- If the wiring is intact but there is a large difference between the measured and displayed voltage (±10 mV) then the motherboard is bad.

### 13.6.6.3. STATUS OUTPUTS

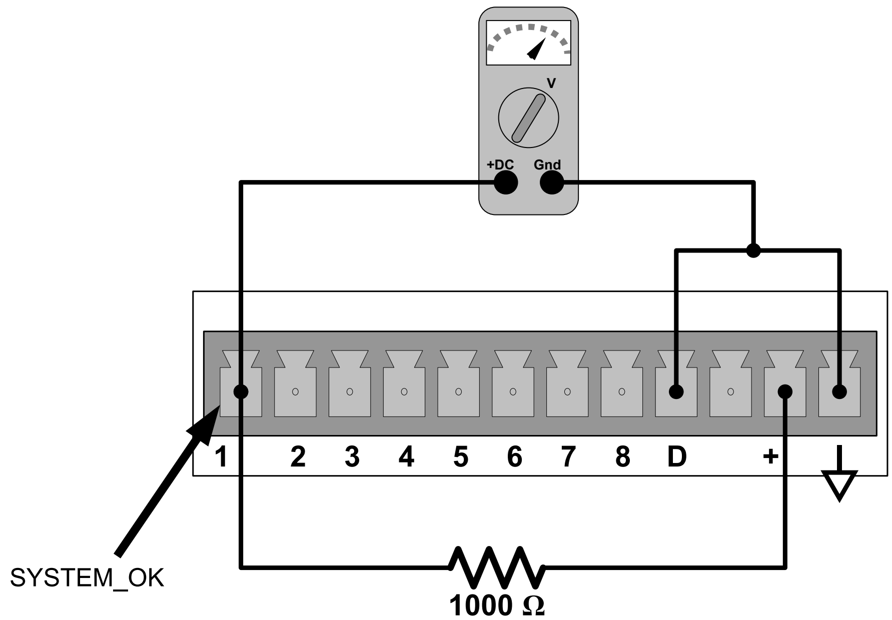



**Figure 13-6: Typical Set Up of Status Output Test**

To test the status output electronics:

1. Connect a jumper between the “D" pin and the “▽” pin on the status output connector.
2. Connect a 1000 ohm resistor between the “+” pin and the pin for the status output that is being tested.
3. Connect a voltmeter between the “▽” pin and the pin of the output being tested.
4. Under the DIAG→ Signal I/O menu (see Section 13.1.3), scroll through the inputs and outputs until you get to the output in question.
5. 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.

**Table 13-8: Status Outputs Check**

| PIN (LEFT TO RIGHT) | STATUS |
|---|---|
| 1 | **ST_SYSTEM_OK** |
| 2 | **ST_CONC_VALID** |
| 3 | **ST_HIGH_RANGE** |
| 4 | **ST_ZERO_CAL** |
| 5 | **ST_SPAN_CAL** |
| 6 | **ST_DIAG_MODE** |
| 7 | *Not Used on T500U* |
| 8 | **ST_O2_CAL** |

### 13.6.6.4. CONTROL INPUTS

The control input bits can be tested by applying a trigger voltage to an input and watching changes in the status of the associated function under the **SIGNAL I/O** submenu:

EXAMPLE: to test the "**A**" control input:

Under the **DIAG→** Signal I/O menu (see Section 13.1.3), scroll through the inputs and outputs until you get to the output named **EXT_ZERO_CAL**.

Connect a jumper from the "+" pin on the appropriate connector to the "U" on the same connector.

Connect a second jumper from the "▽" pin on the connector to the "A" pin.

The status of EXT_ZERO_CAL should change to read "ON".

Connect a second jumper from the "▽" pin on the connector to the "B" pin.

The status of EXT_ZERO_CAL should change to read "ON".

**Table 13-9: T500U Control Input Pin Assignments and Corresponding Signal I/O Functions**

| INPUT | CORRESPONDING I/O SIGNAL |
|---|---|
| **A** | **EXT_ZERO_CAL** |
| **B** | **EXT_SPAN_CAL1** |
| **C, D, E& F** | **NOT USED** |

## 13.6.7. CPU

There are two major types of CPU board failures, a complete failure and a failure associated with the Disk On Module (DOM). If either of these failures occurs, 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 watchdog LED on the motherboard is not flashing.

- 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 invalid.
- If the analyzer stops during initialization (the front panel display shows a fault or warning message), it is likely that the DOM, the firmware or the configuration and data files have been corrupted.

## 13.6.8. RS-232 COMMUNICATIONS

### 13.6.8.1. GENERAL RS-232 TROUBLESHOOTING

Teledyne API's analyzers use the RS-232 communications protocol to allow the instrument to be connected to a variety of computer-based equipment. RS-232 has been used for many years and as equipment has become more advanced, connections between various types of hardware have become increasingly difficult. Generally, every manufacturer observes the signal and timing requirements of the protocol very carefully.

Problems with RS-232 connections usually center around 4 general areas:

- Incorrect cabling and connectors. See Section 3.3.1.8, *RS-232 Connection*, and Figure 3-11 for connector and pin-out information.
- The BAUD rate and protocol are incorrectly configured. See Sections 3.3.1.8 and 7.2.2.
- If a modem is being used, additional configuration and wiring rules must be observed. See Section 9.3
- Incorrect setting of the DTE – DCE Switch. See Section 7.1 to set correctly.
- Verify that cable (P/N 03596) that connects the serial COM ports of the CPU to J12 of the motherboard is properly seated.

#### 13.6.8.2. TROUBLESHOOTING ANALYZER/MODEM OR TERMINAL OPERATION

These are the general steps for troubleshooting problems with a modem connected to a Teledyne API's analyzer.

1. Check cables for proper connection to the modem, terminal or computer.
2. Check to ensure that the DTE-DCE is in the correct position as described in Section 7.1.
3. Check to ensure that the set up command is correct (see Section 9.3).
4. Verify that the Ready to Send (RTS) signal is at logic high. The T500U sets pin 7 (RTS) to greater than 3 volts to enable modem transmission.
5. Ensure that the BAUD rate, word length, and stop bit settings between modem and analyzer match. See Section 7.2.2.
6. Use the RS-232 test function to send “w” characters to the modem, terminal or computer. See Section 7.2.3.
7. Get your terminal, modem or computer to transmit data to the analyzer (holding down the space bar is one way); the green LED should flicker as the instrument is receiving data.
8. Ensure that the communications software or terminal emulation software is functioning properly.

**Note** **Further help with serial communications is available in a separate manual “RS-232 Programming Notes” Teledyne API's P/N 01350.**

### 13.6.9. INTERNAL SPAN GAS GENERATOR AND VALVE OPTIONS

The zero/span valves and internal span gas generator options need to be enabled in the software (contact the factory on how to do this).

- 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 permeation tube of the internal span gas generator option is heated with a proportional heater circuit and the temperature is maintained at 50°C ±1°C. Check the front panel display or the **IZS_TEMP** signal voltage using the **SIGNAL I/O** function under the **DIAG** Menu (Section 6.8.1). At 50° C, the temperature signal from the IZS thermistor should be around 2500 mV.

## 13.6.10. TEMPERATURE SENSOR

### 13.6.10.1. BOX TEMPERATURE SENSOR

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.
- To check the box temperature functionality, we recommend checking the **BOX_TEMP** signal voltage using the **SIGNAL I/O** function under the **DIAG** Menu (Section 13.1.3).
- At about 30° C, the signal should be around 1500 mV.
- To check the accuracy of the sensor, use a calibrated external thermometer / temperature sensor to verify the accuracy of the box temperature as follows:
    - Place it inside the chassis, next to the thermistor labeled **XT1** (above connector J108) on the motherboard.
    - Compare its reading to the value of the test function **BOX TEMP.**

# 13.7. SERVICE PROCEDURES

This section contains some procedures that may need to be performed when a major component of the analyzer requires repair or replacement.

**Note**

**Maintenance procedures (e.g., replacement of regularly changed expendables) are discussed in Section11 and are not listed here).**

**Also, there may be more detailed service notes for some of the below procedures. Contact Teledyne API's Technical Support Department.**

**WARNING – ELECTRICAL SHOCK HAZARD**

**Unless the procedure being performed requires the instrument be operating, turn it off and disconnect power before opening the analyzer and removing, adjusting or repairing any of its components or subsystems.**

**CAUTION – QUALIFIED TECHNICIAN**

**The operations outlined in this chapter are to be performed by qualified maintenance personnel only.**

## 13.7.1. DISK-ON-MODULE REPLACEMENT PROCEDURE

**Note** **Servicing of circuit components requires electrostatic discharge (ESD) protection, i.e. ESD grounding straps, mats and containers. Failure to use ESD protection when working with electronic assemblies will void the instrument warranty. Please learn more about preventing ESD damage in our manual, *Fundamentals of ESD*, PN 04786, available on our website at http://www.teledyne-api.com in Help Center>Product Manuals, under Special Manuals.**

Replacing the Disk-on-Module (DOM) will cause loss of all DAS data; it may also cause loss of some instrument configuration parameters unless the replacement DOM carries the exact same firmware version. Whenever changing the version of installed software, the memory must be reset. Failure to ensure that memory is reset can cause the analyzer to malfunction, and invalidate measurements. After the memory is reset, the A/D converter must be re-calibrated, and all information collected in Step 1 below must be re-entered before the instrument will function correctly. Also, zero and span calibration should be performed.

1. Document all analyzer parameters that may have been changed, such as range, auto-cal, analog output, serial port and other settings before replacing the DOM.
2. Turn off power to the instrument, fold down the rear panel by loosening the mounting screws.
3. While looking at the electronic circuits from the back of the analyzer, locate the Disk-on-Module in the right-most socket of the CPU board.
4. The DOM should carry a label with firmware revision, date and initials of the programmer.
5. Remove the nylon standoff clip that mounts the DOM over the CPU board, and lift the DOM off the CPU. Do not bend the connector pins.
6. Install the new Disk-on-Module, making sure the notch at the end of the chip matches the notch in the socket.
7. It may be necessary to straighten the pins somewhat to fit them into the socket. Press the chip all the way in.
8. Close the rear panel and turn on power to the machine.

If the replacement DOM carries a firmware revision, re-enter all of the setup information.

## 13.7.2. REMOVING / REPLACING THE RELAY PCA FROM THE INSTRUMENT

This is the most commonly used version of the Relay PCA. It includes a bank of solid state AC relays. This version is installed in analyzers where components such as AC powered heaters must be turned ON & OFF.

A retainer plate is installed over the relay to keep them securely seated in their sockets.

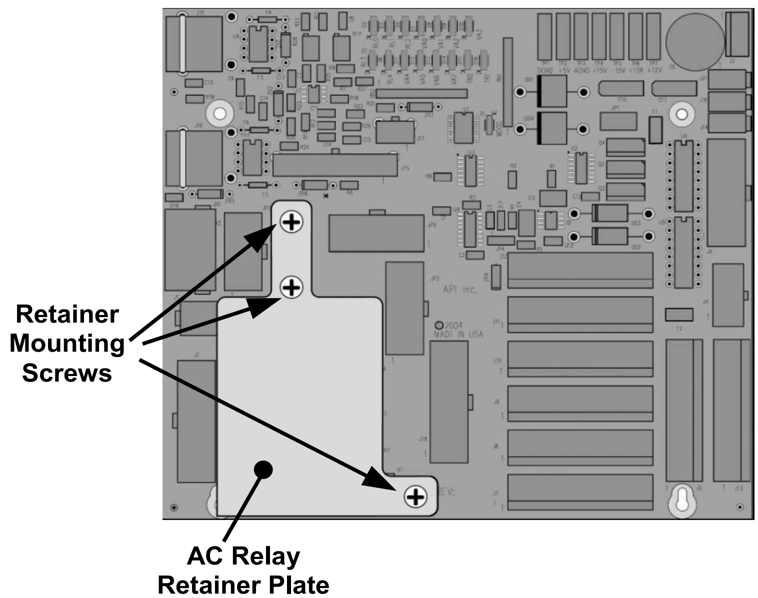



**Figure 13-7: Relay PCA with AC Relay Retainer In Place**

The Relay retainer plate installed on the relay PCA covers the lower right mounting screw of the relay PCA. Therefore, when removing the relay PCA, the retainer plate must be removed first.

