

# Optical Dissolved Oxygen Sensor

## MODBUS RTU Programmer Manual

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# 1 MODBUS RTU Overview

## 1.1 Scope

This document is about MODBUS of optical dissolved oxygen probes with hardware Rev2.0 and software **Rev6.2** or later. This document is intended for software programmers with detailed information about MODBUS RTU protocols.

## 1.2 MODBUS Command Structure

Data format in this document:

- Binary number – shown with suffix B. For example: 10001B
- Decimal number – without nay suffix. For example: 256
- Hexadecimal number—shown with prefix 0x. For example: 0x2A
- ASCII character or string – shown with quotation marks.

### 1.2.1 Command Structure

MODBUS defines a simple protocol data unit (PDU), which is transparent to communication layer.

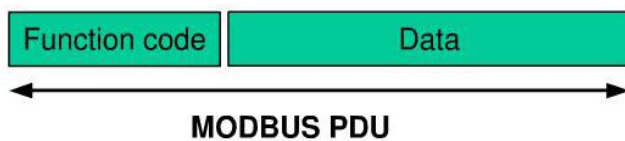


Figure 1: MODBUS Protocol Data Unit

The mapping of MODBUS protocol on a specific bus or network introduces some additional fields on the Protocol Data Unit. The client that initiates a MODBUS transaction builds the MODBUS PDU, and then adds fields in order to build the appropriate communication PDU.

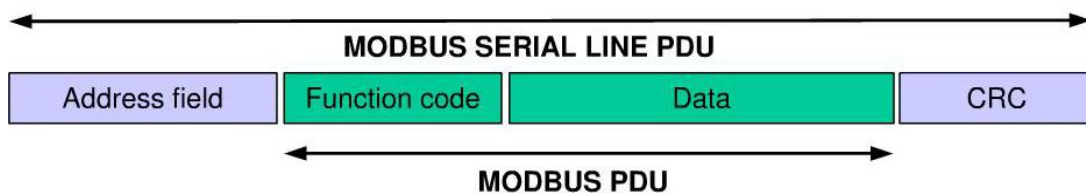


Figure 2: MODBUS Structure for Serial Communication

On a MODBUS serial bus, address field only includes addresses for slave devices.

**Note:**

- Slave address range for optical dissolved oxygen sensor is: 1...247
- Master device sends a “request frame” with a targeted slave address. When slave device responses, it has to put its own address in the “response frame”, so that master device knows where the response comes from.
- Function code indicates type of operations
- CRC is the result of redundancy check.

### 1.2.2 MODBUS RTU Transmission Mode

When devices communicate on a MODBUS using RTU (remote terminal unit) mode, each 8-bit byte contains two 4-bit hexadecimal characters. The main advantage of the RTU mode is that it has higher character density, which enables better throughput compare to ASCII mode at same baud rate. Each RTU message must be transmitted in a continuous string of characters.

#### RTU mode format for each byte (11 bits):

Encoding system      8 bit binary  
                                  Each 8-bit packet contains 4-bit hexadecimal characters (0-9, A-F)

Bit per byte:          1 start bit  
                                  8 data bits, least significant bit first  
                                  No parity check  
                                  1stop bits

Baud rate:              9600bps

#### Serial transmission of characters:

Every character or byte is sent under this sequence (left to right):

Least Significant Bit (LSB).....Most Significant Bit(MSB)

|       |   |   |   |   |   |   |   |   |      |
|-------|---|---|---|---|---|---|---|---|------|
| Start | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Stop |
|-------|---|---|---|---|---|---|---|---|------|

Figure 3: RTU Mode Bit Sequence

#### CRC Field Structure:

Redundancy check (CRC16)

#### Frame Structure:

| Slave address | Function Code | Data          | CRC     |          |
|---------------|---------------|---------------|---------|----------|
| 1 byte        | 1 byte        | 0...252 bytes | 2 bytes |          |
|               |               |               | CRC Low | CRC High |

Figure 4: RTU Message Frame Structure

Maximum size of MODBUS frame is 256 bytes.

### 1.2.3 MODBUS RTU Message Frame

In RTU mode, message frames need to be separated by an idle interval of at least 3.5 character lengths. In rest of this document, this idle interval is called t<sub>3.5</sub>.

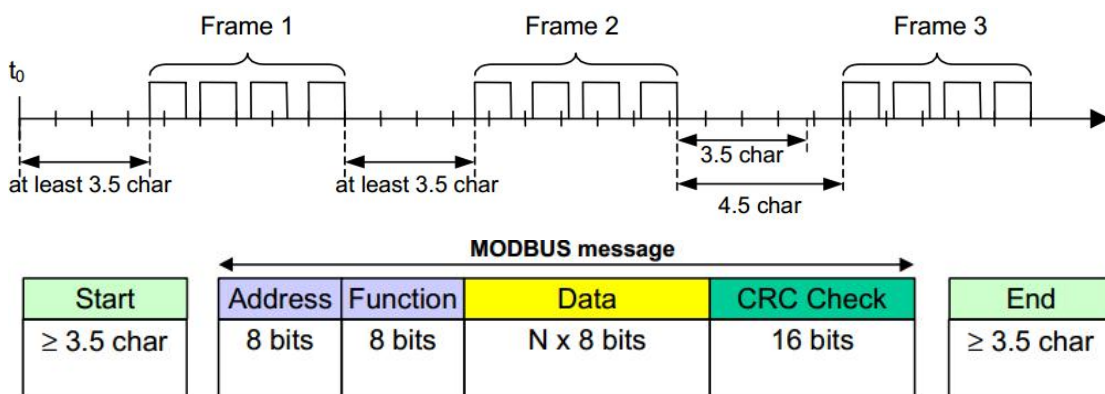


Figure 5: RTU Message Frame

Entire message frame must be sent as continuous stream of characters.

