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MODBUS over Serial Line

Specification and Implementation Guide

V1.02

Contents

Document modifications		
	Month-Year	Modifications
1.0	Nov 02	Creation. This document comprises a description of Master / slave protocol and of the two different transmission modes (RTU, ASCII). The main features of the physical layer (RS485, RS232) and some recommendations are provided. Implementation classes are proposed to guide the implementation.
1.01	Aug 30, 2006	Minor clarifications and correction of typos.
1.02	Dec 20, 2006	Minor clarifications and correction of typos.

1 Introduction

1.1 Scope of this document

The MODBUS standard defines an application layer messaging protocol, positioned at level 7 of the OSI model that provides "client/server" communications between devices connected on different types of buses or networks. It standardizes also a specific protocol on serial line to exchange MODBUS request between a master and one or several slaves.

The objective of this document is to present the MODBUS protocol over serial line, in order to be used by all system designers when they want to implement MODBUS protocol on their serial line products. Thus, this document will facilitate interoperability between devices using the MODBUS protocol.

This document comes in complement to the document called "MODBUS Application Protocol Specification".

In chapter 5 different implementation classes are defined for "MODBUS Serial Line". Specification of a class is the sum of requirements that a device must respect in order to belong to that class.

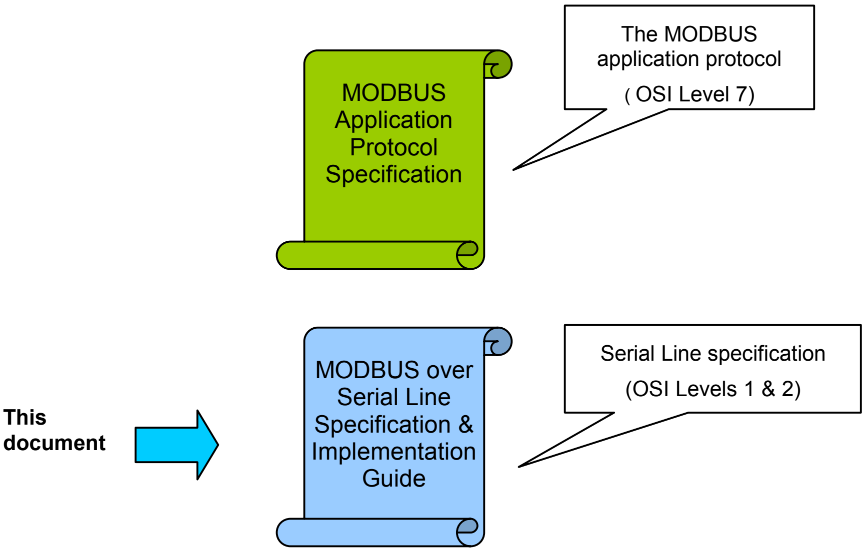


Figure 1: General overview of MODBUS documents

1.2 Protocol overview

This document describes the MODBUS over Serial Line protocol. **MODBUS Serial Line protocol is a Master-Slave protocol.** This protocol takes place at level 2 of the OSI model.

A master-slave type system has one node (the master node) that issues explicit commands to one of the "slave" nodes and processes responses. Slave nodes will not typically transmit data without a request from the master node, and do not communicate with other slaves.

At the physical level, MODBUS over Serial Line systems may use different physical interfaces (RS485, RS232). TIA/EIA-485 (RS485) Two-Wire interface is the most common. As an add-on option, RS485 Four-Wire interface may also be implemented. A TIA/EIA-232-E (RS232) serial interface may also be used as an interface, when only short point to point communication is required. (see chapter "Physical Layer")

The following figure gives a general representation of MODBUS serial communication stack compared to the 7 layers of the OSI model.

Layer	ISO/OSI Model	
7	Application	MODBUS Application Protocol
6	Presentation	Empty
5	Session	Empty
4	Transport	Empty
3	Network	Empty
2	Data Link	MODBUS Serial Line Protocol
1	Physical	EIA/TIA-485 (or EIA/TIA-232)

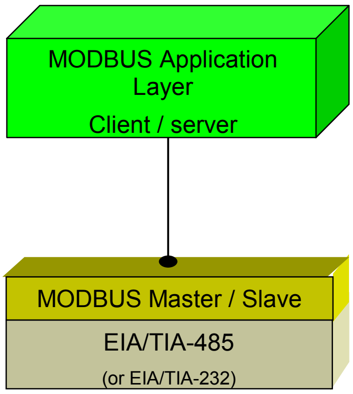


Figure 2: MODBUS Protocols and ISO/OSI Model

MODBUS application layer messaging protocol, positioned at level 7 of the OSI model, provides client/server communication between devices connected on buses or networks. On MODBUS serial line the client role is provided by the Master of the serial bus and the Slaves nodes act as servers.