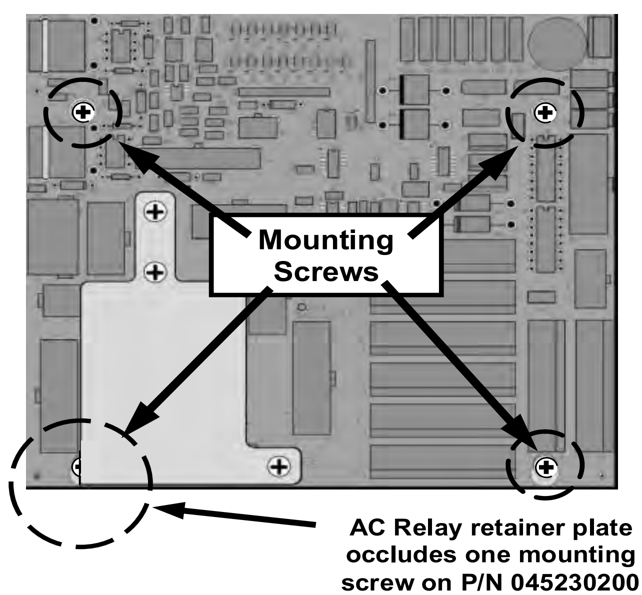



**Figure 13-8: Relay PCA Mounting Screw Locations**

# 13.8. FREQUENTLY ASKED QUESTIONS

The following list was compiled from the Teledyne API's Technical Support Department’s most commonly asked questions relating to the T500U Analyzer.

| QUESTION | ANSWER |
|---|---|
| Why does the **ENTR** button sometimes disappear on the front panel display? | Sometimes the **ENTR** button 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 1 or more than 20000 ppb. Once you adjust the setting to an allowable value, the **ENTR** button will re-appear. |
| Why is the **ZERO** or **SPAN** button not displayed during calibration? | The T500U disables certain these buttons expected span or zero value entered by the users is too different from the gas concentration actually measured value at the time. This is to prevent the accidental recalibration of the analyzer to an out-of-range response curve.<br><br>EXAMPLE: The span set point is 400 ppb but gas concentration being measured is only 50 ppb. |
| How do I enter or change the value of my Span Gas? | Press the **CONC** button found under the **CAL** or **CALS** buttons of the main SAMPLE display menus to enter the expected $NO_2$ span concentration.<br><br>See Section 10.3.3.1 or for more information. |
| Can I automate the calibration of my analyzer? | Any analyzer with zero/span valve can be automatically calibrated using the instrument’s AutoCal feature. |
| How do I measure the sample flow? | 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 900 $cm^3$/min $\pm$10%.<br><br>Section 13.3.12.3 includes detailed instructions on performing a check of the sample gas flow. |
| Can I use the DAS system in place of a strip chart recorder or data logger? | Yes. Section 8 describes the setup and operation of the DAS system in detail. |
| How often do I need to change the particulate filter? | Once per week or as needed. Section 11.1 contains a maintenance schedule listing the most important, regular maintenance tasks. Highly polluted sample air may require more frequent changes. |

| QUESTION | ANSWER |
|---|---|
| How long does the sample pump last? | The sample pump should last one to two years and should be replaced when necessary. Use the **RCEL** pressure indicator on the front panel to see if the pump needs replacement.<br><br>If this value goes above 10 in-Hg-A, on average, the pump needs to be replaced. |
| Why does my RS-232 serial connection not work? | There are several possible reasons:<br>• The wrong cable: please use the provided or a generic “straight-through” cable (do not use a “null-modem” type cable) and ensure the pin assignments are correct (Sections 3.3.1.8 and 7.3).<br><br>• The DCE/DTE switch on the back of the analyzer is not set properly; ensure that both green and red lights are on (Section 7.1).<br><br>• The baud rate of the analyzer’s COM port does not match that of the serial port of your computer/data logger (Section 7.2.2). |
| How do I make the instrument’s display and my data logger agree? | This most commonly occurs when an independent metering device is used besides the data logger/recorder to determine gas concentration levels while calibrating the analyzer. These disagreements result from the analyzer, the metering device and the data logger having slightly different ground levels.<br><br>Use the data logger itself as the metering device during calibration procedures. |
| How do I set up and use the Contact Closures (Control Inputs) on the Rear Panel of the analyzer? | See Section 3.3.1.6. |

# 13.9. TECHNICAL ASSISTANCE

If this manual and its troubleshooting & service section do not solve your problems, technical assistance may be obtained from:

**Teledyne API, Technical Support,**
**9480 Carroll Park Drive**
**San Diego, California 92121-5201USA**

| | |
|---|---|
| **Toll-free Phone:** | 800-324-5190 |
| **Phone:** | 858-657-9800 |
| **Fax:** | 858-657-9816 |
| **Email:** | sda_techsupport@teledyne.com |
| **Website:** | http://www.teledyne-api.com/ |


Before you contact Teledyne API's Technical Support, fill out the problem report form in Appendix C, which is also available online for electronic submission at http://www.teledyne-api.com/manuals/.

# 14. PRINCIPLES OF OPERATION

The Cavity Attenuated Phase Shift (CAPS) $NO_2$ monitor operates as an optical absorption spectrometer that yields both reliable and accurate measurements of ambient nitrogen dioxide down to sub ppb concentrations, with lower noise levels than chemiluminescence-based monitors. The CAPS method uses light from a blue Ultraviolet (UV) light emitting diode (LED) centered at 450 nm, a measurement cell with high reflectivity mirrors located at either end to provide an extensive optical path length, and a vacuum photodiode detector. These components are assembled into the optical cell which resides in a temperature-controlled oven. The oven raises the ambient temperature of the sample gas to 45 degrees Celsius. This mitigates the formation of moisture on the surfaces of the mirrors while also minimizing changes in the absorption coefficient due to temperature fluctuations.

As stated, the T500U analyzer measures $NO_2$ directly, using optical absorption. This phenomenon is well-defined and is described by Beer's Law, where the Absorbance (lost light) is directly proportional to both the path-length and concentration of the absorbing gas.

$$A = \varepsilon \, l \, c$$

*(A = Absorbance, ε = Molar absorptivity, l = Mean path Length, c = concentration)*

The CAPS method employed in the T500U is unique in that it applies this fundamental optical absorption law in the frequency domain, rather than using relative changes in light intensity as the primary signal. Ultraviolet light (UV) from the modulating high intensity LED enters a near confocal optical cell (Figure 14-1) through the rear of mirror A. The intensity of the light, as observed by the detector, which is also modulating at a slightly different frequency, located behind Mirror B, builds exponentially in the cell while the LED is ON. The opposite is true when the LED is OFF. Because both mirrors are highly reflective at 450 nm, a prominent absorption band for $NO_2$, the light takes a considerable amount of time to plateau in the absence of the absorbing gas. However, when $NO_2$ is present, the mean path length traveled by the light is significantly reduced. This has two effects on the observed intensity as measured by the detector:

- The light plateau intensity level is lower, more importantly for the T500U
- The light intensity plateaus sooner.

Thus, an observed phase shift from the modulating LED is detected (Figure 14-2). The phase shift is largest when measuring zero air and decreases when $NO_2$ is present.

Both the LED and the Detector are modulated ON and OFF such that the observed signal has a much lower frequency, equal to the difference between the modulated frequencies and is referred to as a beat frequency. The system hardware and software take advantage of this, as it makes it easier to post process the signal using a micro controller. The technique is known as heterodyning.

The instrument translates the phase shift from the presence of absorbing gas into a concentration measurement. Typical absorption techniques of other analyzers take a reference and measure value of the light intensity "level" in order to derive concentration and compensate for source drift. Using the CAPS technique the amount of phase shift remains constant for a given concentration, even if the LED drifts over time. The measurement approach offers many advantages over traditional (or "Chemi") analyzers, such as faster response (single gas stream), lower noise at span and more importantly greater specificity.

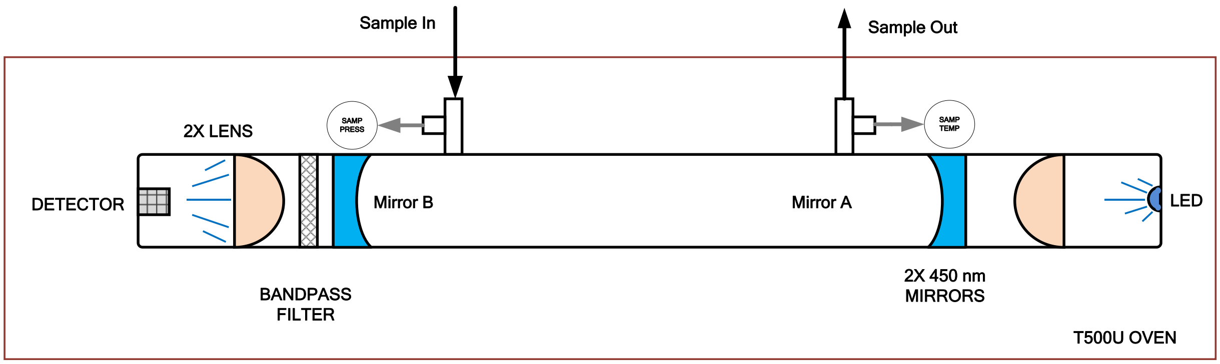



**Figure 14-1: T500U Optical Absorption Cell**

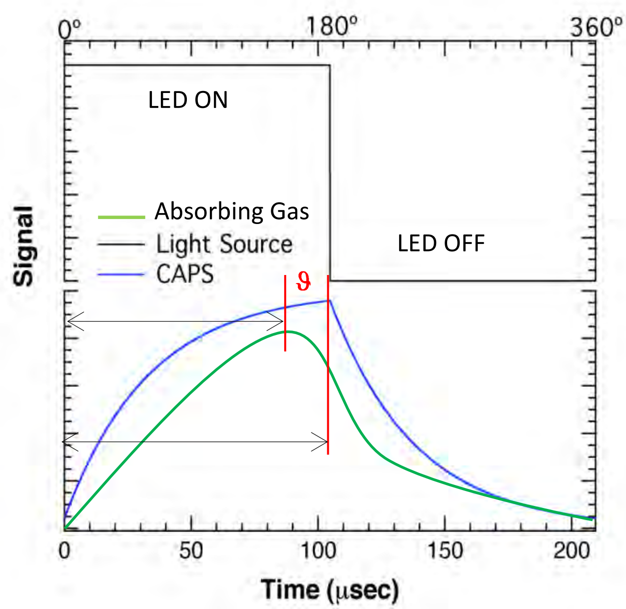



**Figure 14-2: Phase Shift Representation of Increased Concentration of $NO_2$**

(Black = LED State, Blue = Light build up in the absence of $NO_2$, Green = phase shifted\attenuated light)

# GLOSSARY

Note that not all terms defined in this glossary are included in this manual.