If idle time between two characters is longer than 1.5 characters, the message frame will be considered incomplete, and will be discarded by receiving side.

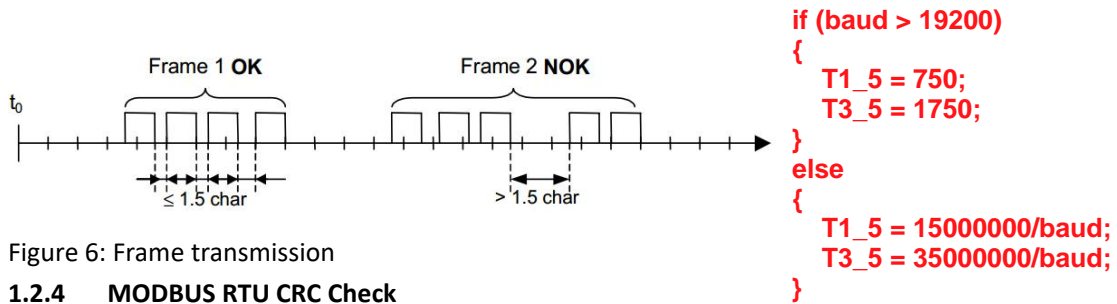


Figure 6: Frame transmission

#### 1.2.4 MODBUS RTU CRC Check

In RTU mode, the error checking field is based on a cyclical redundant checking (CRC) method. The CRC field checks entire content of MODBUS message, regardless of the existence of parity check bit. CRC16 checking method is utilized. CRC result is a 16-bit value with two 8-bit bytes, low order 8-bit byte first followed by high order 8-bit byte.

### 1.3 MODBUS RTU for Optical Dissolved Oxygen Sensor

Based on standard MODBUS definition, message frame starts with t3.5 idle interval, and similarly, ends with t3.5 idle interval. Device address and Function code are both 8-bit byte. Data character string has n\*8 bits, it contains information about register start/end address and number of registers for read/write operation. CRC field is 16 bit in length.

|               | Start                         | Device address | Function code                           | Data                           | CRC     |          | End                           |
|---------------|-------------------------------|----------------|---|--------------------------------|---------|----------|-------------------------------|
| Value         | Idle for 3.5 character length | 1-247          | Comply with MODBUS function code format | Comply with MODBUS data format | CRC Low | CRC High | Idle for 3.5 character length |
| Length (byte) | 3.5                           | 1              | 1                                       | n                              | 1       | 1        | 3.5                           |

Figure 7: Message frame structure for MODBUS

### 1.4 MODBUS RTU Function Code for Optical Dissolved Oxygen Sensor

The optical dissolved oxygen sensor has two MODBUS function codes:

0x03: Read registers      0x10: Write registers

#### 1.4.1 MODBUS Function Code 0x03: Read Registers

This function code is to read a block of continuous registers from a remote device. Request PDU defines start address and number of registers for the read operation. Register addressing starts from 0. Therefore, addresses for register 1-16 are 0-15. Data for each register in Response message have two bytes. For each register data, first byte is for high bits, and second byte for low bits.

Request Frame:

|               |        |      |
|---------------|--------|------|
| Function code | 1 Byte | 0x03 |
|---------------|--------|------|

|                     |         |                  |
|---------------------|---------|------------------|
| Start address       | 2 Bytes | 0x0000....0xffff |
| Number of registers | 2 Bytes | 1...125          |

Figure 8: Request frame for read registers

Response Frame:

|                |                    |              |
|----------------|--------------------|--------------|
| Function code  | 1 byte             | 0x03         |
| Number of byte | 1 byte             | $N \times 2$ |
| Register data  | $N \times 2$ bytes |              |

N = number of registers

Figure 9: Response frame for read registers

Below is an example of Request and Response frames (Read register 108-110. Register 108 is read only with 2-byte value of 0X022B. Registers 109-110 have values of 0X0000 and 0X0064).

| Request Frame   |             | Response Frame                  |             |
|---|-------------|---------------------------------|-------------|
| Data format   | Hexadecimal | Data Format                     | Hexadecimal |
| Function code   | 0x03        | Function code                   | 0x03        |
| Start address(high bits)  | 0x00        | Number of bytes                 | 0x06        |
| Start address (low bits)  | 0x6B        | Register value (high bits, 108) | 0x02        |
| Number of registers (high bits)   | 0x00        | Register value (low bits, 108)  | 0x2B        |
| Number of registers (low bits)  | 0x03        | Register value (high bits, 109) | 0x00        |
| <b>Leer desde la dirección 107 (o sea empezando desde la 108) hasta la 110.</b> |             | Register value (low bits, 109)  | 0x00        |
|   |             | Register value (high bits, 110) | 0x00        |
|   |             | Register value (low bits, 110)  | 0x64        |

Figure 10: Example of request and response frame for read operation

#### 1.4.2 MODBUS Function Code 0x10: Write Registers

This function code is to write a block of continuous registers at a remote device. Request frame contains register data. Each register data have two character bytes. Response frame contains function code, start address, and number of registers that completed write operation.

