PRESYS | Instruments Inc.

Super Thermometer ST-501

TECHNICAL MANUAL

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1 - Introduction

The Super Thermometer ST-501 main purpose is to measure temperature with high accuracy. It uses platinum resistance thermometers sensors and it also accepts thermocouples signals. The digital electronic indicator can be offered complete including the temperature sensor and calibration certificate of the set. The ST-501 has internal algorithms to calculate the temperature value according to Callendar-Van Dusen (CVD), IPTS-68 and ITS-90. For customers that already have one or several RTD's or PRT's sensors/ noble thermocouples with quality enough for being used as standards, it is only necessary to enter its respective coefficients. And for those uncalibrated probes, it is possible to use the standard linearization curves for RTD's and thermocouples.

- PRT reference thermometer, resolution of 0.001ºC.
- Replaces precision glass thermometers.
- Fully electronic, without mechanical parts.
- Uses platinum RTD or thermocouple as temperature sensor.
- Portable and compact (rechargeable battery, charger and carrying case included, besides 4 banana plugs - 2 in red and 2 in black - to be welded on the temperature sensor wire tips).
- Support for best bench viewing angle of the display.
- It has internal memory and serial communication.
- Accepts CVD (Callendar-Van Dusen), IPTS-68 and ITS-90 coefficients.

1.1 - Technical Specifications

General Specifications:

Dimensions: 56mm x 144mm x 72mm (height x width x depth)
Weight: 0.53 kg.
Warm-up time: 5 minutes.
Battery operation: 30-hours (rated).
Operating temperature range: 0 to 50ºC.
Relative humidity: 0 to 90%
Warranty: 1 year, except for rechargeable battery.
Supplied with rechargeable battery, battery charger, support and carrying case.

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1.1.1 - Input Technical Specifications

Ranges		Resolution	Accuracy	Remarks
Resistance	0 to 100 Ω 100 to 500 Ω	0.0001 Ω 0.001 Ω	± 0.001 Ω ± 0.004 Ω	excitation current 1.0 mA
Pt-100	-200 to 850 ºC / -328 to 1562 ºF	0.001 ºC / 0.001 ºF	± 0.01 ºC / ± 0.02 ºF	excitation current 1.0 mA
Pt-25	-200 to 850 ºC / -328 to 1562 ºF	0.001 ºC / 0.001 ºF	± 0.01 ºC / ± 0.02 ºF	excitation current 1.0 mA
TC-J	-210 to 1200 ºC / -346 to 2192 ºF	0.01 ºC / 0.01 ºF	± 0.10 ºC / ± 0.20 ºF	IEC-60584
TC-K	-270 to -150 ºC / -454 to -238 ºF -150 to 1370 ºC / -238 to 2498 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.25 ºC / ± 0.50 ºF ± 0.10 ºC / ± 0.20 ºF	IEC-60584
TC-T	-260 to -200 ºC / -436 to -328 ºF -200 to -75 ºC / -328 to -103 ºF -75 to 400 ºC / -103 to 752 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.30 ºC / ± 0.60 ºF ± 0.20 ºC / ± 0.40 ºF ± 0.10 ºC / ± 0.20 ºF	IEC-60584
TC-B	50 to 250 ºC / 122 to 482 ºF 250 to 500 ºC / 482 to 932 ºF 500 to 1200 ºC / 932 to 2192 ºF 1200 to 1820 ºC / 2192 to 3308 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 1.25 ºC / ± 2.50 ºF ± 0.75 ºC / ± 1.50 ºF ± 0.50 ºC / ± 1.00 ºF ± 0.35 ºC / ± 0.70 ºF	IEC-60584
TC-R	-50 to 300 ºC / -58 to 572 ºF 300 to 1760 ºC / 572 to 3200 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.50 ºC / ± 1.00 ºF ± 0.35 ºC / ± 0.70 ºF	IEC-60584

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TC-S	-50 to 300 ºC / -58 to 572 ºF 300 to 1760 ºC / 572 to 3200 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.50 ºC / ± 1.00 ºF ± 0.35 ºC / ± 0.70 ºF	IEC-60584
TC-E	-270 to -150 ºC / -454 to -238 ºF -150 to 1000 ºC / -238 to 1832 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.15 ºC / ± 0.30 ºF ± 0.05 ºC / ± 0.10 ºF	IEC-60584
TC-N	-260 to -200 ºC / -436 to -328 ºF -200 to -20 ºC / -328 to -4 ºF -20 to 1300 ºC / -4 to 2372 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.50 ºC / ± 1.00 ºF ± 0.20 ºC / ± 0.40 ºF ± 0.10 ºC / ± 0.20 ºF	IEC-60584
TC-L	-200 to 900 ºC / -328 to 1652 ºF	0.01 ºC / 0.01 ºF	± 0.10 ºC / ± 0.20 ºF	DIN-43710
TC-C	0 to 1500 ºC / 32 to 2732 ºF 1500 to 2320 ºC / 2732 to 4208 ºF	0.01 ºC / 0.01 ºF 0.01 ºC / 0.01 ºF	± 0.25 ºC / ± 0.50 ºF ± 0.35 ºC / ± 0.70 ºF	W5Re / W26Re W5Re / W26Re

Accuracy values are valid within one year and temperature range of 20 to 26 °C. Outside these limits add 0.005 % FS / °C taking 23 °C as the reference temperature. For thermocouples, using the internal cold junction compensation add a cold junction compensation error of ± 0.1 °C or ± 0.2 °F max.

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1.1.2 - Serial Communication Technical Specifications

Interface: RS-232 and RS-485.
Word length: 8 bits.
Parity: No parity.
Stop bits: 1 stop bit.
Protocol: Modbus.
Modbus is a trade mark of MODICON and is an open industrial communication protocol which is very popular because of its technical features.
Transmission mode: RTU.
Line distance:

RS-232 Interface - 15 meters maximum;
RS-485 Interface - 1200 meters maximum (i).

