Temperature transducer EDT 101

User manual

Rev. 6

December 2019

This document provides functional description, installation, configuration and operating instructions for ELGAS EDT 101 temperature transducer with Modbus protocol. The information in this document covers software revision 3.11.

Information in this document is subject to change without notice and does not represent a commitment on the part of ELGAS, s.r.o. Improvements and/or changes in this manual or the product may be made at any time. These changes will be made periodically to correct technical inaccuracies or typographical errors.

Contents

Abbreviations and terms

char	8-bit signed integer value
CRC	Cyclical Redundancy Check
dec	Decimal representation
EEPROM	Electrically erasable non-volatile memory
float	32-bit single precision floating point value
hex	Full scale
int	Hexadecimal representation
Modbus	16-bit signed integer value
MSB	The least significant byte
LSB	A vendor-neutral communication protocol intended for supervision and control of automation equipment.
RS 485	The most significant byte
RTU	Standard for data transmission, where a balanced (differential) transmission line is used in a multidrop configuration.
uchar	Remote terminal unit. One of two serial transmission modes of the Modbus communication protocol.
uint	8-bit unsigned integer value

1 Introduction

Temperature transducer EDT 101 (hereinafter “transducer”) is a miniature precision device intended for temperature measurement in applications which require a high precision and ultra-low power consumption. The transducer has RS 485 digital interface, which makes it ideal for use in modern digital systems.

The transducer is dedicated to connect with data loggers, gas-volume correction devices and telemetric systems.

Regarding safety, the transducer is designed to comply with the EN 60079-11 as an intrinsically safe device and is approved for potentially explosive atmospheres. The transducer is manufactured and delivered in compliance with the following guidelines of the European Parliament:

- 2014/34/EU relating to equipment and protective systems intended for use in potentially explosive atmospheres
- 2014/30/EU relating to electromagnetic compatibility

Basic features

- Ranges -25 .. +70°C or -40 .. +70°C
- RS 485 digital interface, Modbus communication protocol
- Ultra-low power consumption: 3 µA standby, 1 mA active, supply voltage from 2.8V
- High accuracy: ±0.2°C
- Small size, rugged housing
- Certified as explosion-proof with type of protection II1G Ex ia IIC T4 Ga

2 Device overview

2.1 Technical Description

Chyba! Nenalezen zdroj odkazů. shows functional diagram of the transducer. Temperature is measured by platinum resistive sensor. The signal from the sensor is converted by a high-resolution analog-to-digital converter into digital form and processed by the microcontroller. Microcontroller digitally compensates the non-linearity of the sensor using calibration data. The calibration data is stored in non-volatile EEPROM memory during transducer manufacturing.

Temperature readout as well as all control functions are accessible via RS 485 interface. The transducer is capable to measure the temperature on request or continuously in preset time intervals and store values in its internal memory for later retrieval.

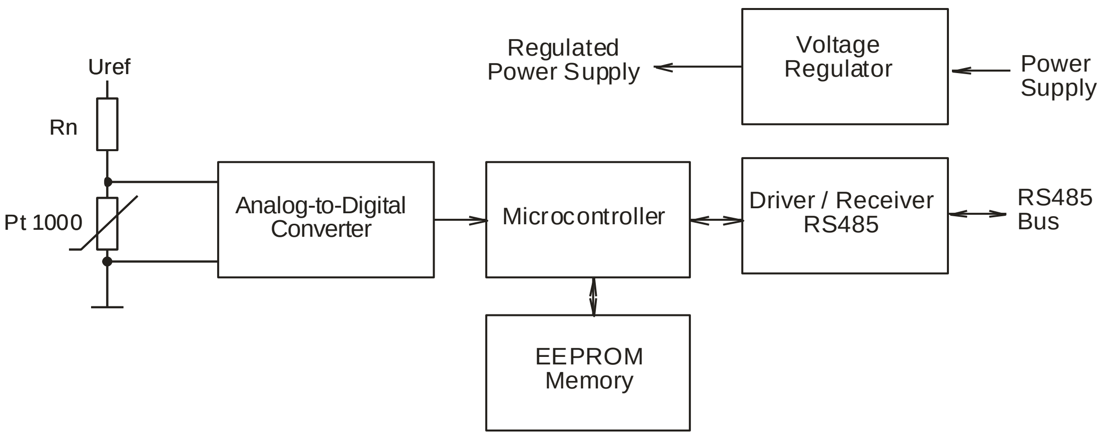

Figure 1. Functional diagram of the transducer

Physically, the transducer consists of the temperature sensor mounted in stainless-steel stem 50 mm long and the cable. A cylindrical plastic case with electronics is integrated into the cable.

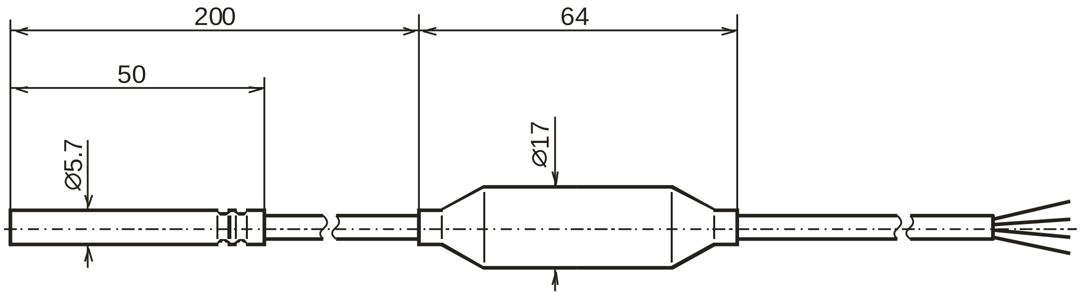

Figure 2. Dimensional drawing of the transducer.

2.2 Device specification

Measurement ranges

Standard range: -25°C to +70°C
Extended range: -40°C to +70°C

Temperature sensor

Platinum resistive element Pt 1000 mounted in ANSI 316L stainless-steel stem, stem diameter: 5.7 mm, stem length: 50 mm standard

Measured media

Liquids and gases, chemically compatible with stainless-steel ANSI 316L

Accuracy

±0.2°C within the full measurement range
Includes non-linearity, repeatability and long-term stability.

Electrical connection

Integral shielded cable 4 x 0.25 mm^2 length 2.6 m with external diameter between 5 to 7 mm. Other lengths of cable on request. Cable shielding is not connected to the stainless-steel stem.

Power supply

The transducer requires external DC power supply. Transducer terminal voltage must be between 2.8 to 5.0 V

Power consumption

Standby: 3 µA typical / 10 µA maximum

Measurement and communication: 0.8 mA typical / 4 mA maximum

Power consumption is not dependent on the supply voltage. Power consumption during the communication depends on the bus impedance.