1.3 Conventions

In this document, the following words are used to define the significance of each particular **requirement**.

- **"MUST" / "REQUIRED"**

All requirements containing the word "**MUST**" are mandatory. The word **MUST**, or the adjective "**REQUIRED**", means that the item is an absolute requirement of the implementation. These words are underlined.

- **"SHOULD" / "RECOMMENDED"**

All recommendations containing the word "**SHOULD**", or the adjective “**RECOMMENDED**”, are considered desired behavior. These recommendations should be used as a guideline when choosing between different options to implement functionality. There may be valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course. These words are underlined.

- **"MAY" / "OPTIONAL"**

The word “**MAY**”, or the adjective "**OPTIONAL**", means that this item is truly optional. One designer may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another designer may omit the same item.

1.4 Compliance

An implementation is **not in conformity** if it fails to satisfy one or more of the **MUST** requirements from its implementation class.

An implementation that satisfies all the MUST requirements and all the SHOULD recommendations is said to be "**unconditionally compliant**".

One that satisfies all the MUST requirements but not all the SHOULD recommendations is said to be "**conditionally compliant**".

1.5 Glossary

Definition of particular words, symbols, and abbreviations used in this document.

2W	The Two-Wire configuration defined in the “Electrical Interface” chapter, or one of its interfaces.
4W	The Four-Wire configuration defined in the “Electrical Interface” chapter, or one of its interfaces.
AUI	Attachment Unit Interface
AWG	American Wire Gauge, a standard method denoting wire diameter; please see Appendix E - References.
Common	The Signal Common in EIA/TIA Standards. In a 2W-or 4W-RS485 MODBUS Network, Signal and optional Power Supply Common
DCE	a MODBUS Device, for example a programmable controller adapter, which implements an RS232 Data Circuit-terminating Equipment, also named Data Communication Equipment.
Device	or “MODBUS device” : see this definition.
Driver	Generator, or Transmitter.
DTE	a MODBUS Device, for example a programming panel or a PC, which implements an RS232 Data Terminal Equipment.
ITr	Physical bus Interface on Trunk side.
IDv	Physical bus Interface on Derivation (or tap or device drop) side.
LT	Line Termination.
MODBUS Device	a Device that implements MODBUS over Serial Line and respects this Technical Note.
RS232	EIA/ TIA -232 Standard.
RS485	EIA/ TIA -485 Standard.
RS485-MODBUS	A 2W-or 4W-Network in accordance with this Technical Note.
Transceiver	a **Trans**mitter and a Re**ceiver** (or Driver and Receiver).

2 MODBUS Data Link Layer

2.1 MODBUS Master / Slaves protocol principle

The MODBUS Serial Line protocol is a Master-Slaves protocol. Only one master (at the same time) is connected to the bus, and one or several (247 maximum number) slaves nodes are also connected to the same serial bus. A MODBUS communication is always initiated by the master. The slave nodes will never transmit data without receiving a request from the master node. The slave nodes will never communicate with each other. The master node initiates only one MODBUS transaction at the same time.

The master node issues a MODBUS request to the slave nodes in two modes :

➔ In **unicast mode**, the master addresses an individual slave. After receiving and processing the request, the slave returns a message (a 'reply') to the master .

In that mode, a MODBUS transaction consists of 2 messages : a request from the master, and a reply from the slave.

Each slave must have an unique address (from 1 to 247) so that it can be addressed independently from other nodes.

➔ In **broadcast mode**, the master can send a request to all slaves.

No response is returned to broadcast requests sent by the master. The broadcast requests are necessarily writing commands. **All devices must accept the broadcast for writing function**. The address 0 is reserved to identify a broadcast exchange.