Number of instruments per line:

1 instrument for RS-232;
31 instruments for RS-485 (i).

Operation mode:

Asynchronous;
Half duplex.

(i) The number of instruments per line can be increased as well as the line length by means of repeaters.

1.2 - Order Code

ST-501 - ☐

Temperature Sensor

1 - Industrial Standard Probe (-200 to 420 °C)
2 - Secondary Standard Probe (-200 to 660 °C)
3 - Secondary Standard Probe (-200 to 480 °C)

1.3 - Optional Accessories

- **Temperature Sensor**

Description	Order Code	Range	Drift	Accuracy*	Dimensional
Industrial Standard Pt-100 Probe - Straight	04.06.0001-21	-200 to 420 °C	0.035 °C	0.030 °C @ 420 °C	305 mm x Ø 6.35 mm
Industrial Standard Pt-100 Probe - Angular 90°	04.06.0007-21	-200 to 420 °C	0.035 °C	0.030 °C @ 180 °C	140 mm x Ø 6.35 mm
Industrial Standard Pt-100 Probe - Long Angular 90°	04.06.0002-21	-200 to 420 °C	0.035 °C	0.030 °C @ 180 °C	170 mm x Ø 6.35 mm

* With ITS-90 coefficients characterization.

- **Communication Interfaces:**

Description	Order Code
RS-232 - DB-9F connector (COM1)	06.02.1001-00
RS-232 - DB-25F connector (COM2)	06.02.1003-00
RS-485	06.02.1005-00

- **Banana type connectors:**

Description	Order Code
Red banana connector	06.07.0008-00
Black banana connector	06.07.0007-00

- **Carrying case.** Order Code: 06.01.0008-00.
- **Calibration Certificate.**

1.4 - Battery and Charger

ST-501 is supplied with a rechargeable battery, which enables up to 30 hours of continuous use. A charger is also provided, which can be connected to 110 or 220 Vac. Care should be taken when changing the 110-220 Vac selection switch in the charger. Time required for a full charge is 14 hours. The charger provides the battery charge while it feeds the Super Thermometer, thus allowing ST-501 to be used normally while the battery is being charged.

1.5 - Use of the Support

The Super Thermometer display visualization in bench can be adjusted by using the support supplied with the instrument.

Just fit the Super Thermometer on the support as shown by the arrow labeled A (see figure below). To withdraw it from the support, do the reverse movement.

In order to get the best screen viewing angle, loose the two hand fasten screws placed on the support sides, as much as to be able to rotate the part that holds the instrument. Then, rotate it to achieve the best viewing angle and tighten the screws.

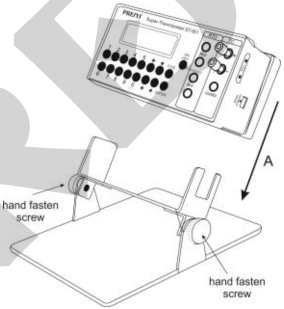

Fig. 1 – Uso of the Support

2 - ST-501 Super Thermometer Operation

When powered on, the Super Thermometer goes through a self-test routine and shows the last calibration date and the value of the battery voltage. The battery voltage is continuously monitored, and the low battery warning is provided. After the self-test is completed, ST-501 goes to the operating mode and the display shows the temperature of the selected sensor. The temperature unit exhibited for the first time (ºC or ºF) is configurable.

To show the main menu press **C/CE**:

⇨ EXEC	**CONF**	**CAL**

Through the keys ⇧, ⇩, ⇦ and ⇨, choose the menu options and press **ENTER**.

EXEC: The Super Thermometer goes to the operating mode.

CONF: Accesses the configuration options of the instrument. For further details see item *2.3 - Menu CONF*.

CAL: This option accesses the adjustment functions of ST-501 Super Thermometer, protected by a password. For further details see section 4 - *Calibration*.

2.1 - Input Connections

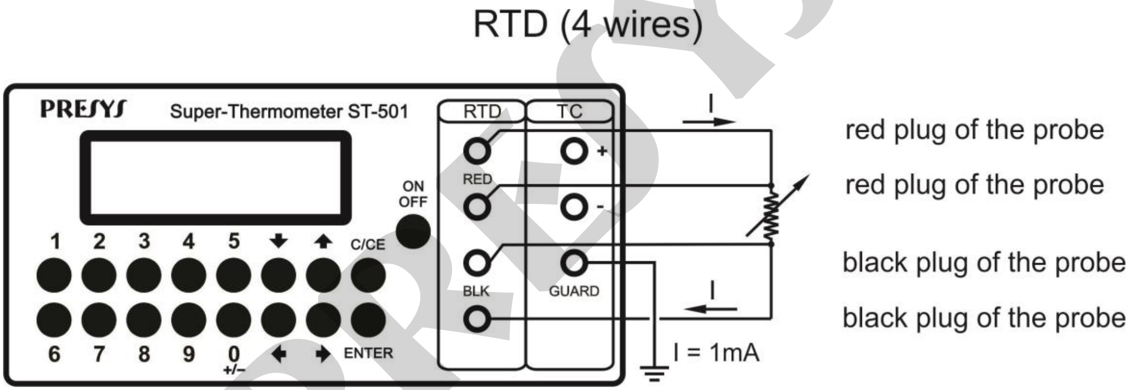

Fig. 2 – Input Connections (4 wires)

RTD (3 wires)