| Term | Description/Definition |
|---|---|
| 10BaseT | an Ethernet standard that uses twisted (“T”) pairs of copper wires to transmit at 10 megabits per second (Mbps) |
| 100BaseT | same as 10BaseT except ten times faster (100 Mbps) |
| APICOM | name of a remote control program offered by Teledyne-API to its customers |
| ASSY | *Assembly* |
| CAS | *Code-Activated Switch* |
| CD | *Corona Discharge*, a frequently luminous discharge, at the surface of a conductor or between two conductors of the same transmission line, accompanied by ionization of the surrounding atmosphere and often by a power loss |
| CE | *Converter Efficiency*, the percentage of the total amount that is actually converted (e.g., light energy into electricity; $NO_2$ into NO, etc.) |
| CEM | *Continuous Emission Monitoring* |
| Chemical formulas that may be included in this document: | |
| $CO_2$ | carbon dioxide |
| $C_3H_8$ | propane |
| $CH_4$ | methane |
| $H_2O$ | water vapor |
| HC | general abbreviation for hydrocarbon |
| $HNO_3$ | nitric acid |
| $H_2S$ | hydrogen sulfide |
| NO | nitric oxide |
| $NO_2$ | nitrogen dioxide |
| $NO_X$ | nitrogen oxides, here defined as the sum of NO and $NO_2$ |
| $NO_y$ | nitrogen oxides, often called odd nitrogen: the sum of $NO_X$ plus other compounds such as $HNO_3$ (definitions vary widely and may include nitrate ($NO_3$), PAN, $N_2O$ and other compounds as well) |
| $NH_3$ | ammonia |
| $O_2$ | molecular oxygen |
| $O_3$ | ozone |
| $SO_2$ | sulfur dioxide |
| $cm^3$ | metric abbreviation for *cubic centimeter* (replaces the obsolete abbreviation “cc”) |
| CPU | *Central Processing Unit* |
| DAC | *Digital-to-Analog Converter* |
| DAS | *Data Acquisition System* |
| DCE | *Data Communication Equipment* |
| DFU | *Dry Filter Unit* |

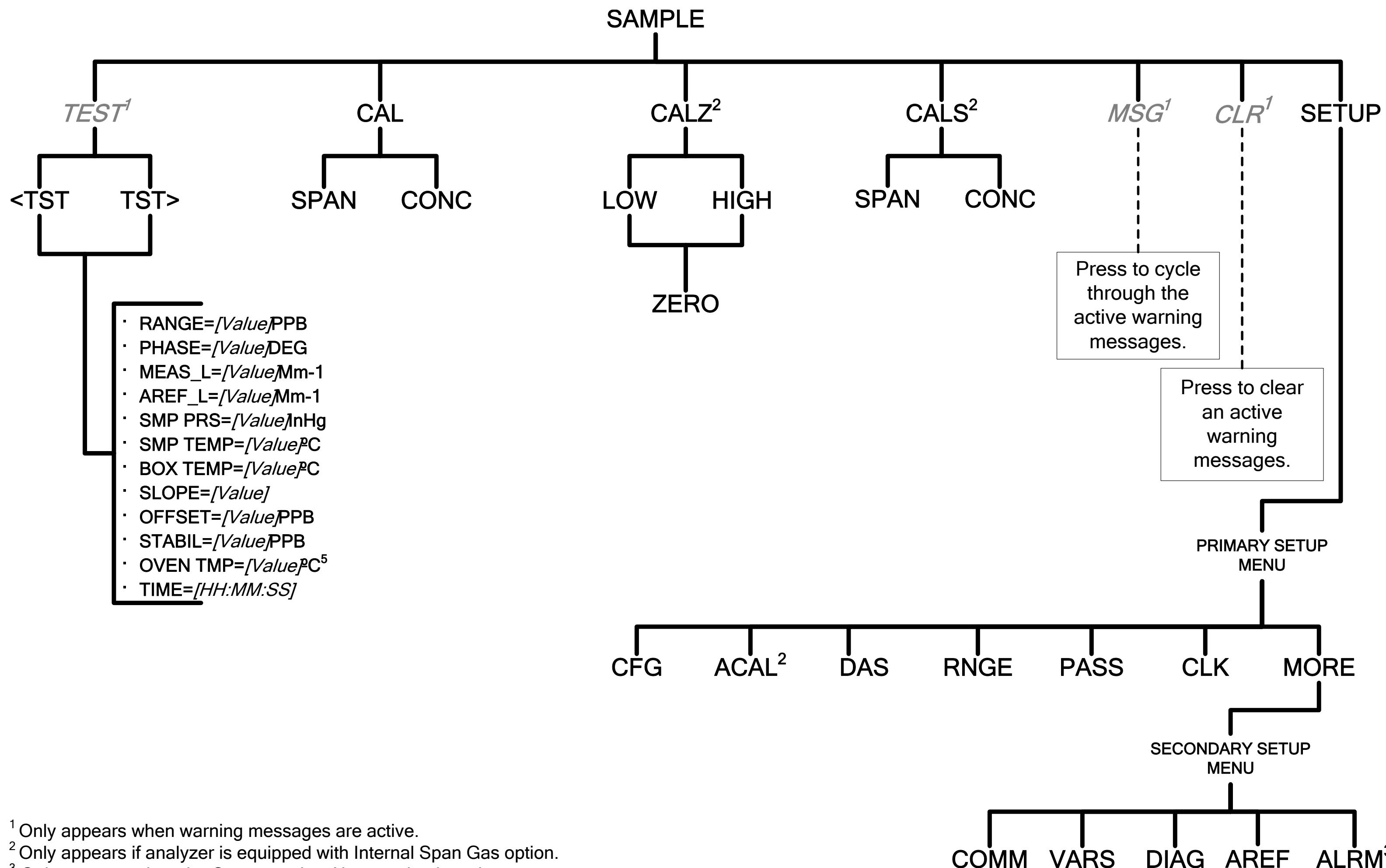
| Term | Description/Definition |
|---|---|
| DHCP | *Dynamic Host Configuration Protocol.* A protocol used by LAN or Internet servers to automatically set up the interface protocols between themselves and any other addressable device connected to the network |
| DIAG | *Diagnostics*, the diagnostic settings of the analyzer. |
| DOM | *Disk On Module,* a 44-pin IDE flash drive with up to 128MB storage capacity for instrument's firmware, configuration settings and data |
| DOS | *Disk Operating System* |
| DRAM | *Dynamic Random Access Memory* |
| DR-DOS | *Digital Research DOS* |
| DTE | *Data Terminal Equipment* |
| EEPROM | *Electrically Erasable Programmable Read-Only Memory* also referred to as a FLASH chip or drive |
| ESD | *Electro-Static Discharge* |
| ETEST | *Electrical Test* |
| Ethernet | a standardized (IEEE 802.3) computer networking technology for local area networks (LANs), facilitating communication and sharing resources |
| FEP | *Fluorinated Ethylene Propylene* polymer, one of the polymers that Du Pont markets as *Teflon®* |
| Flash | non-volatile, solid-state memory |
| FPI | *Fabry-Perot Interface*: a special light filter typically made of a transparent plate with two reflecting surfaces or two parallel, highly reflective mirrors |
| GFC | *Gas Filter Correlation* |
| $I^2C$ bus | a clocked, bi-directional, serial bus for communication between individual analyzer components |
| IC | *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 |
| IP | *Internet Protocol* |
| IZS | *Internal Zero Span* |
| LAN | *Local Area Network* |
| LCD | *Liquid Crystal Display* |
| LED | *Light Emitting Diode* |
| LPM | *Liters Per Minute* |
| MFC | *Mass Flow Controller* |
| Mm-1 | Units of measurement used to express light absorption, expressed in MEGA ($10^6$) per meter. |
| M/R | *Measure/Reference* |
| NDIR | *Non-Dispersive Infrared* |

| Term | Description/Definition |
|---|---|
| MOLAR MASS | the mass, expressed in grams, of 1 mole of a specific substance. Conversely, one mole is the amount of the substance needed for the molar mass to be the same number in grams as the atomic mass of that substance.<br>EXAMPLE: The atomic weight of Carbon is 12 therefore the molar mass of Carbon is 12 grams. Conversely, one mole of carbon equals the amount of carbon atoms that weighs 12 grams.<br>Atomic weights can be found on any Periodic Table of Elements. |
| NDIR | *Non-Dispersive Infrared* |
| NIST-SRM | *National Institute of Standards and Technology - Standard Reference Material* |
| PC | *Personal Computer* |
| PCA | P*rinted Circuit Assembly*, the PCB with electronic components, ready to use |
| PC/AT | *Personal Computer / Advanced Technology* |
| PCB | *Printed Circuit Board*, the bare board without electronic component |
| PFA | *Per-Fluoro-Alkoxy*, an inert polymer; one of the polymers that *Du Pont* markets as *Teflon*® |
| PLC | *Programmable Logic Controller*, a device that is used to control instruments based on a logic level signal coming from the analyzer |
| PLD | *Programmable Logic Device* |
| PLL | *Phase Lock Loop* |
| PMT | *Photo Multiplier Tube*, a vacuum tube of electrodes that multiply electrons collected and charged to create a detectable current signal |
| P/N (or PN) | *Part Number* |
| PPB | *Parts per billion* |
| PPM | *Parts per million* |
| PPT | *Parts per trillion* |
| PSD | *Prevention of Significant Deterioration* |
| PTFE | *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*® |
| PVC | *Poly Vinyl Chloride*, a polymer used for downstream tubing |
| Rdg | Reading |
| RS-232 | specification and standard describing a serial communication method between DTE (Data Terminal Equipment) and DCE (Data Circuit-terminating Equipment) devices, using a maximum cable-length of 50 feet |
| RS-485 | specification and standard describing a binary serial communication method among multiple devices at a data rate faster than RS-232 with a much longer distance between the host and the furthest device |
| SAROAD | *Storage and Retrieval of Aerometric Data* |
| SLAMS | *State and Local Air Monitoring Network Plan* |
| SLPM | *Standard Liters Per Minute* of a gas at standard temperature and pressure |
| STP | *Standard Temperature and Pressure* |

| Term | Description/Definition |
|---|---|
| TCP/IP | *Transfer Control Protocol / Internet Protocol*, the standard communications protocol for Ethernet devices |
| TEC | *Thermal Electric Cooler* |
| TPC | *Temperature/Pressure Compensation* |
| USB | *Universal Serial Bus*: a standard connection method to establish communication between peripheral devices and a host controller, such as a mouse and/or keyboard and a personal computer or laptop |
| VARS | *Variables*, the variable settings of the instrument |
| V-F | *Voltage-to-Frequency* |
| Z/S | *Zero / Span* |