Request Frame:

|                     |                    |                  |
|---------------------|--------------------|------------------|
| Function code       | 1 byte             | 0x10             |
| Start address       | 2 bytes            | 0x0000....0xffff |
| Number of registers | 2 bytes            | 0x0001....0x0078 |
| Number of bytes     | 1 byte             | $N \times 2$     |
| Register data       | $N \times 2$ bytes | value            |

N = number of registers

Figure 11: Request frame for write operation

Response Frame

|                     |         |                  |
|---------------------|---------|------------------|
| Function Code       | 1 byte  | 0x10             |
| Start address       | 2 bytes | 0x0000....0xffff |
| Number of registers | 2 bytes | 1...123(0x7B)    |

Figure 12: Response frame for write operation

Below is an example of Request frame and Response frame (write 0x000A and 0x0102 to two registers starting from address 2):

| Request Frame |             | Response Frame |             |
|---------------|-------------|----------------|-------------|
| Data Format   | Hexadecimal | Data Format    | Hexadecimal |

|                                 |                                      |                                 |      |
|---------------------------------|--------------------------------------|---------------------------------|------|
| Function code                   | 0x10                                 | Function code                   | 0x10 |
| Start address (high bits)       | 0x00                                 | Start address (high bits)       | 0x00 |
| Start address (low bits)        | 0x01 <small>o sea desde el 2</small> | Start address (low bits)        | 0x01 |
| Number of registers (high bits) | 0x00                                 | Number of registers (high bits) | 0x00 |
| Number of registers (low bits)  | 0x02                                 | Number of registers (low bits)  | 0x02 |
| Number of bytes                 | 0x04                                 |                                 |      |
| Register value (high bits)      | 0x00                                 |                                 |      |
| Register value (low bits)       | 0x0A                                 |                                 |      |
| Register value (high bits)      | 0x01                                 |                                 |      |
| Register value (low bits)       | 0x02                                 |                                 |      |

Figure 13: Example of Request frame and response frame for write operation

## 1.5 Data Formats in Optical Dissolved Oxygen Sensor

### 1.5.1 Floating-point number

Definition: floating point number, comply with IEEE754 (single precision)

| Note               | Sign | Exponent | Fraction | Total |
|--------------------|------|----------|----------|-------|
| bit                | 31   | 30...23  | 22...0   | 32    |
| Exponent deviation | 127  |          |          |       |

Figure 14: Single floating point number definition (4 bytes, 2 MODBUS registers)

Example: Convert decimal number 17.625 to binary number

Step 1: Convert decimal number 17.625 to a floating point number with binary format

First, convert integer to binary

$$17_{\text{decimal}} = 16 + 1 = 1 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 0 \times 2^1 + 1 \times 2^0$$

Thus, integer 17 in binary format is 10001B

Then convert decimal part to binary

$$0.625_{\text{decimal}} = 0.5 + 0.125 = 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3}$$

Thus, 0.625 in binary format is 0.101B

Combine above together, 17.625 in binary format is 10001.010B

Step 2: Calculate exponent

Left shift the binary number 10001.010B until only bit left before the decimal point ---

10001.010B = 1.0001101 B  $\times 2^4$ , so exponent value is 4. By adding 127, we have 131, which is 10000011B in binary format

Step 3: Get fraction

Fraction is simply the number after decimal point. Thus from 1.0001101B, fraction number is 0001101B. IMPORTANT NOTE about the 23 bit fraction number: the first bit which on the left side of decimal point is hidden bit and does not need to be compiled.

Step 4: Sign definition

Sign bit is 0 if the number is positive. Sign is 1 if the number is negative. For 17.625, sign bit is 0.

Step 5: Convert to floating point number

1 Sign bit + 8-bit exponent + 23-bit fraction

0            1000011            00011010000000000000000B  
 (Corresponding hexadecimal number is 0x418D0000)

Sample code:

1. If your compiler has similar library functions, it can be called directly. For example if C language is used, we can directly call memcpy() function in C library to convert floating point number. Sample code:

```
float   floatdata;//floating point data to be converted
void*   outdata;
memcpy(outdata,&floatdata,4);
```

If floatdata=17.625,

In little-endian storage mode after the function is called:

Value at address of outdata is 0x00  
 Value at address of (outdata+1) is 0x00  
 Value at address of (outdata+2) is 0x8D  
 Value at address of (outdata+3) is 0x41

In big-endian storage mode after the function is called:

Value at address of outdata is 0x41  
 Value at address of (outdata+1) is 0x8D  
 Value at address of (outdata+2) is 0x00  
 Value at address of (outdata+3) is 0x00

2. If your compiler doesn't have the conversion function, then the following function can be used:

```
void memcpy(void *dest,void *src,int n)
```

```
{
    char *pd = (char *)dest;
    char *ps = (char *)src;
    for(int i=0;i<n;i++) *pd++ = *ps++;
}
```

Then you can get same result by calling this function memcpy(outdata,&floatdata,4);

Example: Convert binary floating point number 0100 0010 0111 1011 0110 0110 0110 0110B to a decimal number

Step 1: Separate this binary number 0100 0010 0111 1011 0110 0110 0110 0110B and get values of Sign , exponent and fraction.

|            |                |                          |
|------------|----------------|--------------------------|
| 0          | 10000100       | 11110110110011001100110B |
| 1 Sign bit | 8-bit exponent | 23-bit fraction          |

Sign bit(s): 0

Exponent(E):  $10000100B = 1 \times 2^7 + 0 \times 2^6 + 0 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 1 \times 2^2 + 0 \times 2^1 + 0 \times 2^0$   
 $= 128 + 0 + 0 + 0 + 0 + 4 + 0 + 0 = 132$

Fraction(M): 11110110110011001100110B = 8087142

Step 2: Calculate decimal value



$$\begin{aligned}
 D &= (-1)^S \times (1.0 + M/2^{23}) \times 2^{E-127} \\
 &= (-1)^0 \times (1.0 + 8087142/2^{23}) \times 2^{132-127} \\
 &= 1 \times 1.964062452316284 \times 32 \\
 &= 62.85
 \end{aligned}$$

Reference code:

```

float floatTODecimal(long int byte0, long int byte1, long int byte2, long int byte3)
{
    long int realbyte0,realbyte1,realbyte2,realbyte3;
    char S;
    long int    E,M;
    float D;
    realbyte0 = byte3;
    realbyte1 = byte2;
    realbyte2 = byte1;
    realbyte3 = byte0;

    if((realbyte0&0x80)==0)
    {
        S = 0; //Positive
    }
    else
    {
        S = 1; //Negative
    }
    E = ((realbyte0<<1)|(realbyte1&0x80)>>7)-127;
    M = ((realbyte1&0x7f)<<16) | (realbyte2<<8) | realbyte3;
    D = pow(-1,S)*(1.0 + M/pow(2,23))* pow(2,E);
    return D;
}

```

Note:

- Function parameters byte0, byte1, byte2 and byte3 represent the 4 sections of a binary floating number.
- Return value is value of decimal number after conversion

For example when a command is sent to a sensor to get temperature value, response frame from the sensor will have measured temperature. If the values are 4 byte floating point number 0x00,0x00,0x8d,0x41, then the following function can be used to get temperature in decimal value:

```

float temperature = floatTODecimal( 0x00, 0x00, 0x8d, 0x41);
and temperature = 17.625.

```

## 2 MODBUS RTU Commands for Optical Dissolved Oxygen Sensor

### 2.1 Overview

In order to communicate with optical dissolved oxygen via MODBUS RTU, master terminal software will be needed. MODBUS RTU is an open standard. There are free commercial software tools available. For applications described in this document, MODBUS register address starts from 1. However, slave address in MODBUS protocol starts from 0, and usually master software compiles addresses. For example, register address 2090 will be compiled by master software as address 2089.

### 2.2 Command Description

#### 2.2.1 Set Slave Device ID

Purpose: Set MODBUS slave address to a sensor probe. Range of address is 1~247.

Sensor probe slave address can be set via MODBUS register 0x3000:

| Start address | Number of registers | Register 1        | MODBUS Function code |
|---------------|---------------------|-------------------|----------------------|
| 0x3000        | 0x01                | New Slave address | 0x10                 |

Figure 15: Set slave ID command

Below is an example of request and response frames for setting slave device ID command. Old slave address is 0x01, new address is 0x14.

| Definition | Address | Function code | Start address |      | Number of registers |      | Number of byte | Register value |      | CRC  |      |
|------------|---------|---------------|---------------|------|---------------------|------|----------------|----------------|------|------|------|
| Byte       | 0       | 1             | 2             | 3    | 4                   | 5    | 6              | 7              | 8    | 9    | 10   |
| Value      | 0x01    | 0x10          | 0x30          | 0x00 | 0x00                | 0x01 | 0x02           | 0x14           | 0x00 | 0x99 | 0x53 |

Figure 16: Example of Request frame to set slave ID \*Note: byte 8 is reserved

| Definition | Address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|---------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0       | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01    | 0x10          | 0x30          | 0x00 | 0x00                | 0x01 | 0x0E | 0xC9 |

Figure 17: Example of response frame for Set slave ID command

#### 2.2.2 Start Measurement

Purpose: Set probe in continuous light emitting mode and start measuring dissolved oxygen.

MODBUS register 0x2500 is used. The Probe starts in auto-measure mode by default.

| Starting address | Number of registers | MODBUS Function code |
|------------------|---------------------|----------------------|
| 0x2500           | 0x01                | 0x03                 |

Figure 18: Start measurement command definition

Below is an example of request and response frames for sending a Start Measurement command to a device with slave address 0x01.