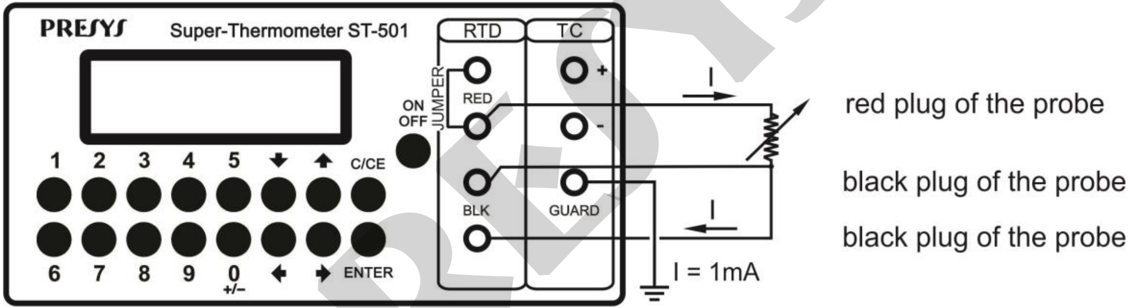

Fig. 3 – Input or Measurement Connections (3 wires)

THERMOCOUPLE (TC)

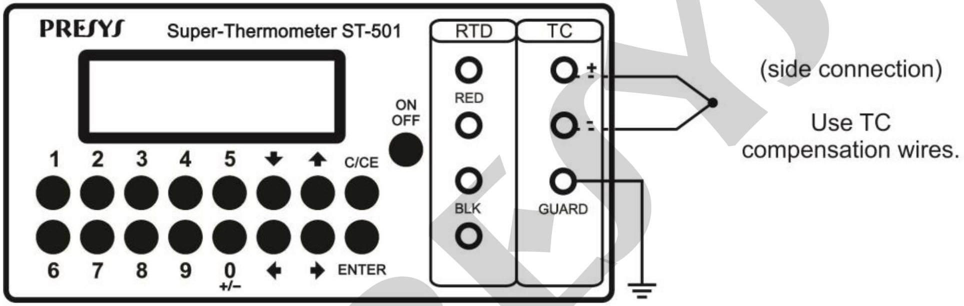

Fig. 4 – Input or Measurement Connections (Thermocouple)

2.2 - Operating Mode

In the first time the instrument is turned on, the display indicates the temperature of the selected sensor. The initial temperature unit is configured in CONF level.

It is possible to change the display visualization mode through the keys **0**, **1**, **2** and **3**.

Key 0: Offsets the display. The subsequent readings are displayed as the difference in relation to the value read at the moment the display was offset.

Key 1: If the selected sensor is a RTD probe, the value of the resistance is given in ohms. If it is a thermocouple probe, it is shown the millivoltage read from the thermocouple and also the cold junction temperature in the same unit the temperature of the sensor was shown previously.

Key 2: Shows the temperature of the selected sensor given in degrees Celsius along with the type of parameter set configured for the sensor. For a thermocouple probe, it is also shown the type of thermocouple configured.

Key 3: Shows the temperature of the selected sensor given in degrees Fahrenheit along with the type of parameter set configured for the sensor. For a thermocouple probe, it is also shown the type of thermocouple configured.

Below there are examples of some display visualization modes.

138.500	**100.231**	**250.01**	**15.1225**
(Ω) ITS90	**RTD (°C) ITS90**	**TC-J (°F) STD90**	**(mV) CJC=27.03°C**

2.3 - Menu CONF

⇨ **PRB_RTD**		**PRB_TC**	
LCD	**BT**	**COM**	**PRG**

PRB_RTD: configures the RTD probe. For further details see item *2.4 - RTD Probe Configuration*.

PRB_TC: configures the thermocouple probe. For further details see item *2.5 - Thermocouple Probe Configuration*.

LCD: performs the setting of the display contrast by means of the arrow keys ⇧ and ⇩. Save the last selection by pressing the **ENTER** key.

BT: Shows the value of the battery voltage since the charger is disconnected. When connected, BT shows the DC level which is provided by the ST-501 charger. If the display indicates LOW BATTERY, it is necessary to recharge the instrument.

Battery level	**Battery state**	**Display**
4.0 to 7.0V	normal	----------
< 4.0V	low	LOW BATTERY

COM: Configures the communication address of ST-501 Super Thermometer. For further details on technical specifications and protocol of the serial communication see item *1.1.2 - Serial Communication Technical Specification* and item *5 - MODBUS Protocol for Serial Communication*.

PRG: Configuration menu.

⇨**CF**

CF: Configures the default temperature unit of the instrument. Whenever the instrument is powered on, the sensor selected will be shown with this unit. The configuration of the manual cold junction temperature is also shown in this unit. Press **ENTER** and choose between degrees Celsius or degrees Fahrenheit.

⇨ **CELSIUS** **FAHRENHEIT**

2.4 - RTD Probe Configuration

Warning: Enter the following options only after understanding them completely because the configuration of the RTD calibration parameters can be changed!

The access password for this option is 9875

It is possible to introduce the configuration and calibration parameters of up to 3 RTD probes. Select one of the 3 probes:

⇨1	**2**	**3**

Then, go to the configuration of the chosen probe.

⇨TAG	**PARAM**	**R0**
NW	**LIMHI**	**LIMLO**

TAG: Identification name of the RTD Probe.

R0: Value of R0 given by the calibration certificate of the sensor. In case the sensor does not have a calibration certificate and the sensor is a Pt-100, enter the default value 100.000 Ω.

NW: Number of wires for the RTD Probe. Choose **3_WIRES** (3-wire connection) or **4_WIRES** (4-wire connection).

LIM_HI: Maximum temperature the Probe may reach or maximum limit which the calibration certificate ensures an uncertainty level. Above this value, the display indicates **OVER**.

LIM_LO: Minimum temperature the Probe may reach or minimum limit which the calibration certificate ensures an uncertainty level. Below this value, the display indicates **UNDER**.

PARAM: Selects the type of parameter set to be used, that is, the interpolation method.