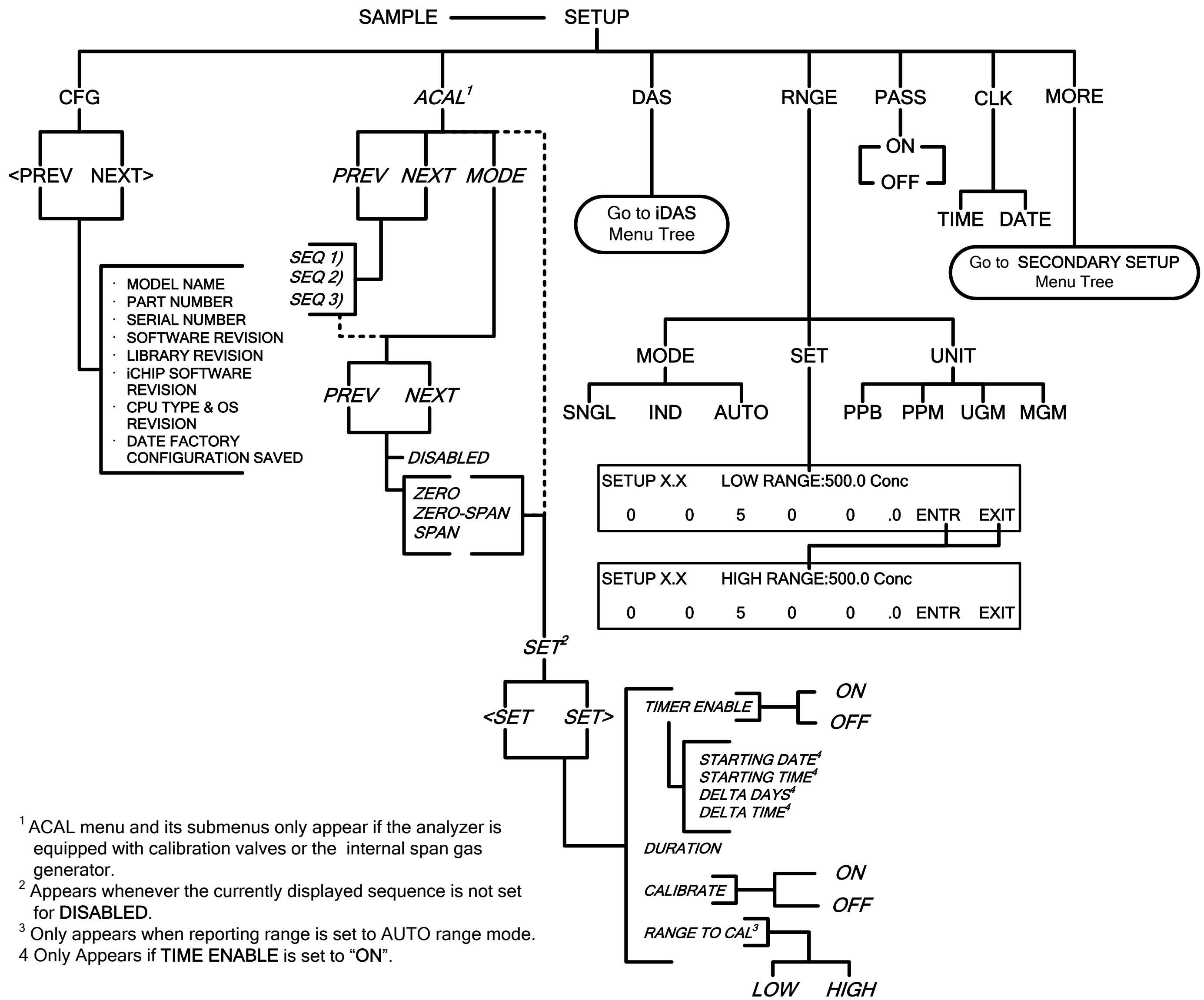
# APPENDIX A: Software Documentation, Library Revision 7.0.3

# APPENDIX A-1: Software Menu Trees and Index



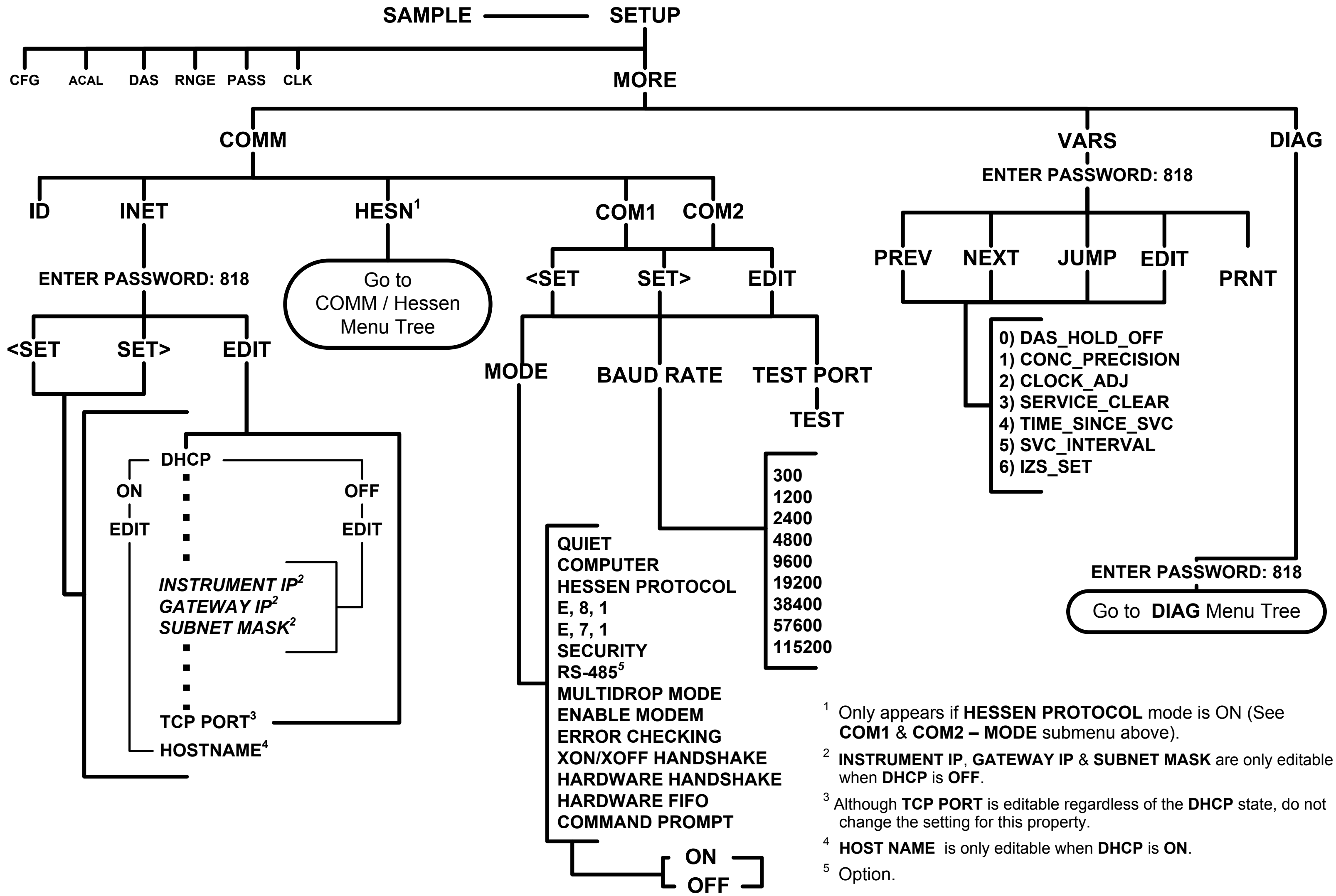

[1] Only appears when warning messages are active.
[2] Only appears if analyzer is equipped with Internal Span Gas option.
[3] Only appears when the Concentration Alarm option is active.

**Figure A-1: Basic Sample Display Menu**




[1] ACAL menu and its submenus only appear if the analyzer is equipped with calibration valves or the internal span gas generator.
[2] Appears whenever the currently displayed sequence is not set for **DISABLED**.
[3] Only appears when reporting range is set to AUTO range mode.
4 Only Appears if **TIME ENABLE** is set to "**ON**".

**Figure A-2: Primary Setup Menu (Except DAS)**




[1] Only appears if **HESSEN PROTOCOL** mode is ON (See **COM1** & **COM2 – MODE** submenu above).

[2] **INSTRUMENT IP**, **GATEWAY IP** & **SUBNET MASK** are only editable when **DHCP** is **OFF**.

[3] Although **TCP PORT** is editable regardless of the **DHCP** state, do not change the setting for this property.

[4] **HOST NAME** is only editable when **DHCP** is **ON**.

[5] Option.

**Figure A-3: Secondary Setup Menu (COMM & VARS)**

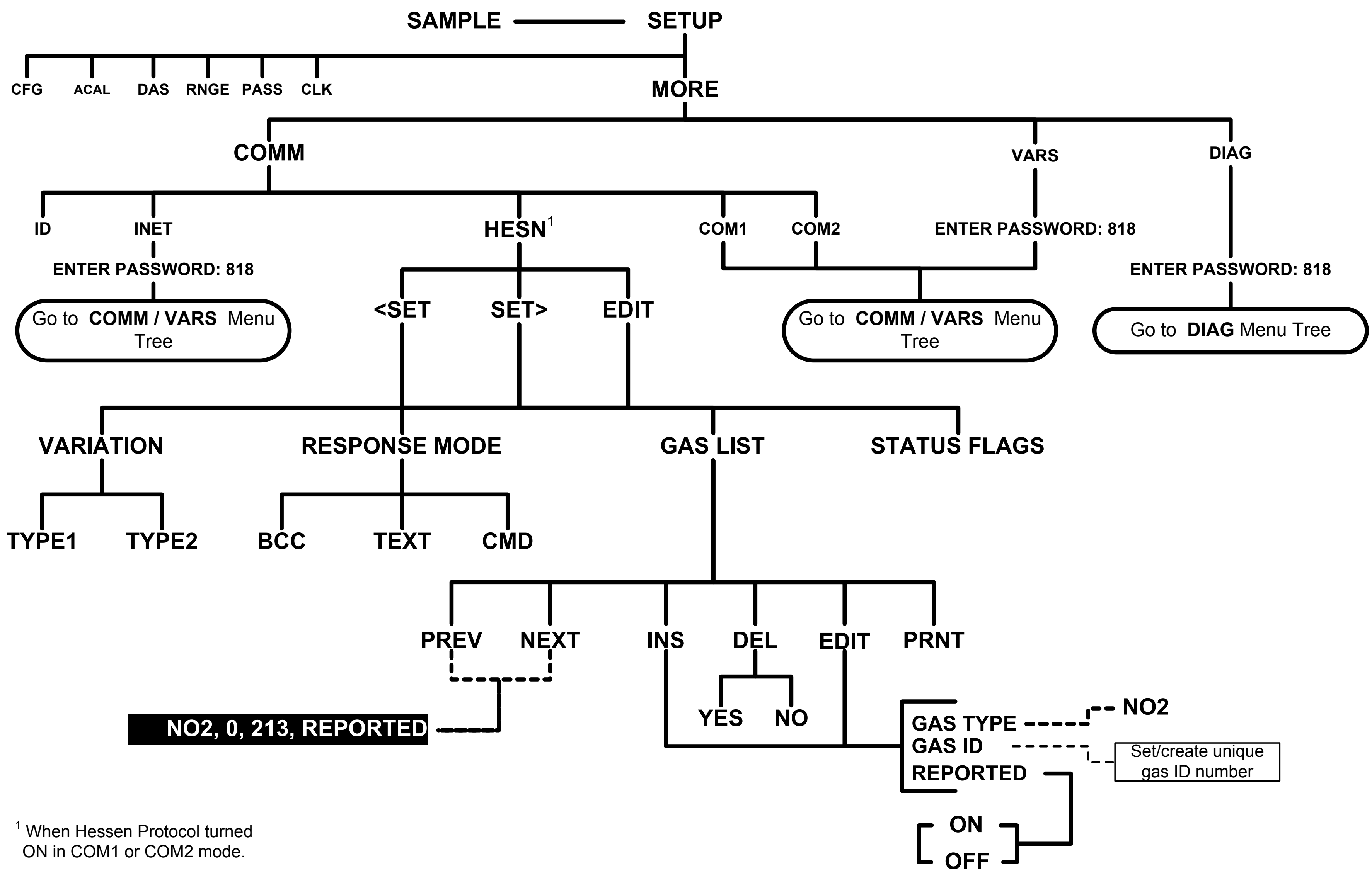
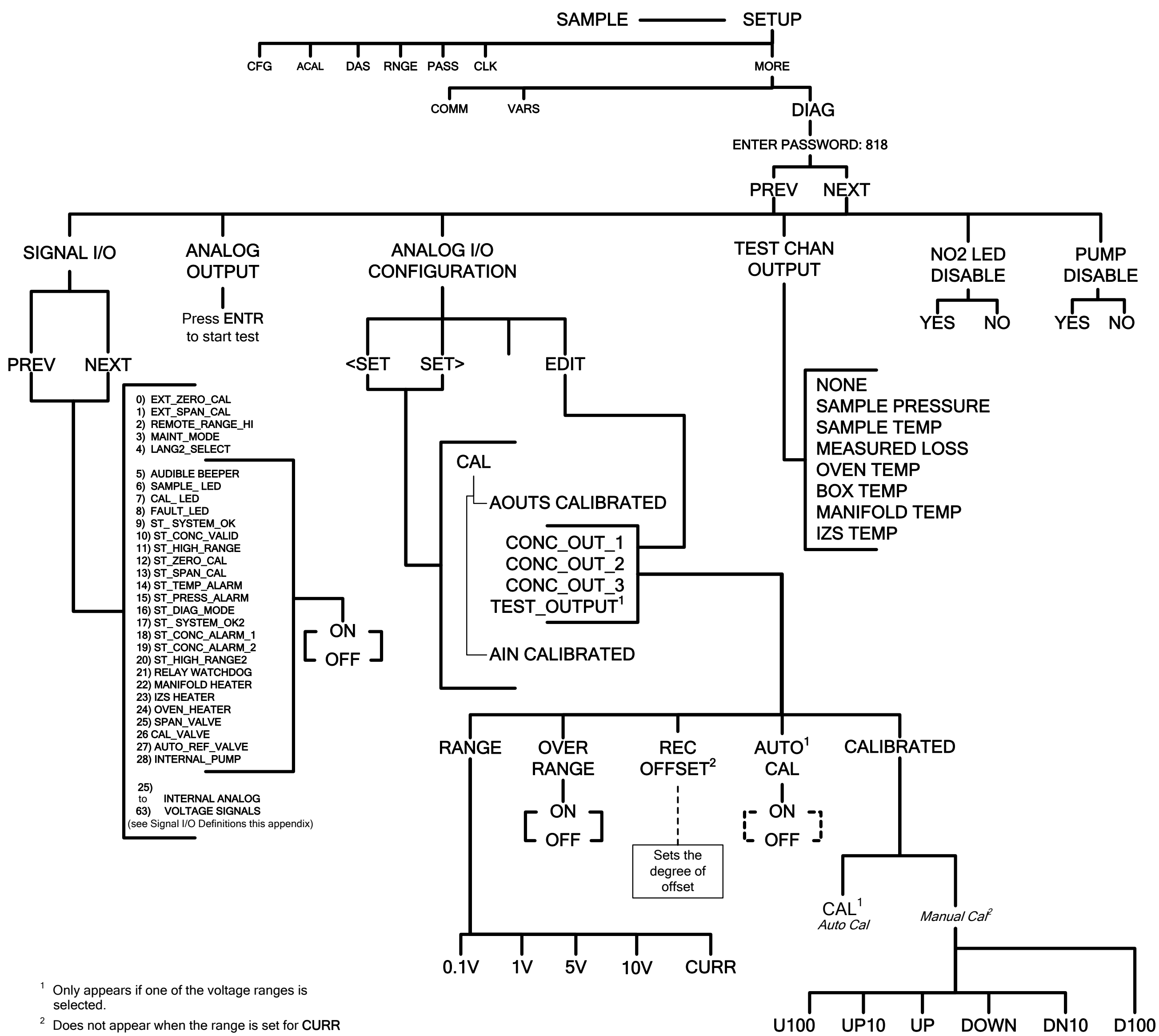