Start-up time

The transducer is ready to operate 20 ms after power supply is applied.

Communication interface

RS 485, 2-wire, half-duplex, minimum bus impedance 1.5 kΩ. Unterminated bus is recommended for low-power consumption. Maximum wiring length is 100 m.

Communication protocol

Modbus RTU, speed 38400 bit/s, 1 start bit, 8 data bits, no parity, 1 stop bit. Standard functions supported: Read holding registers (code 03h), Force single coil (code 05h) and Write holding registers (code 10h). Non-standard functions with codes 45h, 46h, 47h, 48h are implemented.

Datalogging

The transducer is able to measure temprature automatically in regular intervals and store the measured values in the memory to be retrieved from later on.

Measurement period:	adjustable 125 ms to 512 s
Data memory capacity:	80 values
Time base accuracy:	±100 ppm

Electric insulation

Resistance between the stem/cable shielding and signal or power supply wires is greater than 10 MΩ at 500 V AC.

Physical specifications

Dimensions: see chapter 2.1
Weight: 100 – 150 g (depending on mechanical version)

Environmental specifications

Operating temperature:	-40°C to +70°C as sandard
Storage temperature:	-40°C to +85°C
Humidity:	0% to 95% relative, without condensation
Protection:	IP 65

Vibrations: 10 g sinus 10-2000Hz, ČSN EN 60068-2-6 [3]

Electromagnetic compatibility

Complies with immunity requirements for industrial environments EN 61000-6-2 [2]

Explosion-proof design

Equipment with the “i” protection type (intrinsically safe equipment) in compliance with EN 60079-0 [4] and EN 60079-11 [5]. The certificate registered under No. FTZÚ 18 ATEX 0142X at the Physical-Technical Testing Institute Ostrava-Radvanice, notified body No. 1026.

Environment classification: Zone 1, 2 according to the EN 60079-14 [6]

Protection class: II1G Ex ia IIC T4 Ga

Safety descriptions:
U_i = 9.9 V
C_i = 2.65 µF
L_i = 0 µH
P_i = 1.10 W for T_a<70°C

3 Installation

3.1 Mechanical Installation

Temperature transducer is intended for mounting into a thermowell on piping. Operating position of the transducer is arbitrary. The depth of the thermowell must be 50 mm minimum. The transducer stem must be inserted to the very bottom of the thermowell and secured by the fastening nut against pulling-out. It is recommended to fill the space around the stem inside the thermowell with silicone oil.

3.2 Electrical installation

Wires in the cable or the connector pins carry the following signals:

Signal	Description	color
GND	negative power rail (ground)	green
PWR	positive power rail	brown
DATA-	RS 485 inverted data signal	yellow
DATA+	RS 485 non-inverted signal	white

To operate the transducer, apply DC voltage 2.8 to 5.0 V across PWR and GND terminals and connect the DATA+, DATA- signals with the corresponding terminals on the host RS 485 port. The transducer does not provide electrical insulation between the RS 485 bus and the transducer power supply.

Fig. 3 shows connection of the transducers into the data network. In the RS 485 network, up to 32 units can be connected at the same time while every unit must have a unique slave address set.

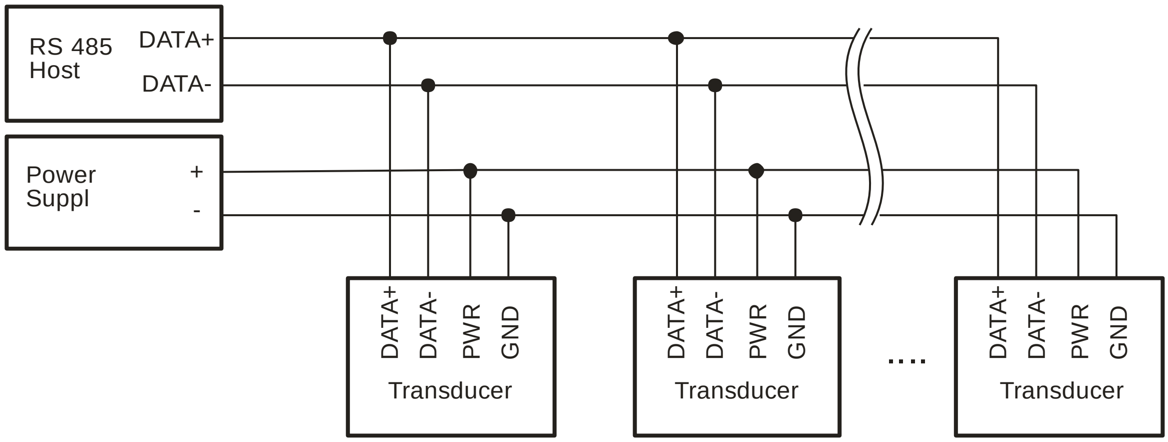

Fig.3 Transducers connection into data network.

To achieve low power consumption, the transducer uses a special RS 485 driver with limited slew rate. It is recommended to leave the RS 485 bus unterminated to maintain power consumption as low as possible. The bus impedance must not be lower than 1.5 kΩ. The length of the bus should not exceed 100 m. Otherwise, a signal distortion due to reflections can occur and communication reliability can be deteriorated.

Any standard RS 485 driver / receiver can be used in the host, however for the low power applications with unterminated bus it is recommended to use a driver with a reduced slew-rate and a receiver with a high input impedance. Suitable types are MAX 3471 form Maxim Integrated Products or ADM 483E from Analog Devices.

3.3 Cabling, grounding

The transducer is interconnected with the host using a shielded 4-wire. The cable should not be laid along power cables, lightning conductors and long metal objects, it should not pass through areas with strong electro-magnetic disturbances or discharges.

The cable shielding on the side of the host should be connected with ground and with the host enclosure, if this is metallic. The cable shielding is not connected to the transducer stainless-steel stem.

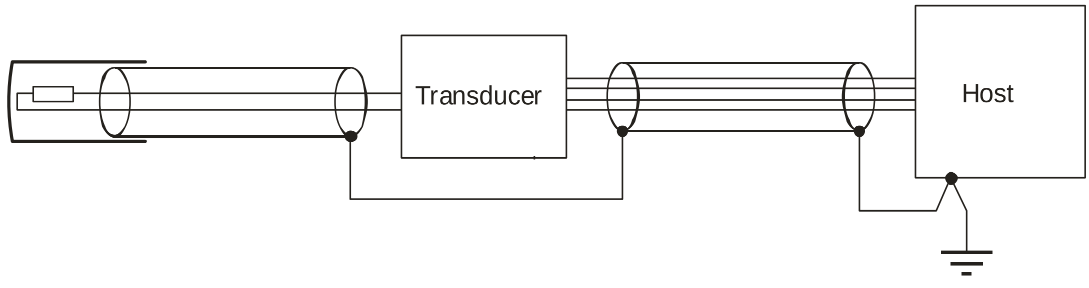

Fig. 4. Transducer grounding

3.4 Power Supply Requirements

The transducer is optimized for very low-power applications. It operates from unregulated single supply voltage in range 2.8 V to 5.0 V. The supply current is independent from the supply voltage.