⇨ITS90	**CCVD**	**CVD**
STD68	**STD90**	

ITS90: Selects the parameter set under ITS-90 for Platinum Resistance Thermometers. For further details see item *2.4.1 - ITS-90 Coefficients*.

CCVD: Selects the parameter set for the Callendar-Van Dusen equation with R0, A, B and C coefficients. For further details see item *2.4.2 - CCVD and CVD Coefficients*.

CVD: Selects the parameter set for the Callendar-Van Dusen equation with R0, α, β and δ coefficients. For further details see item *2.4.2 - CCVD and CVD Coefficients*.

STD68: Selects the linearization table under IEC-60751 international norm for the IPTS-68 temperature scale.

STD90: Selects the linearization table under IEC-60751 norm (defined for the IPTS-68 temperature scale) converted to the ITS-90 temperature scale.

2.4.1 - ITS-90 Coefficients

When using these coefficients, the value of R0 to be provided must correspond to the Probe resistance value when it is at the temperature for the triple point of water (0.01°C).

⇨NEGATIVE_T
POSITIVE_T

NEGATIVE_T: Accesses the coefficients to be used for temperatures below or equal to the temperature of the triple point of water (0.01°C).

⇨RGE_4 RGE_5

When entering this menu, the cursor position indicates the coefficients currently used by the Super Thermometer for reading temperatures lower than or equal to 0.01°C. To change the range, select a new one and press **ENTER**, then leave **NEGATIVE_T** menu.

Recommended Temperature Range (NEGATIVE_T)		**Coefficients**
RGE_4	-189.3442°C to 0.01°C	A4, B4
RGE_5	-38.8344°C to 0.01°C	A5, B5

Table 1 - Temperature Ranges for NEGATIVE_T

By selecting one of the ranges, it is shown the mnemonics corresponding to each one of its coefficients. The RGE_4 range, for example, presents the mnemonics A4, EA4, B4 and EB4:

⇨**A4**	**EA4**	**B4**	**EB4**

To enter the value of a coefficient, it must be split into a mantissa and an exponent as it is used in scientific notation. For a coefficient A4 equal to -3.05870×10^{-6}, for example, type its mantissa (an integer and a fractional part with seven digits) in the mnemonic A4 and the exponent in the mnemonic EA4. Thus, A4 = -3.0587000 and EA4 = -06.

Note that the signal can be inverted by pressing the key **ZERO** when the number on the display is zero. It changes the signal from **+** to **-**, or vice-versa.

POSITIVE_T: Accesses the coefficients to be used for temperatures above the temperature of the triple point of water (0.01°C).

⇨**RGE_5**	**RGE_6**
RGE_7	**RGE_8**
RGE_9	**RGE_10**
RGE_11	

When entering this menu, the cursor position indicates the range currently used by the Super Thermometer for reading temperatures higher than 0.01°C. To change the range, select a new one and press **ENTER**, then leave **POSITIVE_T** menu.

The third line on the display shown above is reached by positioning the cursor on the second line and pressing the key ⇩.

Recommended Temperature Range (POSITIVE_T)		**Coefficients**
RGE_6	0.01°C to 961.78°C	A6, B6, C6 and D
RGE_7	0.01°C to 660.323°C	A7, B7 and C7
RGE_8	0.01°C to 419.527°C	A8 and B8
RGE_9	0.01°C to 231.928°C	A9 and B9
RGE_10	0.01°C to 156.5985°C	A10
RGE_11	0.01°C to 29.7646°C	A11
RGE_5	0.01°C to 29.7646°C	A5 and B5

Table 2 - Temperature Ranges for POSITIVE_T

The configuration of the coefficients of each of the temperature ranges above follows the same considerations taken for the temperature ranges from the **NEGATIVE_T** group.

Note that the **POSITIVE_T** and **NEGATIVE_T** groups include a common mnemonic: **RGE_5**. In case it is required to use its coefficients for the positive and negative ranges, configure the coefficients as usual for both the positive and negative ranges.

Further details on the International Temperature Scale and the interpolation methods used for the coefficients above, refer to: Mangum,B.W. and Furukawa, G.T., “Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)”, *NIST Technical Note 1265*, National Institute of Standards and Technology, 1990.

2.4.2 - CVD and CCVD Coefficients

The CVD coefficients belong to the Callendar-Van Dusen equation: α (Alpha), δ (Delta) and β (Beta). Configure the coefficients as explained on the previous item. The menu for configuring these coefficients is given below:

⇨ALPHA	**EALPHA**
DELTA	**EDELTA**
BETA	**EBETA**

Callendar-Van Dusen equation:

$$R(t) = R_0 \cdot \left\{ 1 + ALPHA \cdot \left[t - DELTA \cdot \left(\frac{t}{100} \right) \cdot \left(\frac{t}{100} - 1 \right) - BETA \cdot \left(\frac{t}{100} - 1 \right) \cdot \left(\frac{t}{100} \right)^3 \right] \right\},$$

BETA = 0 for $t \geq 0$.

The CCVD coefficients belong to the Callendar-Van Dusen equation. In fact, this equation is equivalent to the previous one, but it is arranged in a different way. Its coefficients are: A, B and C. Configure the coefficients as explained on the previous item. The menu for configuring these coefficients is given below:

⇨A	**EA**	**B**	**EB**
C	**EC**		

Callendar and Callendar-Van Dusen equation:

$$R(t) = R_0 \cdot \left\{1 + A \cdot t + B \cdot t^2 + C \cdot t^3 \cdot \left(t - 100^\circ\mathrm{C}\right)\right\}$$, C = 0 for $t \geq 0$.

This equation is usually used with the IPTS-68 temperature scale, where t is referred to the temperature in this scale and R_0, to the resistance at 0°C. Although this equation was not reformulated in the ITS-90 temperature scale, it is also used in this scale.