**Figure A-4: Secondary Setup Menu (HESSEN)**




[1] Only appears if one of the voltage ranges is selected.

[2] Does not appear when the range is set for CURR

**Figure A-5: Secondary Setup Menu (DIAG)**

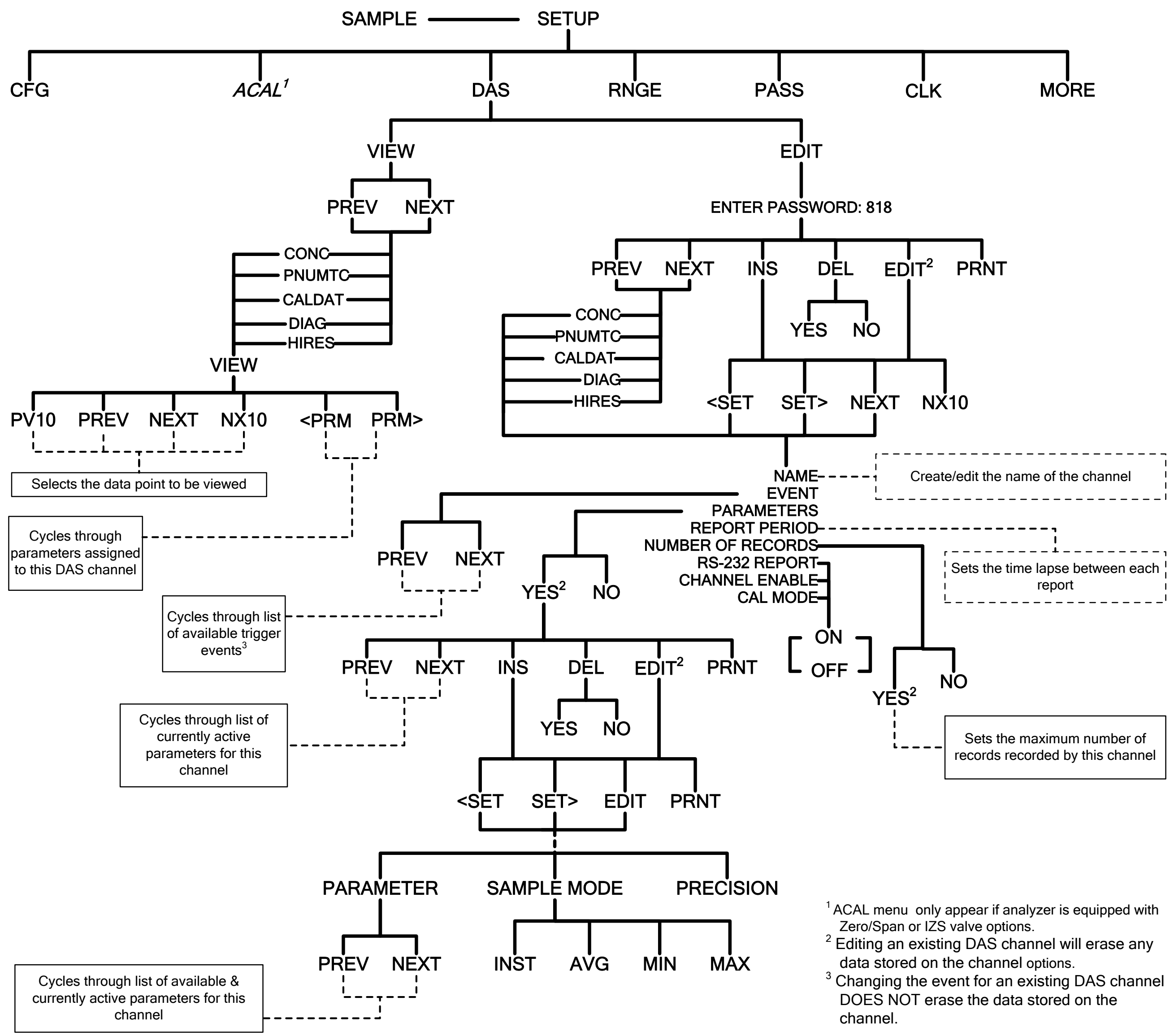



**Figure A-6: Internal Data Acquisition (DAS) Menu**

# APPENDIX A-2: Setup Variables for Serial I/O

## Table A- 1: T500U Setup Variables

| Setup Variable | Numeric Units | Default Value | Value Range | Description |
|---|---|---|---|---|
| DAS_HOLD_OFF | Minutes | 15 | 0.5–20 | Duration of DAS hold-off period. |
| CONC_PRECISION | — | 3 | AUTO,<br>0,<br>1,<br>2,<br>3,<br>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. |
| SERVICE_CLEAR | — | OFF | OFF<br>ON | ON resets the service interval timer. |
| TIME_SINCE_SVC | Hours | 0 | 0–500000 | Time since last service. |
| SVC_INTERVAL | Hours | 0 | 0–100000 | Sets the interval between service reminders. |
| IZS_SET | ºC | 51<br>Warnings:<br>50-52 | 30-70 | IZS temperature set point and warning limits. |

## APPENDIX A-3: Warnings and Test Measurements

### Table A- 2: Warning Messages

| Name | Message Text | Description | Real-Time |
|---|---|---|---|
| WSYSSERVICE | SYSTEM SERVICE | System service interval has elapsed. | Yes |
| WSYSRES | SYSTEM RESET | Instrument was power-cycled or the CPU was reset. | Yes [1] |
| WDATAINIT | DATA INITIALIZED | Data storage was erased. | No |
| WCONFIGINIT | CONFIG INITIALIZED | Configuration storage was reset to factory configuration or erased. | No |
| WNO2ALARM1 [4] | NO2 ALARM1 WARN | $NO_2$ concentration alarm limit #1 exceeded | Yes |
| WNO2ALARM2 [4] | NO2 ALARM2 WARN | $NO_2$ concentration alarm limit #2 exceeded | Yes |
| WMANIFOLD | MANIFOLD TEMP WARN | Manifold temperature outside of warning limits specified by *MANIFOLD_SET* variable. | Yes |
| WIZSTEMP | IZS TEMP WARNING | IZS temperature outside of warning limits specified by *IZS_SET* variable. | Yes |
| WOVENTEMP | OVEN TEMP WARNING | Oven temperature outside of warning limits specified by *OVEN_TEMP_SET* variable. | Yes |
| WSAMPPRESS | SAMPLE PRESS WARN | Sample pressure outside of warning limits specified by *SAMP_PRESS_SET* variable. | Yes |
| WSAMPTEMP | SAMPLE TEMP WARN | Sample temperature outside of warning limits specified by *SAMP_TEMP_SET* variable. | Yes |
| WBOXTEMP | BOX TEMP WARNING | Chassis temperature outside of warning limits specified by *BOX_SET* variable. | Yes |
| WAUTOREF | AUTO REF WARNING | Auto-ref value outside of limit specified by *AREF_LIMIT* variable. | Yes [5] |
| WBASELINE | BASELINE LOSS WARN | Bench baseline loss value outside of limits. | Yes [6] |
| WDYNZERO | CANNOT DYN ZERO | Contact closure zero calibration failed while *DYN_ZERO* was set to *ON*. | Yes [2] |
| WDYNSPAN | CANNOT DYN SPAN | Contact closure span calibration failed while *DYN_SPAN* was set to *ON*. | Yes [3] |
| WREARBOARD | REAR BOARD NOT DET | Rear board was not detected during power up. | Yes |
| WRELAYBOARD | RELAY BOARD WARN | Firmware is unable to communicate with the relay board. | Yes |
| WLAMPDRIVER | LAMP DRIVER WARN | Firmware is unable to communicate with either the $O_3$ generator or photometer lamp $I^2C$ driver chip. | Yes |

| Name | Message Text | Description | Real-Time |
|---|---|---|---|
| WFRONTPANEL | FRONT PANEL WARN | Firmware is unable to communicate with the front panel. | Yes |
| WPUMP | INTERNAL PUMP OFF | Internal pump is not running. | Yes |
| WANALOGCAL | ANALOG CAL WARNING | The A/D or at least one D/A channel has not been calibrated. | Yes |

[1] Cleared 45 minutes after power up.
[2] Cleared the next time successful zero calibration is performed.
[3] Cleared the next time successful span calibration is performed.
[4] Concentration alarm option.
[5] Applies when AREF is enabled.
[6] Applies when AREF is disabled.