The transducer uses an advanced algorithm to maintain the power consumption at a minimum level. Only the modules of the transducer which are necessary for the requested function are powered on. Due to the power consumption management, the supply current varies significantly depending on the function being performed. Figure 5 shows an example of the supply current profile. The first part shows a supply current waveform, when a simple query is received, processed and responded back on the RS 485 bus by the transducer. The second part shows a supply current waveform during measurement.

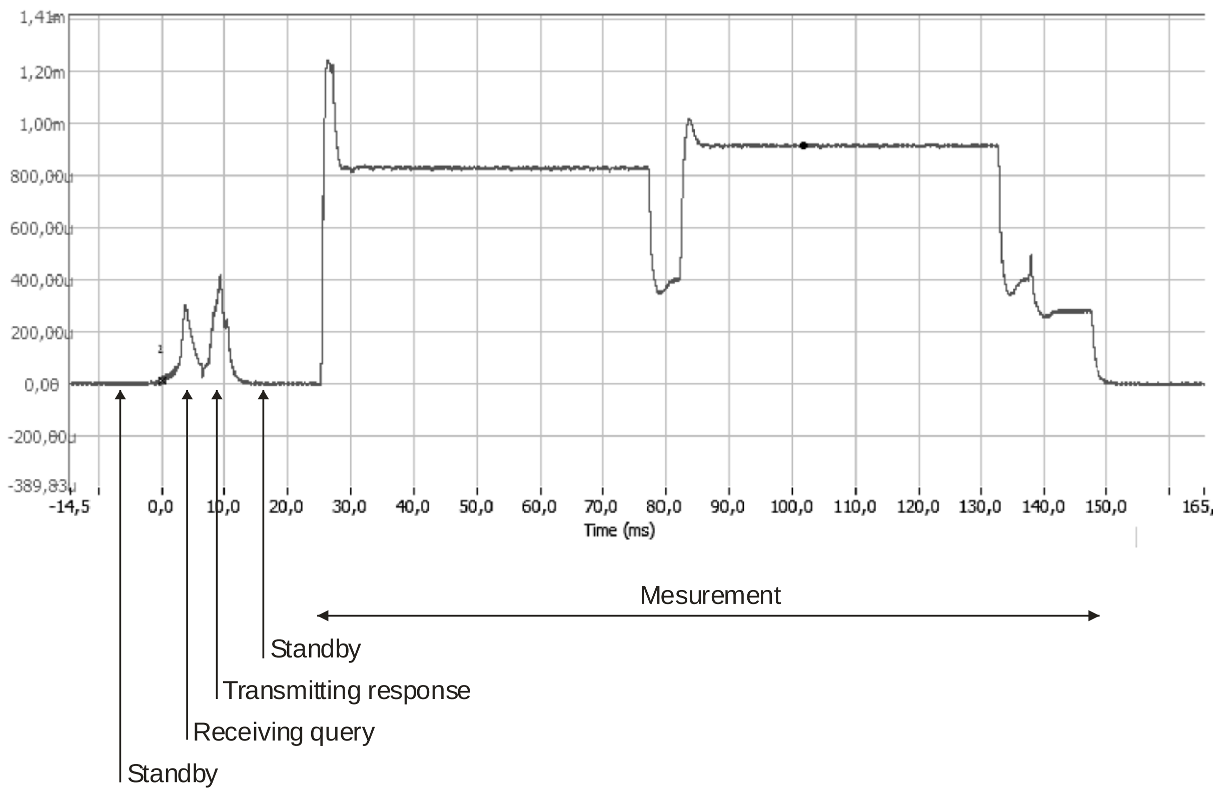

Fig. 5 Supply current profile example.

The following table summarizes transducer’s typical average supply current for various measurement periods. The values include power consumption during the measurement and during necessary communication with the host to initiate the measurement and read measured values.

Measurement period [s]	Average supply current [µA]
Continuous measurement	800
1	100
10	10
30	6
Standby	3

4 Modbus Communication Protocol

The following text describes implementation of the Modbus communication protocol in the transducer. In order to assure a complete understanding of the operation of the device, the user should familiarize himself with the Modbus protocol in detail in the reference literature [1].

Numeric values are given in decimal representation by default. If hexadecimal representation is used, suffix “h” or “hex” is added.

4.1 Modbus Protocol Overview

The transducer is a Modbus compatible measurement device. The transducer supports 8-bit Remote Terminal Unit (RTU) data transmission mode with a subset of the standard commands used by the most Modbus compatible host controllers and a few proprietary commands.

4.1.1 Physical Communication Layer

Communication is carried over the RS 485 bus at baud rate 38400 bit/s. The transmitted characters have 1 start bit, 8 data bits and no parity, 1 stop bit. These parameters are not configurable.

4.1.2 Transactions on Modbus networks

The Modbus protocol uses a master/slave technique to control bus access. There can be one master and up to 247 slave devices. Only the master can initiate a transaction. Transactions are either a query/response or broadcast/no response. During the query/response transaction master sends a query to the single slave which process it and responds. During the broadcast/no response transaction the query is processed by all slave devices but none of them responds.

Queries, responses and broadcasts are transmitted as frames with a fixed structure. In RTU mode, frames start with a silent interval of at least 3.5 character times. The first field then transmitted is the address field followed by a function field, a data field, and CRC field. Following the last transmitted character, a silent interval of at least 3.5 character times marks the end of the frame. A new frame can begin after this interval.

The entire message frame must be transmitted as a continuous stream. If a silent interval of more than 1.5 character times occurs before completion of the frame, the receiving device ignores the incomplete message and assumes that the next byte will be the address field of a new message.

Frame format

Start 3.5 char times	Address field 1 char	Function field 1 char	Data field n chars	CRC field 2 chars	End 3.5 char times

Address field

In a query frame, the address field contains a slave address. In a response frame, the address field contains the address of the responding slave device.

Valid slave addresses are in the range of 1 – 247 decimal. Address 0 is reserved for broadcast messages. Any query message with a slave address of 0 is a broadcast message which all slave devices process but they do not generate any response.

Function field

In a query frame or a broadcast frame, the function field contains a function code, which indicates the command to be performed. In a response frame, the function field contains a copy of the function code received in the query. If the most significant bit in the function field is set, an error occurred during the query processing. In this case the data field contains an exception code that explains the particular error.

Data field

The data field contains information that is specific to each individual function.