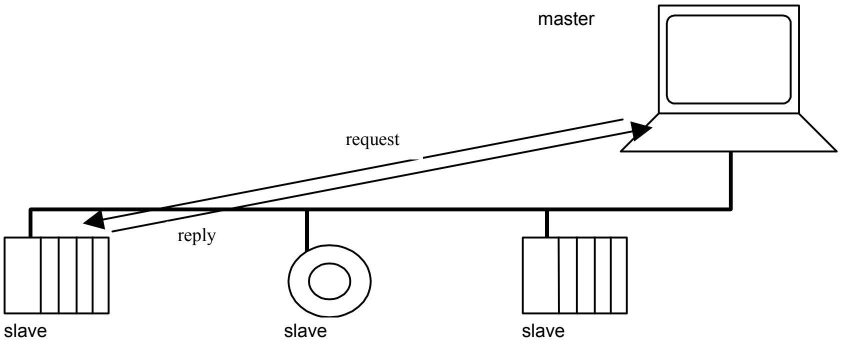


Figure 3: Unicast mode

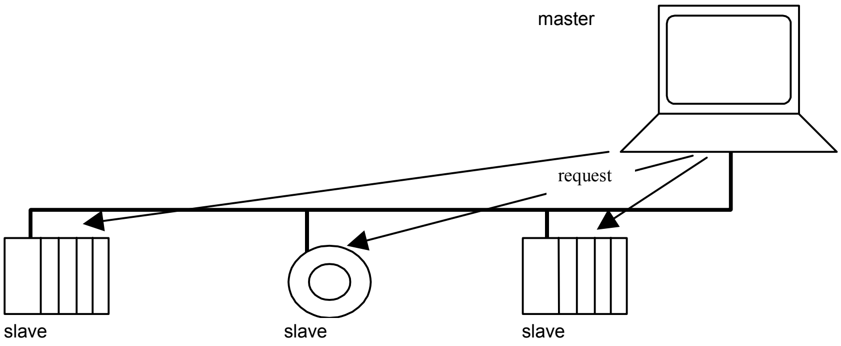


Figure 4: Broadcast mode

2.2 MODBUS Addressing rules

The MODBUS addressing space comprises 256 different addresses.

0	**From 1 to 247**	**From 248 to 255**
Broadcast address	**Slave individual addresses**	**Reserved**

The Address 0 is reserved as the broadcast address. All slave nodes must recognise the broadcast address.

The MODBUS Master node has no specific address, only the slave nodes must have an address. This address must be unique on a MODBUS serial bus.

2.3 MODBUS frame description

The MODBUS application protocol [1] defines a simple **P**rotocol **D**ata **U**nit (**PDU**) independent of the underlying communication layers:

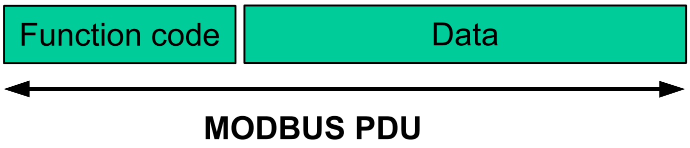


Figure 5: MODBUS Protocol Data Unit

The mapping of MODBUS protocol on a specific bus or network introduces some additional fields on the **P**rotocol **D**ata **U**nit. The client that initiates a MODBUS transaction builds the MODBUS PDU, and then adds fields in order to build the appropriate communication PDU.

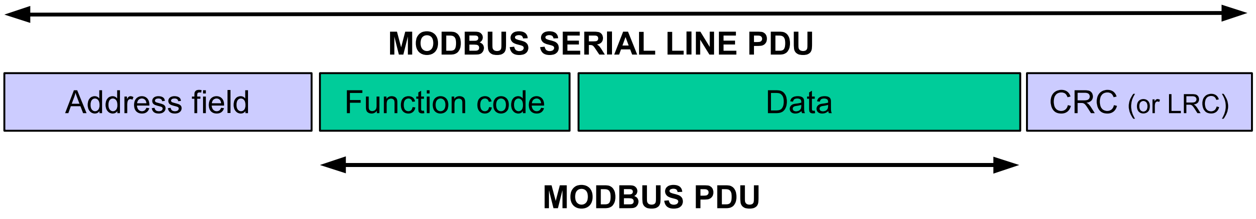


Figure 6: MODBUS frame over Serial Line

- On MODBUS Serial Line, the Address field only contains the slave address.

As described in the previous section the valid slave nodes addresses are in the range of 0 – 247 decimal. The individual slave devices are assigned addresses in the range of 1 – 247. A master addresses a slave by placing the slave address in the address field of the message. When the slave returns its response, it places its own address in the response address field to let the master know which slave is responding.

- The function code indicates to the server what kind of action to perform. The function code can be followed by a data field that contains request and response parameters.

- Error checking field is the result of a "Redundancy Checking" calculation that is performed on the message contents. Two kinds of calculation methods are used depending on the transmission mode that is being used (RTU or ASCII). (see 2.5 section, "*The two serial Transmission Modes*")

2.4 Master / Slaves State Diagrams

The MODBUS data link layer comprises two separate sub layers :

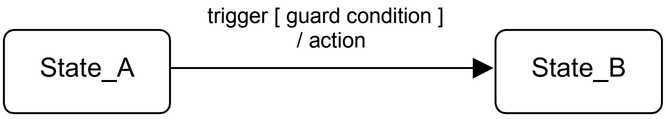
- The Master / slave protocol
- The transmission mode (RTU vs ASCII modes)

The following sections describes the state diagrams of a master and a slave that are independent of transmission modes used.

The RTU and ASCII transmission modes are specified in next chapters using two state diagrams. The reception and the sending of a frame are described.