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x03          | 0x25          | 0x00 | 0x00                | 0x01 | 0x8F | 0x06 |

Figure 19: Request frame of a start measurement command

| Definition | Device address | Function code | Number of bytes | Register value | CRC |   |
|------------|----------------|---------------|-----------------|----------------|-----|---|
| Byte       | 0              | 1             | 2               | 3~4            | 5   | 6 |
| Value      | 0x01           | 0x03          | 0x00            | meaningless    |     |   |

Figure 20: Response frame of a start measurement command

### 2.2.3 Get Temperature and DO values

Purpose: Get temperature and DO measurement results. Temperature unit is Celsius degree (°C), DO unit is percentage (%) and mg/L. User calibration process is automatically applied to DO.

Temperature and DO data can be read from 6 continuous MODBUS registers starting from address 0x2600.

| Start address | Number of registers | Register 1-2 | Register 3-4 | Register 5-6   | MODBUS function code |
|---------------|---------------------|--------------|--------------|----------------|----------------------|
| 0x2600        | 0x06                | Temperature  | DO value(%)  | DO value(mg/L) | 0x03                 |

Modbus Adapter Register Map Definition

| Definition   | Start address | Number of registers | Number of bytes |
|--------------|---------------|---------------------|-----------------|
| Temperature  | 0x2600H       | 2                   | 4               |
| DO% value    | 0x2602H       | 2                   | 4               |
| DOmg/L value | 0x2604H       | 2                   | 4               |

Figure 21: Register definition for Get temperature and DO command

Below is an example of request and response frames for getting temperature and DO command, assuming slave device address is 0x01, returned temperature is 17.625°C and DO value is 95.8% and 8.72mg/L.

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x03          | 0x26          | 0x00 | 0x00                | 0x06 | 0xce | 0x80 |
|            | 0x01           | 0x03          | 0x26          | 0x02 | 0x00                | 0x02 | 0x6e | 0x83 |

Figure 22: Request frame for Get Temperature and DO command

| Definition | Device address | Function code | Number of bytes | Register value |       |       | CRC  |      |
|------------|----------------|---------------|-----------------|----------------|-------|-------|------|------|
| Byte       | 0              | 1             | 2               | 3-6            | 7-10  | 11-14 | 15   | 16   |
| Value      | 0x01           | 0x03          | 0x0C            | 17.625         | 0.958 | 8.72  | 0x12 | 0x65 |
|            | 0x01           | 0x03          | 0x04            | 0.958          |       |       |      |      |

Figure 23: Response frame for Get Temperature and DO command

Note: Temperature and DO values are floating point number in little-endian storage mode. See sample below:

| Temperature(17.625) |      |      |      | DO Value(0.958) |      |      |      | DO Value(8.72) |    |    |    |
|---------------------|------|------|------|-----------------|------|------|------|----------------|----|----|----|
| 0x00                | 0x00 | 0x8D | 0x41 | 0x83            | 0x5B | 0x75 | 0x3F | E8             | 88 | 0B | 41 |

Figure 24: Registers for temperature and DO values.

#### 2.2.4 Get Software and Hardware Rev

Purpose: Get current hardware and software Release Version.

Hardware and software release version numbers of a sensor probe can be read from 2 continuous registers starting from address 0x0700.

| Start address | Number registers | Register 1 | Register 2 | MODBUS function code |
|---------------|------------------|------------|------------|----------------------|
| 0x0700        | 0x02             | HW Rev     | SW Rev     | 0x03                 |

Figure 25: Register definitions for Get software and hardware Rev command

Below is an example of request and response frames for getting hardware and software release version, assuming device slave address is 0x01, returned value for hardware Rev is 2.0 and software Rev is 5.7.

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x03          | 0x07          | 0x00 | 0x00                | 0x02 | 0xc5 | 0x7f |

Figure 26: Request frame of Get Hardware and Software Rev command

| Definition | Device address | Function code | Number of bytes | Register value |      |      |      | CRC  |      |
|------------|----------------|---------------|-----------------|----------------|------|------|------|------|------|
| Byte       | 0              | 1             | 2               | 3-4            |      | 5-6  |      | 7    | 8    |
| Value      | 0x01           | 0x03          | 0x04            | 0x02           | 0x00 | 0x05 | 0x07 | 0xb9 | 0x19 |

Figure 27: Response frame of Get Hardware and Software Rev Command

#### 2.2.5 Stop Measurement

Purpose: After stable test result is obtained, stop measurement activities. If measurement need to start again , use command **Start Measurement**.

MODBUS register 0x2E00 is used for this command.

| Start address | Number of registers | MODBUS function code |
|---------------|---------------------|----------------------|
| 0x2E00        | 0x01                | 0x03                 |

Figure 28: Register definition for Stop measurement command

Below is an example of request and response frames for a device with slave address 0x01 to stop measurement activities.