2.5 - Thermocouple Probe Configuration

Warning: Enter the following options only after understanding them completely because the configuration of the TC calibration parameters can be changed!

The access password for this option is 9875

It is possible to introduce the configuration and calibration parameters of up to 3 TC probes. Select one of the 3 probes:

⇨1	**2**	**3**

Then, go to the configuration of the chosen probe.

⇨TAG	**PARAM**
LIMHI	**LIMLO**

TAG: Identification name of the TC Probe.

LIM_HI: Maximum temperature the Probe may reach or maximum limit which the calibration certificate ensures an uncertainty level. Above this value, the display indicates **OVER**.

LIM_LO: Minimum temperature the Probe may reach or minimum limit which the calibration certificate ensures an uncertainty level. Below this value, the display indicates **UNDER**.

PARAM: Selects the type of parameter set to be used, that is, the interpolation method.

⇨ITS90	**STD90**
STD68	

ITS90: Selects the parameter set under ITS-90 for Thermocouples.

⇨R	**S**	**B**

Choose between R, S or B types.

⇨COEF	**CJC**

COEF: Selects configuration of the thermocouple calibration coefficients (C0, C1, C2 e C3). These coefficients correct the electromotive force (E) given by the linearization table of the thermocouple by the IEC-60751 standard. After correction, the electromotive force of the thermocouple follows this formula:

E' = E + C0 + C1.t + C2.t^2 + C3.t^3, where t is the temperature in °C and E' and E the electromotive force in mV.

⇨C0	**EC0**	**C1**	**EC1**
C2	**EC2**	**C3**	**EC3**

To enter the value of a coefficient, it must be split into a mantissa and an exponent as it is used in scientific notation. For a coefficient C0 equal to -3.05870×10^{-6}, for example, type its mantissa (an integer and a fractional part with seven digits) in the mnemonic C0 and the exponent in the mnemonic EC0. Thus, C0 = -3.0587000 and EC0 = -06.

Note that the signal can be inverted by pressing the key **ZERO** when the number on the display is zero. It changes the signal from **+** to **-**, or vice-versa.

CJC: Selects the type of Cold Junction Compensation: Internal or Manual

⇨ **INTERNAL**
MANUAL

INTERNAL: The instrument itself measures the cold junction temperature, that is, the temperature of the terminal where the thermocouple is connected.

MANUAL: The value of the cold junction temperature must be provided by the operator.

STD68: Selects the linearization table under IEC-60584 and DIN 43710 international norms for the IPTS-68 temperature scale.

STD90: Selects the linearization table under IEC-60584 and DIN 43710 international norms for the ITS-90 temperature scale.

⇨**R**	**S**	**B**	**N**	**C**
J	**K**	**T**	**E**	**L**

29 Choose one of the types **R**, **S**, **B**, **N**, **C**, **J**, **K**, **T**, **E** and **L**.
In the following menu, choose the type of cold junction compensation: internal or manual.

⇨ **INTERNAL**
MANUAL

INTERNAL: The instrument itself measures the cold junction temperature, that is, the temperature of the terminal where the thermocouple is connected.

MANUAL: The value of the cold junction temperature must be provided by the operator.

3 - Super Thermometer Warning Messages

Warning	Meaning	Procedure
RAM ERROR READ MANUAL	Problem in RAM memory	Turn the instrument off and on. If the error persists, contact Presys Technical Support.
EEPROM ERROR READ MANUAL	Problem in EEPROM memory	Same as the previous item
LOW BATTERY	Level of battery voltage is low	Connect the battery charger to ST-501
UNDER / OVER	Input signal out of specifications or range given by LIM_LOW and LIM_HIGH from PRB_RTD	See item 1.1.1 on Input Technical Specifications or see the mnemonics LIM_LOW and LIM_HIGH
???.???ºC	Input sensor is open	Check the input connections of the sensor

4 - Calibration

Warning: Enter the following options only after understanding them completely. Otherwise, it may be necessary to return the instrument to the factory for calibration! For this section Calibration means Adjustment.

Select **CAL** option from the main menu and press **ENTER.** Then enter the PASSWORD **9875** to access the calibration menu.
The password works as a protection to calibration ranges. After entering the password, the menu displays the options:

⇨IN	**DATE**

Then, choose the input range (**IN**). **DATE** is an option which allows you to record the date when the calibration was performed and once it has been filled in, it will be displayed every time the instrument is turned on. The date can only be updated after a calibration (adjust) operation.

The options for **IN** calibration are:

⇨ mV	**OHM**	**CJC**

4.1 - Input Calibration

Select the corresponding mnemonic and apply the signals presented in the tables below.

When calibrating the inputs, the display shows on the 2nd line the value measured by the Super Thermometer and on 1st line the same value is expressed as a percentage.

Note that the applied signals just need to be close to the values shown in the table.

Once the signal has been applied, store the values of the 1st and 2nd calibration points by pressing the keys 1 (1st point) and 2 (2nd point).