**Table A- 3: Test Measurements**

| Name [1] | Message Text | Description |
|---|---|---|
| RANGE | RANGE=500.0 PPB [3] | D/A range in single or auto-range modes. |
| RANGE1 | RANGE1=500.0 PPB [3] | D/A #1 range in dual range mode. |
| RANGE2 | RANGE2=500.0 PPB [3] | D/A #2 range in dual range mode. |
| PHASE | PHASE=15.32 DEG | Box phase value. |
| MEASLOSS | MEAS_L=300.1 $Mm^{-1}$ | Measurement loss value. |
| AUTOREF | AREF_L=400.3 $Mm^{-1}$ | Autoref value. |
| SAMPPRESS | SMP PRS=29.92 InHg | Sample pressure. |
| SAMPTEMP | SMP TEMP=31.2 C | Sample temperature. |
| BOXTEMP | BOX TEMP=31.3 C | Box internal temperature. |
| SLOPE | SLOPE=1.000 | Slope for current range, computed during zero/span calibration. |
| OFFSET | OFFSET=0.0 PPB [3] | Offset for current range, computed during zero/span calibration. |
| STABILITY | STABIL=0.0 PPB [3] | Concentration stability (standard deviation based on setting of *STABIL_FREQ* and *STABIL_SAMPLES*). |
| RESPONSE [2] | RSP=3.11(0.00) SEC | Instrument response. How frequently concentration is updated. Time in parenthesis is standard deviation. |
| MANIFOLDTEMP | MF TEMP= 50.1 C | Manifold temperature. |
| MANIFOLDDTY [2] | MF HTR=45.1% | Manifold heater duty cycle. |
| IZSTEMP | IZS TEMP= 50.1 C | IZS temperature. |
| IZSDTY [2] | IZS HTR=45.1% | IZS heater duty cycle. |
| OVENTEMP | OVEN TMP= 50.1 C | Oven temperature. |
| OVENDTY [2] | OVEN HTR=45.1% | Oven heater duty cycle. |
| SIGTHRUPUT | SIG=2414.7 MV | Bench signal throughput value. |

| **Name** [1] | **Message Text** | **Description** |
|---|---|---|
| SIN_1 | SIN 1=-15413 | Bench SIN_1/2 value. |
| COS_1 | COS 1=25173 | Bench COS_1/2 value. |
| SIN_2 | SIN 2=-15413 | Bench SIN_2/2 value. |
| COS_2 | COS 2=25173 | Bench COS_2/2 value. |
| SIN_OV | SIN OVP=2 | Bench SIN overlap value. |
| COS_OV | COS OVP=3 | Bench COS overlap value. |
| ACCUM_OV | ACCUM OV=0 | Bench accum overflow value. |
| TESTCHAN | TEST=2753.9 MV | Value output to *TEST_OUTPUT* analog output, selected with *TEST_CHAN_ID* variable. |
| XIN1 [4] | AIN1=37.15 EU | External analog input 1 value in engineering units. |
| XIN2 [4] | AIN2=37.15 EU | External analog input 2 value in engineering units. |
| XIN3 [4] | AIN3=37.15 EU | External analog input 3 value in engineering units. |
| XIN4 [4] | AIN4=37.15 EU | External analog input 4 value in engineering units. |
| XIN5 [4] | AIN5=37.15 EU | External analog input 5 value in engineering units. |
| XIN6 [4] | AIN6=37.15 EU | External analog input 6 value in engineering units. |
| XIN7 [4] | AIN7=37.15 EU | External analog input 7 value in engineering units. |
| XIN8 [4] | AIN8=37.15 EU | External analog input 8 value in engineering units. |
| CLOCKTIME | TIME=14:48:01 | Current instrument time of day clock. |

[1] The name is used to request a message via the RS-232 interface, as in “T BOXTEMP”.

[2] Engineering software.

[3] Current instrument units.

[4] External analog input option.

# APPENDIX A-4: Signal I/O Definitions

## Table A-4: Signal I/O Definitions

| 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** | | |
| | 0–5 | Spare |
| I2C_RESET | 6 | 1 = reset I2C peripherals<br>0 = normal |
| I2C_DRV_RST | 7 | 0 = hardware reset 8584 chip<br>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<br>1 = exit zero calibration |
| | 1 | Spare |
| EXT_SPAN_CAL [1] | 2 | 0 = go into span calibration<br>1 = exit span calibration |
| REMOTE_RANGE_HI [2] | 3 | 0 = remote select high range<br>1 = default range |
| | 4–5 | 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** | | |
| ST_SYSTEM_OK2,<br>MB_RELAY_36 [3] | 4 | 1 = system OK<br>0 = any alarm condition or in diagnostics mode |
| | | Controlled by MODBUS coil register |
| ST_CONC_ALARM_1 [4],<br>MB_RELAY_37 [3] | 5 | 1 = conc. limit 1 exceeded<br>0 = conc. OK |
| | | Controlled by MODBUS coil register |
| ST_CONC_ALARM_2 [4],<br>MB_RELAY_38 [3] | 6 | 1 = conc. limit 2 exceeded<br>0 = conc. OK |
| | | Controlled by MODBUS coil register |

| Signal Name | Bit or Channel Number | Description |
|---|---|---|
| ST_HIGH_RANGE2 [5], MB_RELAY_39 [3] | 7 | 1 = high auto-range in use (mirrors *ST_HIGH_RANGE* status output)<br>0 = low auto-range<br>Controlled by MODBUS coil register |
| **A status outputs, U24, J1017, pins 1–8 = bits 0–7, default I/O address 323 hex** | | |
| ST_SYSTEM_OK | 0 | 0 = system OK<br>1 = any alarm condition |
| ST_CONC_VALID | 1 | 0 = conc. valid<br>1 = hold off or other conditions |
| ST_HIGH_RANGE | 2 | 0 = high auto-range in use<br>1 = low auto-range |
| ST_ZERO_CAL | 3 | 0 = in zero calibration<br>1 = not in zero |
| ST_SPAN_CAL | 4 | 0 = in span calibration<br>1 = not in span |
| ST_TEMP_ALARM | 5 | 0 = any temperature alarm<br>1 = all temperatures OK |
| | 6 | Spare |
| ST_PRESS_ALARM | 7 | 0 = any pressure alarm<br>1 = all pressures OK |
| **A status outputs, alternate status outputs factory option** | | |
| ST_DIAG_MODE | 5 | 0 = in diagnostic mode<br>1 = not in diagnostic mode |
| **B status outputs, U27, J1018, pins 1–8 = bits 0–7, default I/O address 324 hex** | | |
| ST_DIAG_MODE | 0 | 0 = in diagnostic mode<br>1 = not in diagnostic mode |
| | 1–7 | Spare |
| **B status outputs, alternate status outputs factory option** | | |
| ST_TEMP_ALARM | 0 | 0 = any temperature alarm<br>1 = all temperatures OK |
| ST_PRESS_ALARM | 3 | 0 = any pressure alarm<br>1 = all pressures OK |
| **Front panel $I^2C$ keyboard, default $I^2C$ address 4E hex** | | |
| MAINT_MODE | 5 (input) | 0 = maintenance mode<br>1 = normal mode |
| LANG2_SELECT | 6 (input) | 0 = select second language<br>1 = select first language (English) |
| SAMPLE_LED | 8 (output) | 0 = sample LED on<br>1 = off |
| CAL_LED | 9 (output) | 0 = cal. LED on<br>1 = off |

| Signal Name | Bit or Channel Number | Description |
|---|---|---|
| FAULT_LED | 10 (output) | 0 = fault LED on<br>1 = off |
| AUDIBLE_BEEPER | 14 (output) | 0 = beeper on (for diagnostic testing only)<br>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 |
| | 1-2 | Spare |
| MANIFOLD_HEATER | 3 | 0 = Manifold heater on<br>1 = off |
| IZS_HEATER | 4 | 0 = IZS heater on<br>1 = off |
| OVEN_HEATER | 5 | 0 = Oven heater on<br>1 = off |
| SPAN_VALVE | 6 | 0 = let span gas in<br>1 = let zero gas in |
| CAL_VALVE | 7 | 0 = let cal. gas in<br>1 = let sample gas in |
| AUTO_ZERO_VALVE | 8 | 0 = let zero air in<br>1 = let sample gas in |
| | 9–14 | Spare |
| INTERNAL_PUMP | 15 | 0 = Internal pump on<br>1 = Internal pump off |
| **Rear board primary MUX analog inputs** | | |
| | 0-3 | Spare |
| | 4 | Temperature MUX |
| | 5-6 | Spare |
| TEST_INPUT_7 | 7 | Diagnostic test input |
| TEST_INPUT_8 | 8 | Diagnostic test input |
| REF_4096_MV | 9 | 4.096V reference from MAX6241 |
| | 10–13 | Spare |
| | 14 | DAC loopback MUX |
| REF_GND | 15 | Ground reference |
| **Rear board temperature MUX analog inputs** | | |
| BOX_TEMP | 0 | Internal box temperature |
| OVEN_TEMP | 1 | Oven temperature |
| IZS_TEMP | 2 | IZS temperature |
| | 3–5 | Spare |
| TEMP_INPUT_6 | 6 | Diagnostic temperature input |
| MANIFOLD_TEMP | 7 | Manifold temperature input |

| Signal Name | Bit or Channel Number | Description |
|---|---|---|
| **Rear board DAC MUX analog inputs** | | |
| DAC_CHAN_1 | 0 | DAC channel 0 loopback |
| DAC_CHAN_2 | 1 | DAC channel 1 loopback |
| DAC_CHAN_3 | 2 | DAC channel 2 loopback |
| DAC_CHAN_4 | 3 | DAC channel 3 loopback |
| **Rear board analog outputs** | | |
| CONC_OUT_1 | 0 | Concentration output #1 |
| DATA_OUT_1 [6] | | Data output #1 |
| CONC_OUT_2 | 1 | Concentration output #2 |
| DATA_OUT_2 [6] | | Data output #2 |
| DATA_OUT_3 [6] | 2 | Data output #3 |
| TEST_OUTPUT | 3 | Test measurement output |
| DATA_OUT_4 [6] | | Data output #4 |
| **External analog input board, default $I^2C$ address 5C hex** | | |
| XIN1 [7] | 0 | External analog input 1 |
| XIN2 [7] | 1 | External analog input 2 |
| XIN3 [7] | 2 | External analog input 3 |
| XIN4 [7] | 3 | External analog input 4 |
| XIN5 [7] | 4 | External analog input 5 |
| XIN6 [7] | 5 | External analog input 6 |
| XIN7 [7] | 6 | External analog input 7 |
| XIN8 [7] | 7 | External analog input 8 |
| **$I^2C$ analog output (AD5321), default $I^2C$ address 18 hex** | | |
| | 0 | Spare |
| **$I^2C$ analog output (AD5321), default $I^2C$ address 1A hex** | | |
| | 0 | Spare |

[1] Internal span option.
[2] Remote range control option.
[3] MODBUS option.
[4] Concentration alarm option.
[5] High auto range relay option.
[6] User-configurable D/A output option.
[7] External analog input option.