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x03          | 0x2E          | 0x00 | 0x00                | 0x01 | 0x8D | 0x22 |

Figure 29: Request frame of stop measurement command

| Definition | Device address | Function code | Number of bytes | Register value | CRC |   |
|------------|----------------|---------------|-----------------|----------------|-----|---|
| Byte       | 0              | 1             | 2               | 3~4            | 5   | 6 |
| Value      | 0x01           | 0x03          | 0x00            | meaningless    |     |   |

Figure 30: Response frame of stop measurement command

### 2.2.6 Get User Calibration Coefficients

Purpose: Get two calibration coefficients K and B. (This is to eliminate measurement errors caused by aging or other reasons. User calibration equation is:  $DO_{final}=K*DO+B$ ; default values are: K=1; B=0)

User calibration coefficients (K and B) can be read from 4 continuous MODBUS registers starting from address 0x1100.

| Start address | Number of registers | Register 1-2 | Register 3-4 | MODBUS function code |
|---------------|---------------------|--------------|--------------|----------------------|
| 0x1100        | 0x04                | K value      | B value      | 0x03                 |

Figure 31: Register definition for Get User calibration coefficients command

Below is an example of request and response frames for getting customer calibration coefficients from a device with slave address 0x01, assuming returned values are: K=1.0; B=0.0.

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x03          | 0x11          | 0x00 | 0x00                | 0x04 | 0x41 | 0x35 |

Figure 32: Request frame of Get customer calibration coefficient command

| Definition | Device address | Function code | Number of bytes | Register value |      | CRC  |      |
|------------|----------------|---------------|-----------------|----------------|------|------|------|
| Byte       | 0              | 1             | 2               | 3-6            | 7-10 | 11   | 12   |
| Value      | 0x01           | 0x03          | 0x08            | 1.0            | 0.0  | 0x9E | 0x12 |

Figure 33: Response frame of get customer calibration coefficient command

Note: K and B are floating point numbers in little-endian storage mode

| K(3-6) |      |      |      | B(7-10) |      |      |      |
|--------|------|------|------|---------|------|------|------|
| 0x00   | 0x00 | 0x80 | 0x3F | 0x00    | 0x00 | 0x00 | 0x00 |

Figure 34: Registers for two coefficients K and B.

### 2.2.7 Set Customer Calibration Coefficients

Purpose: Set two calibration coefficients K and B.

Customer coefficients (K and B) can be set at 4 continuous MODBUS registers starting from address 0x1100.

| Start address | Number of registers | Register 1-2 | Register 3-4 | MODBUS function code |
|---------------|---------------------|--------------|--------------|----------------------|
| 0x1100        | 0x04                | K            | B            | 0x10                 |

Figure 35: Register definition for set customer calibration command

Below is an example of request and response frames for setting customer calibration coefficients, Assuming slave address is 0x01, coefficients are K=1.0; and B=0.0.

| Definition | Device address | Function code | Start address |      | Number of registers |      | Number of bytes | Register value |       | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|-----------------|----------------|-------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6               | 7-10           | 11-14 | 15   | 16   |
| Value      | 0x01           | 0x10          | 0x11          | 0x00 | 0x00                | 0x04 | 0x08            | 1.0            | 0.0   | 0x81 | 0xAE |

Figure 36: Request frame of set customer calibration coefficient command

Note: Coefficients K and B, floating point numbers in little-endian storage mode

| K(7-10) |      |      |      | B(11-14) |      |      |      |
|---------|------|------|------|----------|------|------|------|
| 0x00    | 0x00 | 0x80 | 0x3F | 0x00     | 0x00 | 0x00 | 0x00 |

Figure 37: Registers for two coefficients K and B

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x10          | 0x11          | 0x00 | 0x00                | 0x04 | 0xc4 | 0xf6 |

Figure 38: Response frame of set customer calibration coefficient command

### 2.2.8 Set Optical Sensor Cap Coefficients

Purpose: Set sensor cap coefficients (K0~K7), this is necessary step to replace sensor caps.

Sensor cap coefficients can be set at 16 continuous MODBUS registers starting from address 0x2700.

| Start address | Number of registers | Register 1-16 | MODBUS function code |
|---------------|---------------------|---------------|----------------------|
| 0x2700        | 0x10                | K0- K7        | 0x10                 |

Figure 39: Request frame of set sensor cap coefficient command

Below is an example of request and response frames for setting sensor cap coefficients to a device with slave address 0x01.

| Definition | Device address | Function code | Start address |      | Number of registers |      | Number of bytes | Register value | CRC |    |
|------------|----------------|---------------|---------------|------|---------------------|------|-----------------|----------------|-----|----|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6               | 7-38           | 39  | 40 |
| Value      | 0x01           | 0x10          | 0x27          | 0x00 | 0x00                | 0x10 | 0x20            | K0-K7          | XX  | XX |

Figure 40: Request frame of set sensor cap coefficient command

Note: Ki(i=0-7) sensor cap coefficients, floating point number in little-endian storage mode

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0x01           | 0x10          | 0x27          | 0x00 | 0x00                | 0x10 | 0xcb | 0x71 |

Figure 41: Response frame of set sensor cap coefficient command

### 2.2.9 Get Slave Device ID

Purpose: Get current MODBUS slave address to a sensor probe. Use 0xFF as fixed Device address.