For terminals localization purpose, refer to the figure below:

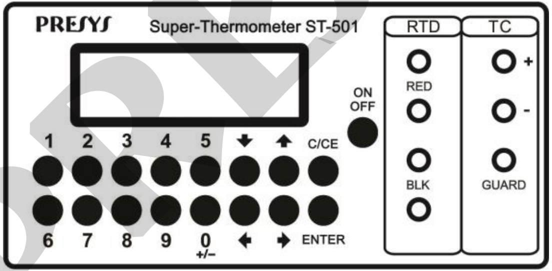

Fig. 5 – Input Calibration

mV Calibration

Use the terminals TC (+) and TC (-).

mV Input	**1st point**	**2nd point**
Single range	0.0000 mV	70.0000 mV

Ohm Calibration

The input calibration for Ω is accomplished in two steps:

a) Application of mV signal:

For the calibrations below, keep the terminals RTD3 and RTD4 short-circuited.

mV Signal	**Terminals**	**1st point**	**2nd point**
G_2	RTD2(+) and RTD3(-)	0.0000 mV	600.0000 mV
G_3	RTD2(+) and RTD3(-)	0.0000 mV	120.0000 mV
G_4	RTD2(+) and RTD3(-)	0.0000 mV	70.0000 mV
V_OHM3	RTD3(+) and TC(-)	250.000 mV	350.000 mV
V_OHM4	RTD4(+) and TC(-)	250.000 mV	350.000 mV

34 b) Application of standard resistors:

Connect a decade box or standard resistors to the terminals RTD1, RTD2, RTD3 and RTD4 (4-wire connection).

Resistors	1st point	2nd point
OHM3	20.000 Ω	50.000 Ω
OHM2	80.000 Ω	150.000 Ω
OHM1	150.000 Ω	400.000 Ω

CJC Calibration

The cold junction calibration (CJC) is performed by measuring the temperature of the terminal TC (-). Store only the 1st point.

Cold Junction	1st point
CJC	32.03ºC

5 - MODBUS Protocol for Serial Communication

The communication protocol defines a language structure for devices connected in a network. That is, it determines how to establish the beginning or end of a contact, how a message is interchanged etc.

In the specific case of MODBUS, the message exchange process is of Master-Slave type. The net, made up of several devices, must have only one device called Master (usually an IBM-PC compatible microcomputer) and the other devices are called Slaves (instruments).

The Master always starts the communication. It can send a message to a certain Slave, identified by a number (address), or to all the Slaves on the net at once (Broadcast-type message). The Slave always answers the Master since the message is not of Broadcast type.

5.1 - Transmission Modes

The message is made up by a group of characters. The character is the smallest information unit. The character transmission complies with certain characteristics configured by the user such as baud rate, parity bit, number of stop bits and transmission mode.

The transmission mode defines the structure of a word to be transmitted. According to MODBUS protocol there are two transmission modes available: RTU and ASCII, however this instrument offers only the RTU mode.

In the RTU mode (Remote Terminal Unit), the character is composed of 8 bits.

For example, the value 177 is expressed in binary system as 10110001 and in hexadecimal system as B1h. Thus the eight bits to be transmitted are 10110001.

5.2 - Error Detection

The MODBUS system has specific methods of handling an error.

A character transmission error is detected by the parity bit or by an error in the character transmission format (start bit and stop bits). Unfortunately, only these two types of error do not assure whether there are errors in a message transmission. To increase the transmission reliability, there is an Error Checking function, which will be explained further.

The Slave which detects a transmission error must abort the message handling and wait for the next message.

The Master expects a return message. If this message is not returned within a certain period of time, the Master must interpret it as a transmission error and retransmit the message. The maximum time the Master waits is a function of the baud rate, transmission mode and the Slave scan time.

5.3 - Message Format

The message format depends on the transmission mode. There are four major fields:

1 - Slave Address
2 - Function Mode
3 - Data
4 - Error Check

The Slave Address field consists of one RTU character. This field identifies the Slave. When the Master wants to exchange a message with a specific Slave, the field value should be the address of that Slave. When the Master wants to send a Broadcast-type message (for all Slaves of the net), this field should be 0.

The Function Code field also consists of one RTU character. This field is related to the function the Slave must perform when receiving the message. The MODBUS protocol allows several functions. However, for communication with this instrument only 5 are enough. Further the available functions are described and exemplified.

The Data field contains the necessary information for the Slave to perform a certain function or the information provided by the Slave in response to the Master.

The Error Check field allows the receiver to check whether there have been message errors during transmission. This field must be filled with algorithm help which calculates a number generated from the words which compose the message. In the RTU mode, the algorithm used is the Cyclic Redundancy Check (CRC). Item 5.6 presents the algorithm written in "C" language.

Message format in RTU mode:

In this format, the message must be sent in a continuous way. The receiver interprets the end of message whenever a period equal to or greater than the time needed to transmit 3 ½ characters is elapsed without receiving any other character.

T1 T2 T3	Slave Address	Function Code	Data	CRC	T1 T2 T3
	1 character	1 character	N x 1 charac.	2 characters	

1 character (charac.) = 8 bits, 1 start bit, 1 or 2 stop bits and 1 optional parity bit

5.4 - MODBUS Functions Description

The available functions are: 3, 4, 6, 8 and 16. The examples below refer to RTU mode. Broadcast-type message is only allowed for functions 6 and 16.

With these functions one can read or modify (write) the value of certain instrument variables. Functions 3, 4, 6 and 16 refer to the register type variables. This type of variables can assume integer values up to two bytes (from 0 to 65535 for unsigned values or from -32768 to 32767 for signed values).

Function 3 - Read Output Registers
Function 4 - Read Input Registers

Query:

These functions are used to obtain the content of one or several consecutive registers of a Slave. Data field must be filled with the initial address of the register, followed by the number of registers whose values are requested. The maximum number of registers allowed by the instrument software is 10.

The message below asks the address 01 Slave to return the value of registers 50, 51, 52 and 53 (totaling 4 registers).

Address	Function	Initial Address (MSB)	Initial Address (LSB)	Number of reg. (MSB)	Number of reg. (LSB)	CRC (MSB)	CRC (LSB)
01	03	00	32	00	04	E5	C6

Note: -The values shown in the figure above and in the next figures are expressed on hexadecimal system.
- MSB stands for most significant byte and LSB for least significant byte.

Response:

Data field should contain the number of characters to be sent, followed by the response characters.

The message below responds the Master that the values of the register values are 0, 0, 7 and 208 respectively.