CRC field

The CRC field contains a 16 bit CRC error check value that is used to verify the integrity of the message frame.

4.2 Device Specific Features

4.2.1 Service Address

Due to the small dimensions of the transducer, no DIP switches or similar components can be used for slave address setting. Instead, the slave address is software configurable. In some cases, however, the slave address can be unknown. Thus, a service address 248 (dec) has been assigned which the transducer always responds.

Any query frame with a slave address of 248 (dec) the transducer processes and generates a response. The response is returned with the actual slave address in the address field instead of the service address 248 (dec). When using the service address, only one transducer may be connected on the bus with the only exception of the query with the “48h” function code as described hereinafter in chapter **Chyba! Nenalezen zdroj odkazů.**.

4.2.2 Communication Buffer Length

The transducer implements communication buffer 64 bytes long. If the length of the query frame exceeds capacity of the buffer, the frame is flushed and no response is generated. If the master requires such amount of data to be sent which exceeds the capacity of the buffer, the response is truncated to the total frame length of 64 bytes.

4.2.3 Response Time

The transducer responds 4 to 20 ms after the last character of the query has been received. The exact time of the response depends on the query length, response length and on the function processed.

4.3 Holding Registers Map

The transducer's memory is mapped into Modbus holding registers address space (*4xxxx* reference). This address space can be read by the Read multiple registers (03h) command and written by the Write multiple registers (10h) command. The commands are described in chapter **Chyba! Nenalezen zdroj odkazů.**. All registers are 16-bit long.

Register numbers shown in the text are in the *4xxxx* format which follows the Modicon protocol specification for data item addressing. The actual register address sent in the Modbus message frame is the register number shown in the text minus 40001. In other words, the leading "4" is omitted, and the remaining 4-digit number is decremented by 1.

4.3.1 Holding Registers Map Overview

An overview of all holding registers of the transducer is shown in the table. Description of the individual registers is in the following paragraphs.

Section name	Register number	Register name	Data type	Access control	Stored in EEPROM
Factory configuration	40001	Hardware revision number	uint	FP	N
	40002	Software revision number	uint	read only	N
	40003 – 40004	Serial number	ulong	FP	Y
	40005	Sensor type	uint	FP	Y
	40006	not used		FP	Y
	40007	Units	uint	FP	Y
	40008 – 40009	Operation range lower limit	float	FP	Y
	40010 – 40011	Operation range upper limit	float	FP	Y
	40012 – 40013	Measurement range lower limit	float	FP	Y
	40014 – 40015	Measurement range upper limit	float	FP	Y
	40016	not used		FP	Y
	40017	Primary channel offset+gain	uint	FP	Y
	40018	Auxiliary channel offset+gain	uint	FP	Y
	40019 – 40052	Calibration coefficients	float[17]	FP	Y
	40053	Coefficient format	uint	FP	Y
	40054	not used		FP	Y

Holding register map overview - 2nd part

Section name	Register number	Register name	Data type	Access control	Stored in EEPROM
Service config.	40055 – 40056	Offset trim	float	SP	Y
	40057 – 40058	Span trim	float	SP	Y
	40059 – 40061	not used		SP	Y
User config.	40062	Modbus slave address	uchar	UP	Y
	40063	Group assignment register	uchar	UP	Y
	40064	Default operation mode	uchar	UP	Y
	40065 – 40066	for internal use, do not change		UP	Y
Misc.	40067 – 40068	Password	ulong	N	N
	40069 – 40071	not used		N	N
Measured variables	40072 – 40073	Primary chan. direct readout	float	N	N
	40074 – 40075	Auxiliary chan. direct readout	float	N	N
	40076 – 40081	not used		N	N
	40082	Temperature	uint	N	N
	40083	Status register	uint	N	N
	40084	not used		N	N
Datalogger section	40085	Delay	uint	N	N
	40086	Period	uint	N	N
	40087	Number of samples	uint	N	N
	40088 – 40167	Data memory	uint[80]	N	N

Memory locations marked in column "Stored in EEPROM" as "Y" can be stored into the transducer's non-volatile EEPROM memory using Write EEPROM function (see paragraph 4.4.3). The stored configuration is recalled after power-up or using Read EEPROM function (see paragraph **Chyba! Nenalezen zdroj odkazů.**).

Memory locations marked in column "Access control" as "N" can be read and written with no restrictions. Memory locations marked as "FP" (Factory password), "SP" (Service password) and "UP" (User password) can be read without restriction, but can be written only when the particular section is unlocked using a password. The unlocking procedure is described in paragraphs **Chyba! Nenalezen zdroj odkazů.** and **Chyba! Nenalezen zdroj odkazů.**.

4.3.2 Factory configuration section

This section contains a basic information about the transducer and calibration data. The parameters are entered during manufacturing and calibration procedures and cannot be changed by the user.

Hardware revision number identifies a version of the transducer's hardware.

Software revision number identifies a version of the transducer's software. MSB indicates a main revision number, LSB sub-revision number.

Serial number identifies each transducer individually.

Sensor type. Information about the type of the sensor. Code 10h is used for the temperature sensor.

Units. Information about physical units used for Measurement and Operation range limits representation. Code 20h is used for °C.

Measurement range lower and upper limit provide the range of input temperature in which the transducer is calibrated and in which measures with the specified accuracy.

Operation range lower and upper limit provide the range of input temperature which is correctly handled by the analog-to-digital converter and numerical calculation. If the temperature value is outside the measurement range but inside the operation range, the measurements are still performed but the accuracy is undefined.

Standard values of the limits of the measurement and operation range are shown in the following table:

Transducer range (information on label)	Measurement range [°C]		Operation range [°C]	
	Lower limit	Upper limit	Lower limit	Upper limit
-25°C to +70°C	-25	70	-50	100
-40°C to +70°C	-40	70	-50	100

Primary channel offset and gain provide an offset and gain of the analog-to-digital converter when primary channel (temperature) is measured. The offset is stored in the MSB of the register, the gain in the LSB.

Auxiliary channel offset and gain provide an offset and gain of the analog-to-digital converter when auxiliary channel is measured. The offset is stored in the MSB of the register, the gain in the LSB.

Calibration coefficients are used to calculate actual temperature using values obtained from the analog-to-digital converter for the primary and auxiliary channel.

Coefficient format specifies a layout of the coefficients and algorithm for calculation.

4.3.3 Service Configuration Section

Parameters in the Service configuration section allows to adjust the offset and span of the transducer. The default parameters are entered during calibration procedure and can be changed only by an authorized person using Service password.

Offset trim is an additive constant which defines the shift of the transducer characteristics relative to the factory calibration data. When the transducer is factory calibrated, the Offset trim is set to 0.0000. During the field calibration the value can be changed to compensate for possible characteristics deviation.