# APPENDIX A-5: DAS Trigger Events and Parameters

## Table A- 5: DAS Trigger Events

| Name | Description |
|---|---|
| ATIMER | Automatic timer expired |
| EXITZR | Exit zero calibration mode |
| EXITSP | Exit span calibration mode |
| EXITMP | Exit multi-point calibration mode |
| SLPCHG | Slope and offset recalculated |
| EXITDG | Exit diagnostic mode |
| CONC1W [1] | Concentration limit 1 exceeded |
| CONC2W [1] | Concentration limit 2 exceeded |
| AREFW | Auto-ref warning |
| BASELW | Bench baseline loss warning |
| BCHCOM | Bench communication failure warning |
| MFTMPW | Manifold temperature warning |
| IZSTMPW | IZS temperature warning |
| OVTMPW | Oven temperature warning |
| STEMPW | Sample temperature warning |
| SPRESW | Sample pressure warning |
| BTEMPW | Box temperature warning |
| [1] Concentration alarm option. | |

## Table A- 6: DAS Parameters

| Name | Description | Units |
|---|---|---|
| SLOPE1 | Slope for range #1 | — |
| SLOPE2 | Slope for range #2 | — |
| OFSET1 | Offset for range #1 | PPB |
| OFSET2 | Offset for range #2 | PPB |
| ZSCNC1 | Concentration for range #1 during zero/span calibration, just before computing new slope and offset | PPB |
| ZSCNC2 | Concentration for range #2 during zero/span calibration, just before computing new slope and offset | PPB |
| CONC1 | Concentration for range #1 | PPB |
| CONC2 | Concentration for range #2 | PPB |
| STABIL | Concentration stability | PPB |
| AREF | Auto-ref offset | $Mm^{-1}$ |
| MFTEMP | Manifold temperature | °C |
| MFDUTY | Manifold temperature duty cycle | % |

| Name | Description | Units |
|---|---|---|
| IZTEMP | IZS temperature | °C |
| IZDUTY | IZS temperature duty cycle | % |
| OVTEMP | Oven temperature | °C |
| OVDUTY | Oven temperature duty cycle | % |
| SMPTMP | Sample temperature | °C |
| SMPPRS | Sample pressure | Inches Hg |
| PHASE | Phase | Deg |
| MEASLS | Measured loss | $Mm^{-1}$ |
| BOXTMP | Internal box temperature | °C |
| TEST7 | Diagnostic test input (TEST_INPUT_7) | mV |
| TEST8 | Diagnostic test input (TEST_INPUT_8) | mV |
| TEMP6 | Diagnostic temperature input (TEMP_INPUT_6) | °C |
| REFGND | Ground reference | mV |
| RF4096 | Precision 4.096 mV reference | mV |
| XIN1 [10] | External analog input 1 value | Volts |
| XIN1SLPE [10] | External analog input 1 slope | eng unit / V |
| XIN1OFST [10] | External analog input 1 value | eng unit |
| XIN2 [10] | External analog input 2 value | Volts |
| XIN2SLPE [10] | External analog input 2 slope | eng unit / V |
| XIN2OFST [10] | External analog input 2 value | eng unit |
| XIN3 [10] | External analog input 3 value | Volts |
| XIN3SLPE [10] | External analog input 3 slope | eng unit / V |
| XIN3OFST [10] | External analog input 3 value | eng unit |
| XIN4 [10] | External analog input 4 value | Volts |
| XIN4SLPE [10] | External analog input 4 slope | eng unit / V |
| XIN4OFST [10] | External analog input 4 value | eng unit |
| XIN5 [10] | External analog input 5 value | Volts |
| XIN5SLPE [10] | External analog input 5 slope | eng unit / V |
| XIN5OFST [10] | External analog input 5 value | eng unit |
| XIN6 [10] | External analog input 6 value | Volts |
| XIN6SLPE [10] | External analog input 6 slope | eng unit / V |
| XIN6OFST [10] | External analog input 6 value | eng unit |
| XIN7 [10] | External analog input 7 value | Volts |
| XIN7SLPE [10] | External analog input 7 slope | eng unit / V |
| XIN7OFST [10] | External analog input 7 value | eng unit |
| XIN8 [10] | External analog input 8 value | Volts |
| XIN8SLPE [10] | External analog input 8 slope | eng unit / V |
| XIN8OFST [10] | External analog input 8 value | eng unit |
| [10] External analog input option. | | |

# APPENDIX A-6: Terminal Command Designators and Command Line Options

## Table A-7: Terminal Command Designators

| 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 DAS configuration |
| | RECORDS ["name"] | Print number of DAS 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 DAS records |
| | CANCEL | Halt printing DAS 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 DAS configuration |
| | CHANNELBEGIN propertylist CHANNELEND | Upload single DAS channel |
| | CHANNELDELETE ["name"] | Delete DAS 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 |

**Table A-8 Firmware Command Line Options**

| Option | Description |
|---|---|
| /?, /h | Prints command line usage without executing the firmware. |
| /u CPU-type | *CPU-type* specifies the CPU type to use:<br>**0 = Generic PC (default)**<br>1 = AR-B1320, 386SX, PC/104<br>2 = AR-B9612A, 386SX, PC/104 |
| /d device | *Device* specifies the display type to use:<br>**0 = PC video display and keyboard (default)**<br>1 = Onyx I/O, parallel display (not currently supported)<br>2 = DMM-32 I/O, parallel display (not currently supported)<br>3 = ICA90, 8574-based $I^2C$ display<br>4 = API "E" series rear board, parallel display<br>5 = API "E" series rear board, 8574-based $I^2C$ display |
| /y | Runs the firmware without prompting. This is useful for executing the firmware automatically from within a batch file. **The default is to prompt for confirmation.** |
| /w | Disables the watchdog timer. **The default is enabled.** |
| /n file | *File* specifies a different name and/or location for the configuration file. **The default is "config.bin" in the same directory as the executable file.** If you have configured flash memory as a disk drive, such as B:, then you can store the configuration information in the flash using the command line option *–o "b:\config.bin"*. |
| /r file | *File* specifies an alternate resource file containing the firmware's default configuration. **The default is the executable file.** |
| /a address | *Address* specifies the Com port for the bench interface. **The default is 3.** Valid values are 2-4. |
| /b address [3, 5] | *Address* specifies the I/O address of the $I^2C$ interface data register. **The default is 0x32c (hex).** This is usually 0x310 for the ICA90 board. |
| /c address [3, 5] | *Address* specifies the I/O address of the $I^2C$ interface control register. **The default is 0x32f (hex).** This is usually 0x311 for the ICA90 board. |
| /q irq [3, 5] | *IRQ* specifies the IRQ number of the $I^2C$ interface. **The default is IRQ5.** |
| /k irq [3, 4, 5] | *IRQ* specifies the IRQ number of the keyboard (0 = use polling mode instead of interrupt mode). **The default is IRQ12.** |

| Option | Description |
| --- | --- |
| /i address [3, 5] | *Address* specifies the $I^2C$ bus address of the host CPU. **The default is 0x57 (hex).** |
| /s address [3, 5] | *Address* specifies the $I^2C$ bus address of the keyboard/display. **The default is 0x4A (hex).** |
| /l address | *Address* specifies the $I^2C$ bus address of the relay board. **The default is 0x44 (hex).** |
| [3] This option is used with display type 3.<br>[4] This option is used with display type 4.<br>[5] This option is used with display type 5. | |
| Typical command lines<br>• PC keyboard/display: T500U_B7 /y /w<br>• AR-B1320 CPU and 8574-based keyboard/display: T500U_B7 /y /u 1 /d 5 | |

## APPENDIX A-7: MODBUS Register Map

| MODBUS Register Address (dec., 0-based) | Description | Units |
|---|---|---|
| **MODBUS Floating Point Input Registers (32-bit IEEE 754 format; read in high-word, low-word order; read-only)** | | |
| 6 | Slope for range #1 | — |
| 8 | Slope for range #2 | — |
| 10 | Offset for range #1 | PPB |
| 12 | Offset for range #2 | PPB |
| 14 | Concentration for range #1 during zero/span calibration, just before computing new slope and offset | PPB |
| 16 | Concentration for range #2 during zero/span calibration, just before computing new slope and offset | PPB |
| 18 | Concentration for range #1 | PPB |
| 20 | Concentration for range #2 | PPB |
| 22 | Concentration stability | PPB |
| 24 | Auto-ref value | $Mm^{-1}$ |
| 26 | Oven temperature | °C |
| 28 | Oven temperature duty cycle | % |
| 30 [5] | Manifold temperature | °C |
| 32 [5] | Manifold temperature duty cycle | % |
| 34 [6] | IZS lamp temperature | °C |
| 36 [6] | IZS temperature duty cycle | % |
| 38 | Sample temperature | °C |
| 40 | Sample pressure | Inches Hg |
| 42 | Internal box temperature | °C |
| 46 | Diagnostic test input (TEST_INPUT_7) | mV |
| 48 | Diagnostic test input (TEST_INPUT_8) | mV |
| 50 | Diagnostic temperature input (TEMP_INPUT_6) | °C |
| 54 | Ground reference | mV |
| 56 | Precision 4.096 mV reference | mV |
| 130 [10] | External analog input 1 value | Volts |
| 132 [10] | External analog input 1 slope | eng unit /V |
| 134 [10] | External analog input 1 offset | eng unit |
| 136 [10] | External analog input 2 value | Volts |
| 138 [10] | External analog input 2 slope | eng unit /V |
| 140 [10] | External analog input 2 offset | eng unit |
| 142 [10] | External analog input 3 value | Volts |
| 144 [10] | External analog input 3 slope | eng unit /V |
| 146 [10] | External analog input 3 offset | eng unit |
| 148 [10] | External analog input 4 value | Volts |

| MODBUS Register Address (dec., 0-based) | Description | Units |
|---|---|---|
| 150 [10] | External analog input 4 slope | eng unit /V |
| 152 [10] | External analog input 4 offset | eng unit |
| 154 [10] | External analog input 5 value | Volts |
| 156 [10] | External analog input 5 slope | eng unit /V |
| 158 [10] | External analog input 5 offset | eng unit |
| 160 [10] | External analog input 6 value | Volts |
| 162 [10] | External analog input 6 slope | eng unit /V |
| 164 [10] | External analog input 6 offset | eng unit |
| 166 [10] | External analog input 7 value | Volts |
| 168 [10] | External analog input 7 slope | eng unit /V |
| 170 [10] | External analog input 7 offset | eng unit |
| 172 [10] | External analog input 8 value | Volts |
| 174 [10] | External analog input 8 slope | eng unit /V |
| 176 [10] | External analog input 8 offset | eng unit |
| **MODBUS Floating Point Holding Registers (32-bit IEEE 754 format; read/write in high-word, low-word order; read/write)** | | |
| 2 | Maps to *NO2_SPAN1* variable; target span concentration for range #1 | Conc. units |
| 6 | Maps to *NO2_SPAN2* variable; target span concentration for range #2 | Conc. units |
| **MODBUS Discrete Input Registers (single-bit; read-only)** | | |
| 0 | Auto-ref warning | |
| 1 | Oven temperature warning | |
| 2 [5] | Manifold temperature warning | |
| 3 [6] | IZS temperature warning | |
| 4 | Baseline loss warning | |
| 5 | Bench com warning | |
| 6 | | |
| 7 | Box temperature warning | |
| 8 | Sample temperature warning | |
| 9 | | |
| 10 | Sample pressure warning | |
| 11 | System reset warning | |
| 12 | Rear board communication warning | |
| 13 | Relay board communication warning | |
| 14 | | |
| 15 | Front panel communication warning | |
| 16 | Analog calibration warning | |

| MODBUS Register Address (dec., 0-based) | Description | Units |
|---|---|---|
| 17 | Dynamic zero warning | |
| 18 | Dynamic span warning | |
| 19 | Invalid concentration | |
| 20 | In zero calibration mode | |
| 21 | | |
| 22 | In span calibration mode | |
| 23 | In multi-point calibration mode | |
| 24 | System is OK (same meaning as *SYSTEM_OK* I/O signal) | |
| 25 [3] | $NO_2$ concentration alarm limit #1 exceeded | |
| 26 [3] | $NO_2$ concentration alarm limit #2 exceeded | |
| 27 [4] | In Manual mode | |
| **MODBUS Coil Registers (single-bit; read/write)** | | |
| 0 | Maps to relay output signal 36 (*MB_RELAY_36* in signal I/O list) | |
| 1 | Maps to relay output signal 37 (*MB_RELAY_37* in signal I/O list) | |
| 2 | Maps to relay output signal 38 (*MB_RELAY_38* in signal I/O list) | |
| 3 | Maps to relay output signal 39 (*MB_RELAY_39* in signal I/O list) | |
| 20 [1] | Triggers zero calibration of $NO_2$ range #1 (on enters cal.; off exits cal.) | |
| 22 [1] | Triggers span calibration of $O_3$ range #1 (on enters cal.; off exits cal.) | |
| 23 [1] | Triggers zero calibration of $NO_2$ range #2 (on enters cal.; off exits cal.) | |
| 25 [1] | Triggers span calibration of $NO_2$ range #2 (on enters cal.; off exits cal.) | |

[1] Set *DYN_ZERO* or *DYN_SPAN* variables to *ON* to enable calculating new slope or offset. Otherwise a calibration check is performed.