Addr.	Function	No. of charac.	Reg. 50 (MSB)	Reg. 50 (LSB)	Reg. 51 (MSB)	Reg. 51 (LSB)	Reg. 52 (MSB)	Reg. 52 (LSB)	Reg. 53 (MSB)	Reg. 53 (LSB)	CRC (MSB)	CRC (LSB)
01	03	08	00	00	00	00	00	07	00	D0	25	8A

Function 6 - Preset Single Register

Query:

This function is used for changing the value of a single register of the Slave. Data field must be filled with the register address, followed by its new value.

The message below asks the address 01 Slave to change the value of the register 60 to 1:

Address	Function	Register Address (MSB)	Register Address (LSB)	Register Value (MSB)	Register Value (LSB)	CRC (MSB)	CRC (LSB)
01	06	00	3C	00	01	88	06

Response:

The response message should be identical to that one sent by the Master. It should be transmitted after the register is changed.

For the example above, the Slave should response as follows:

Address	Function	Register Address (MSB)	Register Address (LSB)	Register Value (MSB)	Register Value (LSB)	CRC (MSB)	CRC (LSB)
01	06	00	3C	00	01	88	06

Function 8 - Loopback Test

Query:

The purpose of this function is to test the communication system. Data field must be filled with the diagnostic code (2 bytes) followed by the action to be carried out (2 bytes). The only diagnostic code implemented to this function is zero. Such code asks for the return of the data which were sent (action to be carried out). In this case, the action to be carried out could be any value.

The message below asks the Slave to retransmit the same message:

Address	Function	Diagnostic Code (MSB)	Diagnostic Code (LSB)	Action to be carried out (MSB)	Action to be carried out (LSB)	CRC (MSB)	CRC (LSB)
11	08	00	00	A5	37	D8	1D

Response:

For this diagnostic code (0), the message to be sent should be identical to that transmitted by the Master.

For the example above, the Slave should return the following message:

Address	Function	Diagnostic Code (MSB)	Diagnostic Code (LSB)	Action to be carried out (MSB)	Action to be carried out (LSB)	CRC (MSB)	CRC (LSB)
11	08	00	00	A5	37	D8	1D

Function 16 - Preset Multiple Registers

Query:

This function is used for changing the value of one or several registers of a Slave at once. Data field must be filled with the initial address of the register set, followed by the number of registers to be changed, the number of characters to be sent and the new register values. The maximum number of registers allowed by the instrument software is 10.

The message below asks the address 01 Slave to change the value of register 60 to 01 and the value of register 61 to 0.

Add.	Function	Initial Add MSB	Initial Add LSB	No. of Reg. (MSB)	No. of Reg. (LSB)	No. of charac.	Reg 60 MSB	Reg. 60 LSB	Reg 61 MSB	Reg. 61 LSB	CRC MSB	CRC LSB
01	10	00	3C	00	02	04	00	01	00	00	31	2E

Response:

45 The Data field should be filled with the initial address of the register set and the number of registers changed.

For the example above, the Slave should return the following message:

Address	Function	Initial Address (MSB)	Initial Address (LSB)	No. of Reg. (MSB)	No. of Reg. (LSB)	CRC (MSB)	CRC (LSB)
01	10	00	3C	00	02	81	C4

Error Message

Whenever, by any reason, the Slave can not perform certain action requested by the Master, it must return an error message in the following way:

- The Function Code field must be filled with the Function Code sent by the Master plus 128 units.
- The Data field must be filled with one byte containing the number of the Exception Code. The implemented codes are:

01: when the function requested by the Master is not possible to be performed.
02: when the register address is out of the allowed range.
03: when the value of the Data field is out of the allowed range.

Example:
Suppose the Master asks the Slave to read a register (function 3) whose address does not exist. The Slave should return the following message:

Address	Function	Exception Code	CRC (MSB)	CRC (LSB)
11	83	02	C1	34

5.5 - List of Registers

The table below presents a list with all the registers found in the instrument, the respective addresses and ranges of allowed values.

Address	Registers	Remarks
50 to 53	Input signal	Read only
54	Number of decimals of the input signal	Read only
55 to 58	Cold junction temperature	Read only
59	Number of decimals of cold junction temperature	Read only
60	Presentation of the signal on the display	0 - ohms or mV and cold junction (depending on the configured sensor); 1 - °C or °F
61	Temperature unit to be shown on the display	0 - °C 1 - °F
100 to 109	First to the tenth character of the Tag of RTD Probe 1	‘A’ to ‘Z’, ‘0’ to ‘9’ and ‘ ’.
110 to 113	Maximum temperature shown on the display for RTD Probe 1	Value with 3 decimals

114 to 117	Minimum temperature shown on the display for RTD Probe 1	Value with 3 decimals
118	Type of parameter set or table used for RTD Probe 1	0 - ITS90 1 - CCVD 2 - CVD 3 - STD68 4 - STD90
119	Number of wires for connection of the RTD Probe 1	0 - 3-wire connection 1 - 4-wire connection
120 to 123	Value of R0 for RTD Probe 1	Value with 6 decimals
124 to 127	Mantissa value of parameter A5, A6, A7, A8, A9, A10 or A11 (for ITS90), A (for CCVD) or Alpha (for CVD) expressed in scientific notation for RTD Probe 1	Value with 7 decimals
128	Exponent value of parameter A5, A6, A7, A8, A9, A10 or A11 (for ITS90), A (for CCVD) or Alpha (for CVD) expressed in scientific notation for RTD Probe 1	-19 to 19
129 to 132	Mantissa value of parameter B5, B6, B7, B8 or B9 (for ITS90), B (for CCVD) or Delta (for CVD) expressed em scientific notation for RTD Probe 1	Value with 7 decimals