Span trim is a multiplicative constant which defines the change of the slope of the transducer characteristics relative to the factory calibration data. When the transducer is factory calibrated, the Span trim is set to 1.0000. During the field calibration the value can be changed to compensate for possible characteristics deviation.

4.3.4 User configuration section

User configuration section contains parameters used for Modbus network setup. The section is protected by the User password to prevent accidental change of settings.

Modbus slave address contains address to which the transducer responds. When entering a new address, this is valid immediately after writing to this register.

Group assignment register defines group(s) the transducer belongs to. Transducers belonging to the same group can be forced to start measurement simultaneously by a single Start measurement with mask command transmitted as broadcast as described in paragraph 4.5.4.

Default operation mode specifies whether the transducer after power-up or reset starts the continuous temperature measurement or not. When changing this register, Write EEPROM command must be issued to store the change in the EEPROM memory.

Code	**Default operation mode**
00h	standby
01h	continuous measurement

4.3.5 Miscellaneous

This section contains registers used for password manipulation. The password protects write access to the configuration sections.

Password. After writing correct value to the password registers, desired section can be unlocked for writing by Unlock section function (see paragraphs **Chyba! Nenalezen zdroj odkazů.** a **Chyba! Nenalezen zdroj odkazů.**).

4.3.6 Measured variables

In this section, measured and calculated variables are stored. All variables are updated at the end of each single temperature measurement.

Primary channel direct readout store value measured directly by the analog-to-digital converter for the primary channel. The value is presented for factory purposes and it is not significant for user.

Auxiliary channel direct readout store value measured directly by the analog-to-digital converter for the auxiliary channel (not used for temperature measurement). The value is presented for factory purposes and it is not significant for user.

Temperature stores actual measured temperature. The value stored as unsigned integer with range from 0 to 65535. 0 corresponds to the Operating range lower limit and 65535 corresponds to the Operating range upper limit. Temperature in the physical units can be calculated using formula

t = Temperature / 65535 * (Operation range upper limit - Operation range lower limit) +
+ Operation range lower limit

where Temperature is the value read form the register 40082, Operation range lower limit is the value read from registers 40008 – 40009 and Operation range upper limit is the value read from registers 40010 – 40011.

Status register stores information about transducer's status. Description of the particular bits is given in the following table:

Bit	Name	Description
15	EEPROM error	The bit is set if the internally generated EEPROM checksum does not match the stored value. Possible malfunction of the transducer may be expected in this case (see sections 4.4.3 and 4.4.4)
14	Sensor error	The bit is set if sensor or AD converter failure is detected. Temperature readout cannot be considered as reliable in this case (see section 4.4.6)
13	Out of range	The bit is set if the measured temperature is outside the measurement range. The measurement accuracy is lower compared to the specified.
12	Timing error	The bit is set when timing error during datalogging is detected. Measurement period is shorter the time required to complete one measurement (see section 4.5.5)
11	Data memory overflow	The bit is set when the data memory overflows. This can happen when the datalogging is in progress and master fails to read and erase the stored data quickly enough (see sections 4.5.5 and 4.5.6)
4 - 10	Not used	
3	Continuous mode	The bit is set when the transducer is in continuous measurement mode (see section 4.4.7)
2	Start command received	The bit is set after receiving the Start measurement command. Master can test this bit to determine whether Start command transmitted as broadcast was accepted by the transducer. The bit is reset after the first Read multiple registers command (see section 4.4.6)
1	Datalogging in progress	The bit is set as long as the datalogging is in progress (see section 4.5.5)
0	Measurement in progress	The bit is set as long as the temperature measurement is in progress. The master can poll this bit to determine end of the measurement (see section 4.4.6)

4.3.7 Datalogger section

Datalogger registers store the values measured during datalogging and a few related parameters. The detailed description of using the transducer as a datalogger is given in the paragraph 4.5.5.

Delay stores copy of the Delay parameter passed by the Synchronize Datalogging command.

Period stores copy of the Period parameter passed by the Synchronize Datalogging command.

Number of samples gives the actual number of samples stored in the Data memory.

Data registers store temperature samples measured during datalogging. The registers are being filled starting with register 40088 and continuing towards higher register numbers. The oldest sample can be found in the register 40088, the most recent one in the register

Most recent sample register no. = 40088 + Number of samples - 1.

Each sample is represented as unsigned integer which can be converted to temperature in physical units using formula given in paragraph 4.3.6.

4.3.8 Data types

A few different data types are used to represent various parameters stored in the transducer's memory:

uchar 8-bit unsigned value. Range from 0 to +255. The 8-bit value is stored in the Least significant byte of the 16-bit register. The most significant byte of the 16-bit register is ignored however it is recommended to write it always as 0x00.

int 16-bit signed value in 2's complement format. Range from –32768 to +32767.

uint 16-bit unsigned value. Range from 0 to 65535.

ulong 32-bit unsigned value stored in two subsequent 16-bit registers. Higher order bits are stored in register n, lower order bits in register n+1. Range from 0 to 4294967295.

float 32-bit single precision floating point value stored in two subsequent 16-bit registers.
Register n, `[EEEE EEEE SMMM MMMM]` – exponent (offset 129), sign and mantisa
Register n+1, `[MMMM MMMM MMMM MMMM]` – mantisa
examples: +100.25 is coded as 8748h, 8000h
-12.5 is coded as 84C8h, 0000h
+3.1415 is coded as 8249h, 0E56h

4.4 Discrete outputs map

Discrete outputs (coils) can be set by the Force single coil (05h) command. Discrete outputs address space is accessible only for writing. Reading is not supported.

Physically, the transducer does not have any discrete outputs. Discrete outputs address space is implemented to allow access to several functions. Forcing a particular discrete output into ON state starts the assigned function (starts a single measurement, for example).

4.4.1 Overview of the discrete outputs map

Modbus coil numbers shown in the text are in the 0*xxxx* format which follow the Modicon protocol specification for data items addressing. The actual coil address sent in the Modbus message frame is the coil number shown in the text minus 1.

The following table shows the discrete outputs map of the transducer. Individual functions are described in the subsequent paragraphs.

Coil no.	Coil / Function name
0001	Reset
0002	Write EEPROM
0003	Read EEPROM
0004	Stop measurement
0005	Start single measurement
0006	Start continuous measurement
0017	Unlock user configuration section
0018	Unlock service configuration section
0025	Change user password
0026	Change service password

4.4.2 Reset

Forcing the Master reset coil ON performs a software reset of the transducer. This is similar to shutting off the power and then reapplying power. The Master reset takes approximately 20 milliseconds to complete. The force master reset coil ON query is not responded.