Sensor probe slave address can be read from MODBUS registers 0x3000.

| Start address | Number of registers | Register 1            | MODBUS Function code |
|---------------|---------------------|-----------------------|----------------------|
| 0x3000        | 0x01                | Current Slave address | 0x10                 |

Figure 42: Get slave ID command

Below is an example of request and response frames for getting slave device id, assuming returned address is 0x03.

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC  |      |
|------------|----------------|---------------|---------------|------|---------------------|------|------|------|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6    | 7    |
| Value      | 0xFF           | 0x03          | 0x30          | 0x00 | 0x00                | 0x01 | 0x9E | 0xD4 |

Figure 43: Request frame of get slave device ID comment

| Definition | Device address | Function code | Number of bytes | Register value |               | CRC  |      |
|------------|----------------|---------------|-----------------|----------------|---------------|------|------|
| Byte       | 0              | 1             | 2               | 3              | 4             | 5    | 6    |
| Value      | 0xFF           | 0x03          | 0x02            | 0x03           | 0x00(reserve) | 0x91 | 0x60 |

Figure 44: Response frame of get slave device ID comment

### 2.2.10 Set Salinity

Purpose: Set sensor salinity value, the unit is ‰. The default value is 0. And automatically save the settings in Flash.

Salinity value can be set at 2 continuous MODBUS registers starting from address 0x1500.

| Start address | Number of registers | Register 1-2 | MODBUS function code |
|---------------|---------------------|--------------|----------------------|
| 0x1500        | 0x02                | salinity     | 0x10                 |

Figure 45: Request frame of set salinity command

Below is an example of request and response frames for setting salinity to a device with slave address 0x01.

| Definition | Device address | Function code | Start address |      | Number of registers |      | Number of bytes | Register value | CRC |    |
|------------|----------------|---------------|---------------|------|---------------------|------|-----------------|----------------|-----|----|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6               | 7-10           | 11  | 12 |
| Value      | 0x01           | 0x10          | 0x15          | 0x00 | 0x00                | 0x02 | 0x04            | salinity       | XX  | XX |

Figure 46: Request frame of set salinity command.

Note: Floating point number in little-endian storage mode

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC |   |
|------------|----------------|---------------|---------------|------|---------------------|------|-----|---|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6   | 7 |
| Value      | 0x01           | 0x10          | 0x15          | 0x00 | 0x00                | 0x02 |     |   |

Figure 47: Response frame of set salinity command

### 2.2.11 Set atmospheric pressure

Purpose: Set sensor pressure value, the unit is kPa. The default value is 101.325kpa. And automatically save the settings in Flash.

Pressure value can be set at 2 continuous MODBUS registers starting from address 0x2400.

| Start address | Number of registers | Register 1-2 | MODBUS function code |
|---------------|---------------------|--------------|----------------------|
| 0x2400        | 0x02                | pressure     | 0x10                 |

Figure 48: Request frame of set atmospheric pressure command

Below is an example of request and response frames for setting pressure to a device with slave address 0x01.

| Definition | Device | Function | Start | Number of | Number | Register | CRC |
|------------|--------|----------|-------|-----------|--------|----------|-----|
|------------|--------|----------|-------|-----------|--------|----------|-----|

|       | address | code | address |      | registers |      | of bytes | value    |    |    |
|-------|---------|------|---------|------|-----------|------|----------|----------|----|----|
| Byte  | 0       | 1    | 2       | 3    | 4         | 5    | 6        | 7-10     | 11 | 12 |
| Value | 0x01    | 0x10 | 0x24    | 0x00 | 0x00      | 0x02 | 0x04     | pressure | XX | XX |

Figure49: Request frame of set pressure command.

Note: Floating point number in little-endian storage mode

| Definition | Device address | Function code | Start address |      | Number of registers |      | CRC |   |
|------------|----------------|---------------|---------------|------|---------------------|------|-----|---|
| Byte       | 0              | 1             | 2             | 3    | 4                   | 5    | 6   | 7 |
| Value      | 0x01           | 0x10          | 0x24          | 0x00 | 0x00                | 0x02 |     |   |

Figure50: Response frame of set pressure command.