[3] Concentration alarm option.

[4] Hessen option.

[5] Manifold heater option.

[6] IZS option.

[10] External analog input option.

# APPENDIX B - Spare Parts

| | |
|---|---|
| **Note** | **Use of replacement parts other than those supplied by Teledyne Advanced Pollution Instrumentation (TAPI) may result in non-compliance with European standard EN 61010-1.** |

| | |
|---|---|
| **Note** | **Due to the dynamic nature of part numbers, please refer to the TAPI Website at http://www.teledyne-api.com or call Customer Service at 800-324-5190 for more recent updates to part numbers.** |

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# T500U Spare Parts List

08067A DCN5543, 18 March 2014



| Item number | Product name |
|---|---|
| 004330000 | ZERO AIR SCRUBBER (NO/NO2) |
| 005960000 | AKIT, EXP, ACT CHARCOAL, (2 BTL@64 FL-OZ EA) |
| 005970000 | AKIT, EXP, PURAFIL (2 BTL@64 FL-OZ EA) |
| 014030000 | AKIT, NOX EXPENDABLES, IZS |
| 019340700 | ASSY, SAMPLE THERMISTOR, T500U |
| 040010000 | ASSY, FAN REAR PANEL (B/F) |
| 045230200 | PCA, RELAY CARD |
| 052820000 | ASSY, IZS, HEATER/THERM, NOX |
| 058021100 | PCA, MOTHERBD, GEN 5-ICOP(PA) |
| 058800000 | ASSY, THERMISTOR, OVEN |
| 058820100 | ASSY, HEATER w/THERM, 75W 120V |
| 058820200 | ASSY, HEATER w/THERM, 75W 240V |
| 059940200 | ASSY, SAMPLE GAS CONDITIONER, T500U |
| 066970000 | PCA, INTRF. LCD TOUCH SCRN, F/P |
| 067240000 | CPU, PC-104, VSX-6154E, ICOP *(PA) |
| 067300000 | PCA, AUX-I/O BD, ETHERNET, ANALOG & USB |
| 067300100 | PCA, AUX-I/O BOARD, ETHERNET |
| 067300200 | PCA, AUX-I/O BOARD, ETHERNET & USB |
| 067900000 | LCD MODULE, W/TOUCHSCREEN(PA) |
| 068810000 | PCA, LVDS TRANSMITTER BOARD |
| 069500000 | PCA, SERIAL & VIDEO INTERFACE BOARD |
| 072150000 | ASSY. TOUCHSCREEN CONTROL MODULE |
| 076490000 | ASSY, LED, T500U |
| 076730000 | PCA, CAPS DAQ |
| 077660000 | ASSY, CARTRIDGE, MIRROR, T500U |
| 077670000 | ASSY, DETECTOR / MIXER, W/O COVER, T500U |
| 078330000 | DOM, W/SOFTWARE, T500U* |
| 078340000 | MANUAL, OPERATORS, T500U |
| 078510000 | ASSY, PUMP, INTERNAL, T500U |
| 080680000 | ASSY, SAMPLE FILTER, T500U, FL-33 |
| 080680100 | ASSY, SCRUBBER, AREF, T500U, FL-20 |
| 080680200 | ASSY, FILTER, AREF, T500U, FL-03 |
| 080680300 | ASSY, FILTER, EXH, T500U, FL-03 |
| KIT000207 | KIT, RELAY RETROFIT |
| KIT000219 | AKIT, 4-20MA CURRENT OUTPUT |
| KIT000231 | KIT000231 KIT, RETROFIT, M200E Z/S VALVE |
| KIT000253 | ASSY & TEST, SPARE PS37 |
| KIT000254 | ASSY & TEST, SPARE PS38 |
| RL0000015 | RELAY, DPDT, (KB) |
| SW0000025 | SWITCH/CIR BRK, VDE, CE *(KB) |
| WR0000008 | POWER CORD, 10A |

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CUSTOMER: ______________________________ PHONE: ______________________________

CONTACT NAME: __________________________ FAX NO. ______________________________

SITE ADDRESS: ____________________________________________________________

MODEL 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 | 5 PPB TO 1000 PPB |
| **PHASE** | DEG | 30 ± 10 WITH ZERO AIR |
| **MEAS_L WITH ZERO AIR** | Mm-1 | 400 – 800 WITH ZERO AIR |
| **MEAS_L WITH SPAN GAS** | Mm-1<br>PPB | 400 – 1800 Mm-1<br>0-1000 PPB |
| **AREF_L** | Mm-1 | 400 – 800 WITH ZERO AIR |
| **SMP PRS** | IN-HG-A | ~ 1-5” < AMBIENT (CONSTANT) |
| **SMP TEMP** | ºC | 45 ± 3ºC |
| **BOX TEMP** | ºC | AMBIENT ± 5ºC |
| **SLOPE** | | 1.0 ± 0.3 |
| **OFFSET** | PPB | 0.0 ± 5 |
| **$NO_2$ STAB** | PPB/PPM | ≤ 1 PPB WITH ZERO AIR |
| **OVEN TMP** | ºC | 45 ± 1ºC |
| **IZS TEMP*** | ºC | 50 ± 1ºC |
| 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 |

2. WHAT IS THE SAMPLE PRESSURE WITH THE SAMPLE INLET ON REAR OF MACHINE CAPPED?

SAMPLE PRESSURE - _____IN-HG-A

3. WHAT IS THE SAMPLE FLOW MEASURED AT THE SAMPE INPUT?

SAMPLE FLOW - _____CM3

4. WHAT ARE THE FAILURE SYMPTOMS? ________________________________________

____________________________________________________________________________

____________________________________________________________________________

Teledyne API Technical Support
EMAIL: sda_techsupport@teledyne.com
PHONE: (858) 657-9800 TOLL FREE: (800) 324-5190 FAX: (858) 657-9816

5. WHAT TEST(S) HAVE YOU DONE TRYING TO SOLVE THE PROBLEM? ________________________________

____________________________________________________________________________

____________________________________________________________________________

____________________________________________________________________________

____________________________________________________________________________

____________________________________________________________________________

6. IF POSSIBLE, PLEASE INCLUDE A PORTION OF A STRIP CHART PERTAINING TO THE PROBLEM AND CIRCLE THE PERTINENT DATA.

THANK YOU FOR PROVIDING THIS INFORMATION. YOUR ASSISTANCE ENABLES TELEDYNE API TO RESPOND FASTER TO THE PROBLEM THAT YOU ARE ENCOUNTERING.

# APPENDIX D – Interconnect Diagram

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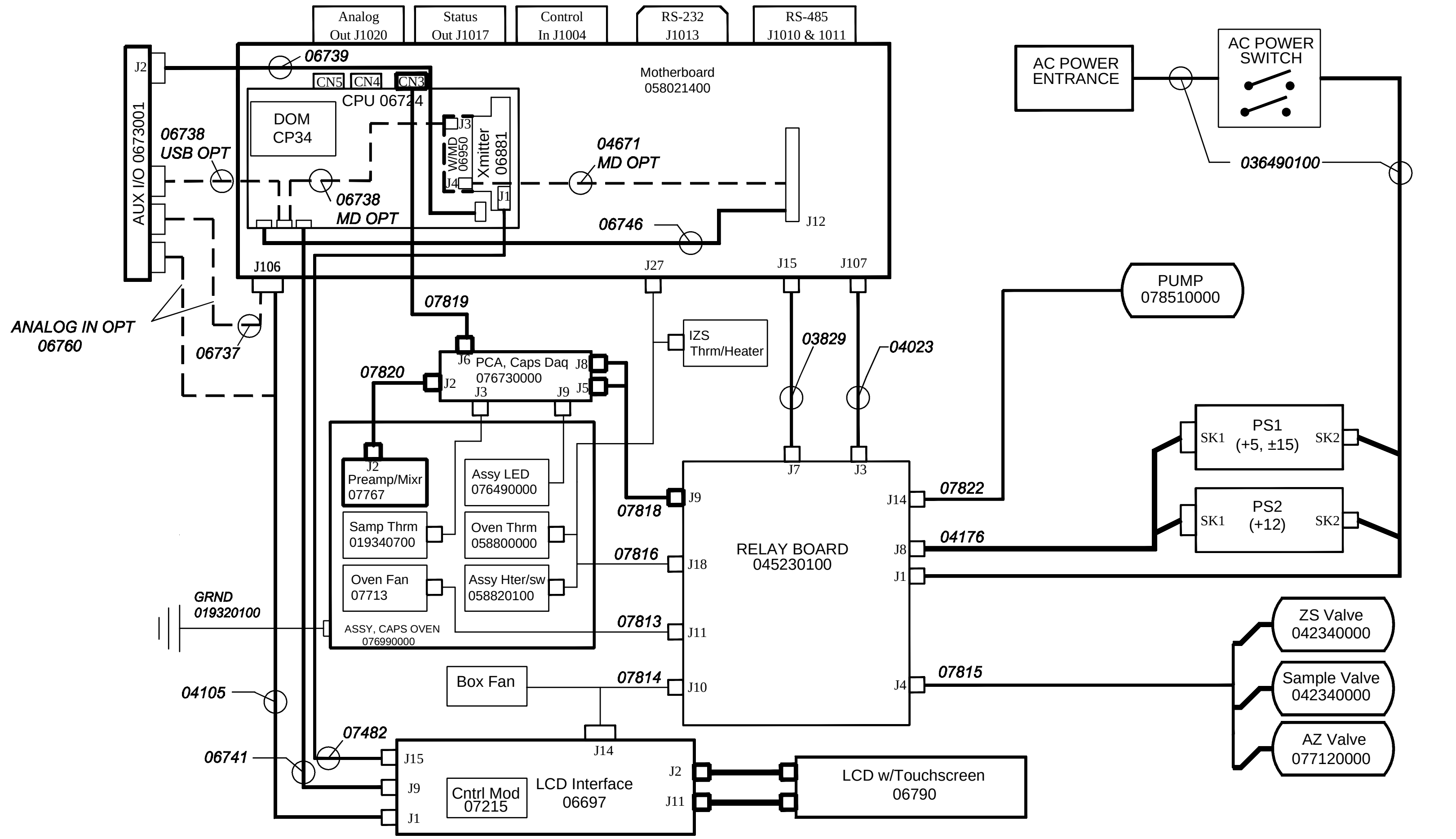
| REVISIONS | | | | |
|---|---|---|---|---|
| REV | DESCRIPTION | DATE | DCN | APPROVED |
| A | INITIAL RELEASE | 11/1/13 | 6764 | TN |




KEY:

1. All part numbers in *Italic* identify cables that are refered to in the accompanying document 078480100.
2. All items in Dashed boxes are optional.

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THIRD ANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ARE: FRACTIONS ± 1/32; DECIMALS ±.03[0.76] ±.010[0.25]; ANGULAR ±0° 30'
DO NOT SCALE DRAWING
TREATMENT: NA
FINISH
SIMILAR TO

CONTRACT: NA

| APPROVALS | | DATE |
|---|---|---|
| DRAWN | TN | 10/13 |
| CHECK | PK | 11/13 |
| CCB | | |
| ISSUED | | |

TELEDYNE ADVANCED POLLUTION INSTRUMENTATION
Everywhereyoulook

TITLE: INTERCONNECT DIAGRAM T500U

SIZE: C | CAGE CODE NO.: 1JZF4 | DWG. NO.: 07848 | REV: A

SCALE: 1/1 | FILE | SHEET: 1 OF 1