4.4.3 Write EEPROM

Forcing the Write EEPROM coil ON writes copy of the registers 40003 to 40066 into EEPROM memory. The registers 40003 to 40066 hold the transducer's configuration which is recalled after power-up or by function Read EEPROM. Write cycle takes 10 ms to complete. Any query received during this time is responded with Exception response code 06 – Slave device busy.

4.4.4 Read EEPROM

Forcing the Read EEPROM coil ON recalls transducer's configuration from the EEPROM memory and stores it into registers 40003 to 40066. When the data stored in EEPROM are corrupted (internally generated checksum does not match the stored value), bit 15 (EEPROM error) in the Status register is set to indicate possible malfunction of the transducer.

4.4.5 Stop measurement.

Forcing the Stop measurement coil ON stops the single measurement, continuous measurement or datalogging if this is in progress, otherwise the function has no effect.

4.4.6 Start single measurement.

Forcing the Start measurement coil ON starts a single measurement of temperature. The query is responded immediately, but the measurement takes 120 ms. During the time when the measurement is in progress, bit 0 (Measurement in progress) in the Status register is set. Polling this bit enables a host to determine the end of the measurement. Until the measurement is completed, the registers in the Measured variables section contain the old values. These are replaced with new values as soon as the measurement is complete.

After the measurement is completed, bit 14 in the Status register is set when a sensor or analog-to-digital converter failure is detected.

A typical procedure executed by the master to measure temperature is shown in **Chyba! Nenalezen zdroj odkazů.**6. The master sends a query with the function Start measurement. The transducer responds and starts the measurement simultaneously. After receiving the response, the master waits until the measurement is finished. The master can either wait for a fixed time which is equal or longer than the measurement time (see paragraph 4.3.3) or it can poll bit 0 (Measurement in progress) of the Status register to determine the end of the measurement (see paragraph 4.3.6). As soon as the fixed time interval elapse or Status register bit 0 is reset, the measurement is complete and the master reads the value of measured temperature.

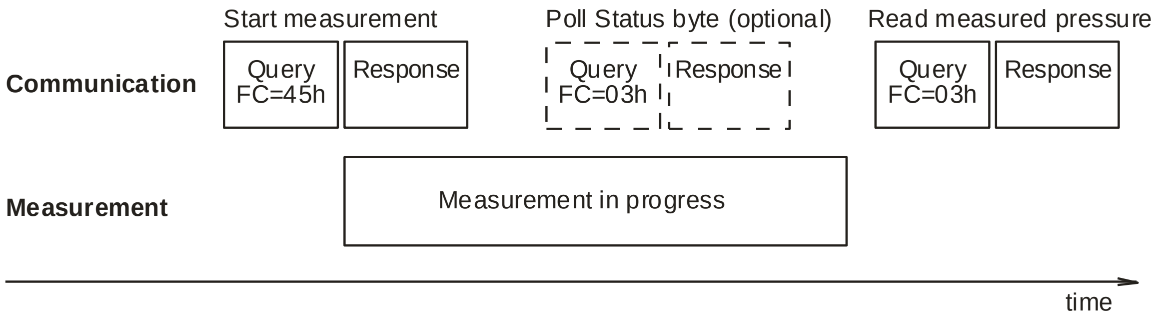

Figure 6. Using Start measurement command.

4.4.7 Start continuous measurement.

Forcing the Start continuous measurement coil ON starts a continuous measurement of temperature. During the continuous measurement mode, the temperature measurements are started and measured variables are updated automatically at the fastest possible rate. The update rate is 125 ms.

During the continuous measurement, bit 3 (Continuous mode) in the Status register is set.

If the continuous measurement mode is required to be entered automatically after power-up or reset, value 0x01 should be written into the Default operation mode register (register no. 40064) and Write EERPOM command must be issued.

4.4.8 Unlock user configuration section

Forcing the Unlock user configuration section coil ON when the correct value is written in the Password registers unlocks the user configuration section of registers 40062 – 40066 for write operation.

To unlock and write into the User configuration section, the following procedure has to be executed:

1. Write correct password into registers 40067 – 40068 using the Write multiple registers command
2. Force coil 0017 (Unlock user configuration section) ON. If the password is correct, the normal response is returned and the desired section is unlocked. If the password is incorrect, the exception response 03 – Illegal data is returned and the section remains locked.
3. Write memory locations in the User configuration section by the Write multiple registers command.

The section is then unlocked only for one Write multiple registers command. After the Write command is complete, the section is locked automatically. If another write to the protected section is required, the steps 1 to 3 must be repeated.

4.4.9 Unlock service configuration section

Forcing the Unlock service configuration section coil ON when the correct value is written in the Password registers unlocks the service and user configuration sections of registers 40055 – 40066 for write operation.

To unlock and write into the User configuration section, the following procedure has to be executed:

1. Write correct password into registers 40067 – 40068 using the Write multiple registers command
2. Force coil 0018 (Unlock service configuration section) ON. If the password is correct, the normal response is returned and the desired section is unlocked. If the password is incorrect, the exception response 03 – Illegal data is returned and the section remains locked.
3. Write memory locations in the service and / or user configuration section by the Write multiple registers command.

The section is then unlocked only for one Write multiple registers command. After the write command is complete, the section is locked automatically. If another write to the protected section is required, the steps 1 to 3 must be repeated.

4.4.10 Change password

Forcing the Change user password coil or Change service password coil ON changes password for the particular section of registers. The change password procedure is similar for both section passwords, therefore only the Change user password function is described.

To change user password, the following procedure has to be executed:

1. Write the old password into registers 40067 – 40068 using the Write multiple registers command.
2. Force coil 0017 (Unlock user configuration section) ON. If the password is correct, the normal response is returned and the change password function is enabled. If the password is incorrect, the exception response 03 – Illegal data is returned and change password function is disabled.
4. Write the new password into registers 40067 – 40068 by the Write multiple registers command.
5. Force coil 0025 (Change user password) ON. If the change password function has been enabled in step 2, the password is changed and immediately stored into EEPROM together with a copy of the holding registers 40003 – 40066.

   If the change password function has been disabled in step 2, the exception response 03 - Illegal data is returned and change password is not performed. The old password remains valid.

Setting the user or service password to 0 unlocks the particular section permanently. In this case no unlocking procedure is required before writing into the section. Normal operation is restored as soon as the password is changed to any non-zero value.

User and service passwords are both set to 0 when the transducer is shipped from factory.

4.5 Modbus function codes

Three standard function codes are implemented to access the transducer's memory and simple functions:

Function code (hex)	Function
03	Read multiple registers
05	Force single coil
10	Write multiple registers

Four non-standard function codes are implemented to allow easy and efficient access to special functions of the transducer:

Function code (hex)	Function
45	Start measurement with mask
46	Synchronize datalogging
47	Erase data
48	Set slave address

The implemented functions are described in the following paragraphs including example queries and responses. Normal responses are shown. If an error is found during the query processing, an exception response is generated by the transducer as described in section **Chyba! Nenalezen zdroj odkazů.**.