### 3 Procedure to Get DO Value

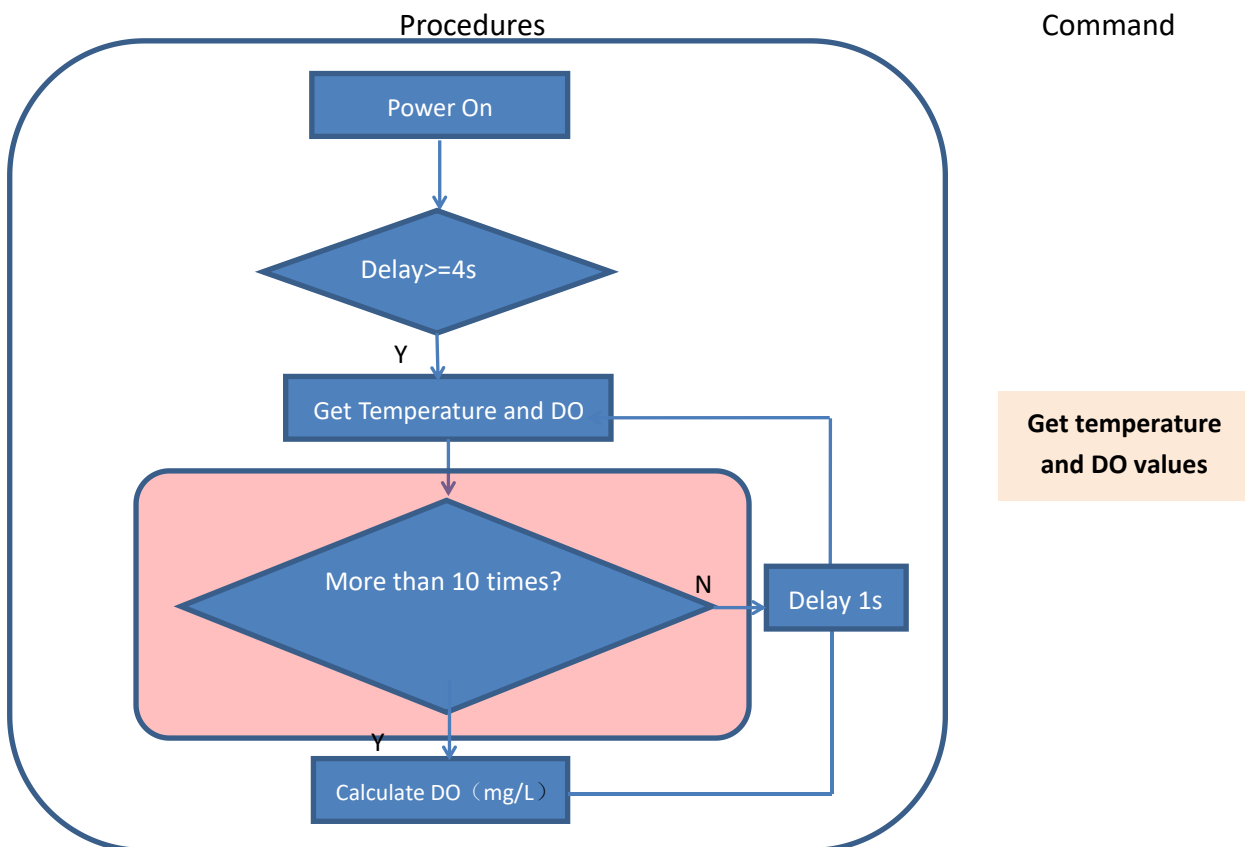


Figure 46: Flow chart to get DO measurement

- **Get temperature and DO values** – Get measurement results including temperature (°C) and DO (%) after 1 second of measurements.

**Note:** Please pay attention to highlighted portion (red) in the flow chart above. It's highly recommended that customers get an average DO results (%) after 10 consecutive measurements, then convert the average DO percentage to a DO value in mg/L unit.



- Calculate DO (mg/L) , converting the average DO percentage to a DO value in mg/L unit.

According to the formula:  $DO(\text{mg/L}) = DO(\%) * X1 * X2 * 1.4276$ ;

$1 \text{ ml/L} = 1.4276 \text{ mg/L}$ ;

$\ln X1 = A1 + A2 \cdot 100/T + A3 \cdot \ln T/100 + A4 \cdot T/100 + S * [B1 + B2 \cdot T/100 + B3 \cdot (T/100)^2]$ ;

$A1 = -173.4292, \quad B1 = -0.033096,$

$A2 = 249.6339, \quad B2 = 0.014259,$

$A3 = 143.3483, \quad B3 = -0.001700;$

$A4 = -21.8492;$

$T = 273.15 + t$  ,T represent for Kelvin temperature and t represent for Celsius temperature;

S is salinity, S=0 in pure water;

$X2 = (\text{Phmg} - u) / (760 - u)$ ;

Phmg= pressure \* 760 / 101.325, pressure is the barometer in kPa unit;

$\text{Logu} = 8.10765 - (1750.286 / (235+t))$ , t represent for Celsius temperature.

Reference code:

```
#include <math.h>
```

```
float pressure = 0.0;
```

```
float Phmg= 0.0;
```

```
float t = 0.0;
```

```
float T = 0.0;
```

```
float S = 0.0;
```

```
T = 273.15 + t; //t is current temperature which get from probe
```

```
X1' = -173.4292 // X1' = ln X1
```

```
+ 249.6339*(100/ T)
```

```
+ 143.3483*log(T /100) //Function log() is equal to ln(x)
```

```
+ -21.8492*( T /100)
```

```
+S*(-0.033096 + (0.014259* T)/100
```

```
-0.001700*( T /100)*( T /100));
```

```
X1 = exp(X1');
```

```
// log u = 8.10765 - (1750.286/ (235+t))
```

```
u' = 8.10765 - (1750.286/ (235 + t)); // u' = log u
```

```
u = pow(10, u'); //u=10^u'
```

```
Phmg = pressure*760/101.325;
```

```
X2 = ((Phmg - u)/(760 - u));
```

```
DO(mg/L)= DO(%)*X1*X2*1.4276;
```