133	Exponent value of parameter B5, B6, B7, B8 or B9 (for ITS90), B (for CCVD) or Delta (for CVD) expressed in scientific notation for RTD Probe 1	-19 to 19
134 to 137	Mantissa value of parameter C6, C7 (for ITS90), C (for CCVD) or Beta (for CVD) expressed in scientific notation for RTD Probe 1	Value with 7 decimals
138	Exponent value of parameter C6, C7 (for ITS90), C (for CCVD) or Beta (for CVD) expressed in scientific notation for RTD Probe 1	-19 to 19
139 to 142	Mantissa value of parameter D (for ITS90) expressed in scientific notation for RTD Probe 1	Value with 7 decimals
143	Exponent value of parameter D (for ITS90) expressed in scientific notation for RTD Probe 1	-19 to 19
144 to 147	Mantissa value of parameter A4 or A5 (for ITS90 and negative temperature) expressed in scientific notation for RTD Probe 1	Value with 7 decimals
148	Exponent value of parameter A4 or A5 (for ITS90 and negative temperature) expressed in scientific notation for RTD Probe 1	-19 to 19

149 to 152	Mantissa value of parameter B4 or B5 (for ITS90 and negative temperature) expressed in scientific notation for RTD Probe 1	Value with 7 decimals
153	Exponent value of parameter B4 or B5 (for ITS90 and negative temperature) expressed in scientific notation for RTD Probe 1	-19 to 19
154	Parameters used for measurements of positive temperature for RTD Probe 1	0 - A5 and B5 1 - A6, B6, C6 and D 2 - A7, B7 and C7 3 - A8 and B8 4 - A9 and B9 5 - A10 6 - A11
155	Parameters used for measurements of negative temperature for RTD Probe 1	0 - A4 and B4 1 - A5 and B5
156 to 211	Same as parameters 100 to 155, but referring to RTD Probe 2	
212 to 267	Same as parameters 100 to 155, but referring to RTD Probe 3	

268 to 277	First to the tenth character of the Tag of TC Probe 1	‘A’ to ‘Z’, ‘0’ to ‘9’ and ‘ ’.
278 to 281	Maximum temperature shown on the display for TC Probe 1	Value with 2 decimals
282 to 285	Minimum temperature shown on the display for TC Probe 1	Value with 2 decimals
286	Type of parameter set or table used for TC Probe 1	0 - ITS90 1 – STD90 2 – STD68
287	Selects the type of thermocouple of TC Probe 1	0 - thermocouple R 1 - thermocouple S 2 - thermocouple B 3 - thermocouple N 4 - thermocouple C 5 - thermocouple J 6 - thermocouple K 7 - thermocouple T 8 - thermocouple E 9 - thermocouple L
288	Selects the type of cold junction compensation of TC Probe 1	0 - internal 1 - manual

289 and 290	Cold junction compensation temperature for manual mode of TC Probe 1	Value with 2 decimals
291	Temperature unit for TC Probe 1	0 - °C 1 - °F
292 to 295	Mantissa value of parameter C0 (for ITS90) expressed in scientific notation for TC Probe 1	Value with 7 decimals
296	Exponent value of parameter C0 (for ITS90) expressed in scientific notation for TC Probe 1	-19 to 19
297 to 300	Mantissa value of parameter C1 (for ITS90) expressed in scientific notation for TC Probe 1	Value with 7 decimals
301	Exponent value of parameter C1 (for ITS90) expressed in scientific notation for TC Probe 1	-19 to 19
302 to 305	Mantissa value of parameter C2 (for ITS90) expressed in scientific notation for TC Probe 1	Value with 7 decimals
306	Exponent value of parameter C2 (for ITS90) expressed in scientific notation for TC Probe 1	-19 to 19
307 to 310	Mantissa value of parameter C3 (for ITS90) expressed in scientific notation for TC Probe 1	Value with 7 decimals

311	Exponent value of parameter C3 (for ITS90) expressed in scientific notation for TC Probe 1	-19 to 19
312 to 355	Same as parameters 268 to 311, but referring to TC Probe 2	
356 to 399	Same as parameters 268 to 311, but referring to TC Probe 3	
400	Selects the reading of RTD or TC	0 - RTD 1 - TC
401	Selects one of the 3 RTD Probes	0 - RTD Probe 1 1 - RTD Probe 2 2 - RTD Probe 3
402	Selects one of the 3 TC Probes	0 - TC Probe 1 1 - TC Probe 2 2 - TC Probe 3

Note:

The value ranges of certain registers listed in the table above have a fixed number of decimals. For purpose of message formation, one should ignore the presence of this decimal point since it is fixed. So, in order to change the temperature value of cold junction compensation (registers 385|386) to 30.35°C, for example, it is necessary that the values from the two registers change (most significant byte and least significant byte) so that the resulting value is 3035.

(*i*) The values formed by 4 consecutive registers have a long integer format, each register corresponding to one byte of the long integer (the most significant byte belongs to the register with the smallest identification number). For instance, the value 300001 (000493E1h, in hexadecimal system) is read by registers 50 to 53 as: 0|4|147|225 or 0h|4h|93h|E1h (in hexadecimal system).

5.6 - Algorithm for Check Error Field

The procedure below presents the algorithm for calculating this field in “C” language.

```
unsigned int CalcCRC ( unsigned char *Str , unsigned char NumBytes )
  {
  unsigned intCrc = 0xFFFF;
  unsigned chari , j;

  for (i = 0 ; i < NumBytes ; i++)
    {
    Crc ^= Str[i];
    for (j = 0 ; j < 8 ; j++)
      {
      if (Crc & 1)
        {
        Crc >>= 1;
        Crc ^= 0xA001;
        }
```

```
            else
              Crc >>= 1;
        }
      }
  return ( Crc );
  }
```

Note: The actual CRC value corresponds to the return value of this function with the most significant byte replaced by the least significant byte.

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