4.5.1 Read multiple registers (03h)

Reads the contents of transducer's registers. Broadcast is not supported. The query specifies the starting register and quantity of registers to be read.

Here is an example of the request to read holding registers 40049 – 40051 from the transducer with slave address 11h:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	03
3	Starting address (Hi)	00
4	Starting address (Lo)	30
5	Number of registers (Hi)	00
6	Number of registers (Lo)	03
7	CRC (Lo)	xx
8	CRC (Hi)	xx

The response contains data read from the specified registers. The register data in the response message are packed as two bytes per register. For each register, the first byte contains the most significant byte and the second contains the least significant byte. An example of the response to the query:

Byte no.	Field name	Example (hex)
1	Slave Address	11
2	Function Code	03
3	Number of Data Bytes	06
4	Contents of register 30h – MSB	00
5	Contents of register 30h – LSB	01
6	Contents of register 31h – MSB	C8
7	Contents of register 31h – LSB	00
8	Contents of register 32h – MSB	F3
9	Contents of register 32h – LSB	15
10	CRC (Lo)	xx
11	CRC (Hi)	xx

4.5.2 Force single coil (05h)

Forces a single coil to either ON or OFF state. Forcing the particular coil ON initiates assigned function as described in paragraph 4.4. When broadcast, the function is performed in all attached slaves.

The query specifies the coil address (function). The requested ON / OFF state is specified by a constant in the query data field. A value FF00h requests to perform function. A value 0000h means no action. Here is an example of the request to initiate the Write EEPROM function (coil no. 0002) for the transducer with slave address 11h:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	05
3	Coil address (Hi)	00
4	Coil address (Lo)	01
5	Force data (Hi)	FF
6	Force data (Lo)	00
7	CRC (Lo)	xx
8	CRC (Hi)	xx

The normal response is an echo of the query. Here is an example of the response to the query shown above:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	05
3	Coil address (Hi)	00
4	Coil address (Lo)	01
5	Force data (Hi)	FF
6	Force data (Lo)	00
7	CRC (Lo)	xx
8	CRC (Hi)	xx

4.5.3 Write multiple registers (10h)

Writes data into a sequence of specified registers. When broadcast, the function writes the same registers in all attached slaves. If an attempt is made to write at least some of the data into password-protected sections, no data are written and exception response Illegal address is generated (see paragraph **Chyba! Nenalezen zdroj odkazů.**).

The query specifies the registers to be written. The requested data values are specified in the query data field. Here is an example of the request to write data in registers 40067 - 40068 of the transducer with slave address 11h:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	10
3	Starting address (Hi)	00
4	Starting address (Lo)	42
5	Number of registers (Hi)	00
6	Number of registers (Lo)	02
7	Number of data bytes	04
8	Data to register 42h - MSB	4A
9	Data to register 42h - LSB	0C
10	Data to register 43h - MSB	01
11	Data to register 43h - LSB	C8
12	CRC (Lo)	xx
13	CRC (Hi)	xx

The normal response returns the slave address, function code, starting address, and number of registers written. Here is an example of the response to the query shown above:

Byte no.	**Field name**	**Example (hex)**
1	Slave address	11
2	Function code	10
3	Starting register (Hi)	00
4	Starting register (Lo)	42
5	Number of registers (Hi)	00
6	Number of registers (Lo)	02
7	CRC (Lo)	xx
8	CRC (Hi)	xx

4.5.4 Start measurement with mask (45h)

Starts single measurement for selected transducer s. For multidrop configuration, the following algorithm was implemented to allow multiple transducer to be started by a single Start measurement with mask command transmitted as broadcast. Transducer s on the bus can be individually assigned to one or multiple groups by setting corresponding bit in the Group assignment register 40063. Up to 7 different groups can be created. Beside this, all transducers belong to group 0 by default (bit 0 in the Group Assignment Byte is always considered to be set regardless its real state).

Transducers assigned to the same group can be started simultaneously by a Start measurement with mask command transmitted as broadcast. The group mask byte transmitted in this query specifies which group(s) of transducers will start a single measurement. Every transducer makes logical AND between Group mask byte in the received query and Group assignment register. If the result is non-zero, the transducer starts single measurement.

Behavior of the transducer during the measurement is the same as it was started with Start measurement command as described in the paragraph 4.4.5.

Here is an example of the request to start single measurement for all transducer s assigned to groups 2 and 7. No response is generated for the broadcast frame.

Byte no.	**Field name**	**Example (hex)**
1	Slave address	00
2	Function code	45
3	Group mask	84
4	CRC (Lo)	xx
5	CRC (Hi)	xx

4.5.5 Synchronize datalogging (46h)

The transducer is able to automatically measure temperature in preset time intervals and store the values into the registers 40088 - 40167 (datalogging). Synchronize Datalogging command can be used to start or re-synchronize the datalogging.

The query specifies Period parameter which describe measurement timing. If no datalogging is in progress, the Synchronize Datalogging command starts it. The first temperature measurement is initiated immediately after receiving the query. The next measurements are then initiated in regular intervals defined by the Period value.

If datalogging is already in progress, the Synchronize Datalogging command re-synchronize the internal time base. The oncoming measurement is expedited in order to start immediately after receiving the query. The next measurements are again initiated in regular intervals defined by Period value. Figure 7 illustrates using of the Synchronize Datalogging command.

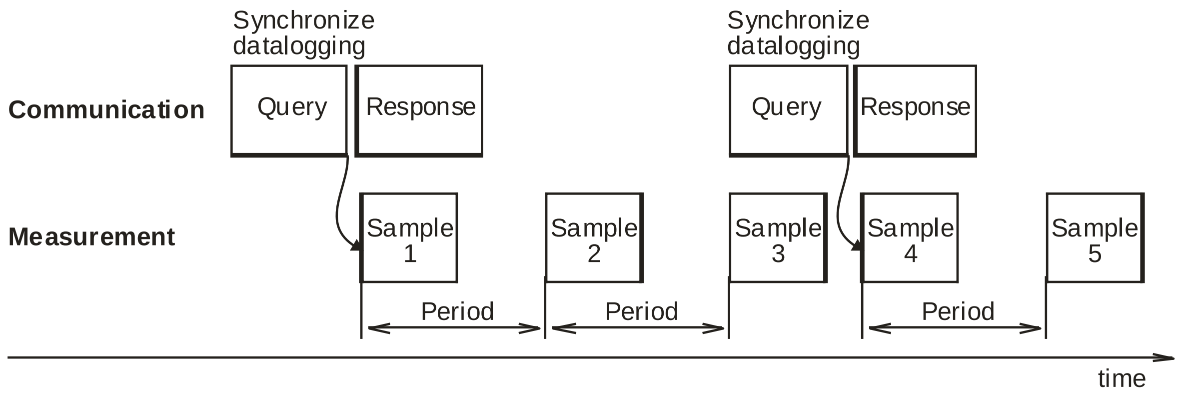

Figure 7. Using of Synchronize datalogging command.

Bit 1 (Datalogging in progress) in the Status register is set during datalogging. When the data memory is full, measurement continues, but no values are stored, bit 11 (Data memory overflow) in the Status register is set. Datalogging resumes after the memory is erased by the Erase data command (see paragraph **Chyba! Nenalezen zdroj odkazů.**) If the Period parameter is set too short with respect to the time of measurement, the measurements are initiated as fast as possible and bit 12 (Timing error) in the Status register is set to indicate error.

Value of the Period parameters can be calculated using formula:

Period = 128.*t*-1,

where *t* is time of the period in seconds.

The period value can be also set anywhere from 1/128 s to 512 s (0000h to FFFFh) with resolution of 1/128 s, but the period should be longer than time of the measurement 125 ms.

Datalogging can be stopped at any moment by Stop measurement function, see chapter 4.4.5.

Here is an example of the request to start / synchronize datalogging for the transducer with slave address 11h. The measurement period is 1 s.

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	46
3	not used	00
4	not used	00
5	Period (Hi)	00
6	Period (Lo)	80
7	CRC (Lo)	xx
8	CRC (Hi)	xx

Response to the query:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	46
3	CRC (Lo)	xx
4	CRC (Hi)	xx

4.5.6 Erase data (47h)

Erases desired number of the oldest temperature samples from the data memory. Remaining samples are moved at the beginning of the data memory. If the requested number of samples is higher than actual number of samples stored in the memory, the whole data memory is erased. Response contains number of remaining samples.

Here is an example of the request to erase 6 temperature samples from the data memory for the transducer with slave address 11h:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	47
3	Requested number of samples to be erased	06
4	CRC (Lo)	xx
5	CRC (Hi)	xx

Response to the query:

Byte no.	Field name	Example (hex)
1	Slave address	11
2	Function code	47
3	Number of remaining samples	03
4	CRC (Lo)	xx
5	CRC (Hi)	xx

4.5.7 Set slave address (48h)

This function allows to set a slave addresses of the particular transducer in case that multiple transducers are connected to the same bus. The function is intended to be transmitted as a query with universal service address 248. The serial number and the desired slave address are transmitted as parameters of the function in the data filed. If any of the connected transducers finds that its own serial number is equal to the serial number transmitted in the query, it sets its own slave address to the value transmitted in the query and responds to it. The other transducers do not perform any action and do not generate any response

Here is an example of broadcast which requires the transducer with serial number 00010285h to set its own slave address to 07h.

Byte no.	Field name	Example (hex)
1	Slave address	00
2	Function code	48
3	Serial number (MSB)	00
4	Serial number	01
5	Serial number	02
6	Serial number (LSB)	85
7	Desired slave address	07
8	CRC (Lo)	xx
9	CRC (Hi)	xx

Generated response. The new slave address is transmitted in the address field of the response:

Byte no.	Field name	Example (hex)
1	Slave address	07
2	Function code	48
4	CRC (LSB)	xx
5	CRC (MSB)	xx

4.6 Exception responses

When a master device sends a query to a slave device it expects a normal response. One of four possible events can occur from the master's query:

- If the slave device receives the query without a communication error and can handle the query normally, it returns a normal response.
- If the slave does not receive the query due to a communication error, no response is returned. The master program will eventually process a timeout condition for the query.
- If the slave receives the query, but detects a checksum error (CRC), no response is returned. The master program will eventually process a timeout condition for the query.
- If the slave receives the query without a communication error, but cannot handle it (for example, if the non-supported function is requested), the slave will return an exception response informing the master about the nature of the error.

The exception response message has two fields that differentiate it from a normal response:

Function code field

In a normal response, the slave echoes the function code of the original query in the function code field of the response. All function codes have a most–significant bit (MSB) of 0 (their values are all below 80 hexadecimal). In an exception response, the slave sets the MSB of the function code to 1. This makes the function code value in an exception response exactly 80 hex higher than the value would be for a normal response.

With the function code's MSB set, the master's application program can recognize the exception response and can examine the data field for the exception code.

Data field

In a normal response, the slave may return data or statistics in the data field (any information that was requested in the query). In an exception response, the slave returns an exception code in the data field. This defines the slave condition that caused the exception.

An example of the master query and slave exception response is shown below. In this example, the master addresses a query to slave device 11h. The function code 01h is for a Read coil status operation.

Byte no.	Field name	Example (Hex)
1	Slave address	11
2	Function code	01
3	Starting address (Hi)	00
4	Starting address (Lo)	20
5	Number of coils (Hi)	00
6	Number of coils (Lo)	01
7	CRC (Lo)	xx
8	CRC (Hi)	xx

Function 01h (Read coil status) is not supported by the transducer. The transducer will return the exception response with the exception code Illegal function (01).

Byte no.	Field name	Example (Hex)
1	Slave address	11
2	Function code	81
3	Exception code	01
4	CRC (Lo)	xx
5	CRC (Hi)	xx

List of exception codes supported by the transducer:

01 Illegal function

The function code received in the query is not an allowable action for the slave.

02 Illegal data address

The data address received in the query is not an allowable address for the slave. For example, an attempt is made to write into password-protected memory locations without correct password being entered.

03 Illegal Data Value

A value contained in the query is not an allowable value for the slave. This exception response is generated when illegal password has been entered and Unlock section or Change password function is requested.

06 Slave device busy

The slave is performing a long-duration function and cannot perform the requested action. The master should retransmit the message later when the slave is free. This response is generated when the Write EEPROM function has been initiated and the following query is received before the function is completed.

5 Related Publications

[1] Modicon Modbus Protocol Reference Guide, Modicon Inc., Industrial Automation Systems, 1996

[2] ČSN EN 61000-6-2 ed.3: 2006, Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for industrial environments

[3] ČSN EN 60068-2-6 ed.2: 2008, Environmental testing - Part 2-6: Tests - Test Fc: Vibration (sinusoidal)

[4] ČSN EN 60079-0 ed.4: 2013 + A1:2014+Rev.2:2014, Explosive atmospheres - Part 0: Equipment - General requirements

[5] ČSN EN 60079-11 ed.2: 2012, Explosive atmospheres - Part 11: Equipment protection by intrinsic safety "i"

[6] ČSN EN 60079-14 ed.4:2014 + Cor.1:2016, Explosive atmospheres - Part 14: Electrical installations design, selection and erection.

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