Syntax of state diagram :

The following state diagrams are drawn in compliance with UML standard notations. The notation is briefly recalled below :



When a "trigger" event occurs in a system being in "State_A", system is going into "State_B", only if "guard condition" is true. An action "action" is then performed.

2.4.1 Master State diagram

The following drawing explains the Master behavior :

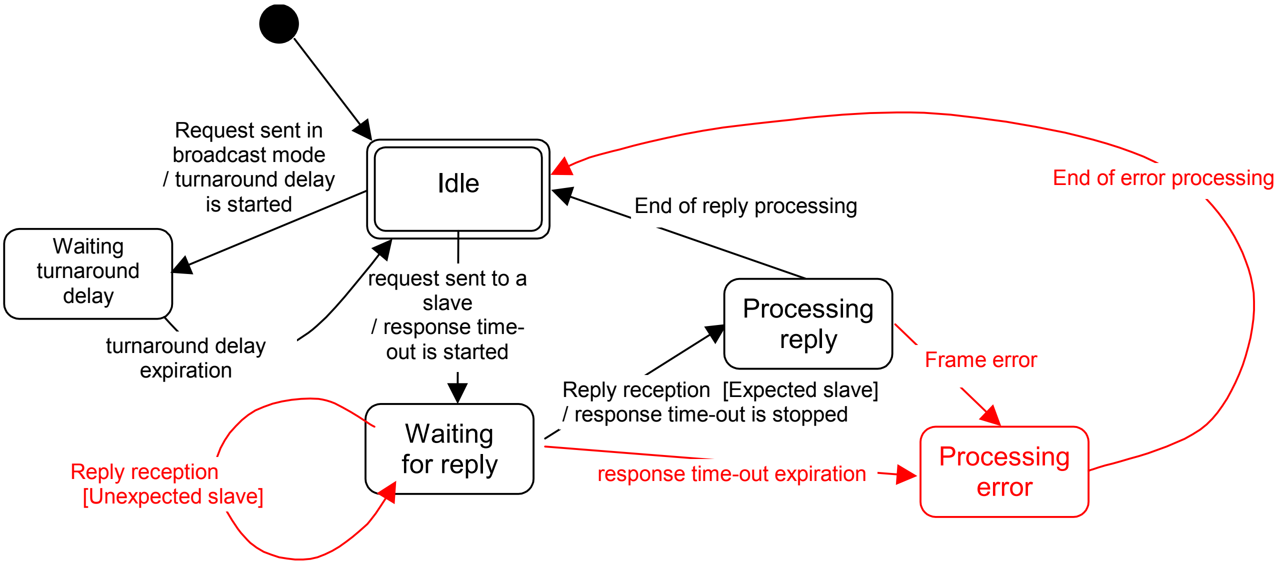


Figure 7: Master state diagram

<u>Some explanations about the state diagram above</u> :

- State "Idle" = no pending request. This is the initial state after power-up. A request can only be sent in "Idle" state. After sending a request, the Master leaves the "Idle" state, and cannot send a second request at the same time
- When a unicast request is sent to a slave, the master goes into "Waiting for reply" state, and a “Response Time-out” is started. It prevents the Master from staying indefinitely in "Waiting for reply" state. Value of the Response time-out is application dependant.
- When a reply is received, the Master checks the reply before starting the data processing. The checking may result in an error, for example a reply from an unexpected slave, or an error in the received frame. In case of a reply received from an unexpected slave, the Response time-out is kept running. In case of an error detected on the frame, a retry <u>may</u> be performed.
- If no reply is received, the Response time-out expires, and an error is generated. Then the Master goes into "Idle" state, enabling a retry of the request. The maximum number of retries depends on the master set-up.

- When a broadcast request is sent on the serial bus, no response is returned from the slaves. Nevertheless a delay is respected by the Master in order to allow any slave to process the current request before sending a new one. This delay is called "Turnaround delay". Therefore the master goes into "Waiting Turnaround delay" state before going back in "idle" state and before being able to send another request.
- In unicast the Response time out must be set long enough for any slave to process the request and return the response, in broadcast the Turnaround delay must be long enough for any slave to process only the request and be able to receive a new one. Therefore the Turnaround delay should be shorter than the Response time-out. Typically the Response time-out is from 1s to several second at 9600 bps; and the Turnaround delay is from 100 ms to 200ms.
- Frame error consists of : 1) Parity checking applied to each character; 2) Redundancy checking applied to the entire frame. See §2.6 "*Error Checking Methods*" for more explanations.

The state diagram is intentionally very simple. It does not take into account access to the line, message framing, or retry following transmission error, etc … For more details about frame transmission, please refer to 2.5 paragraph, "*The two serial Transmission Modes*".

2.4.2 Slave State Diagram

The following drawing explains the Slave behavior :

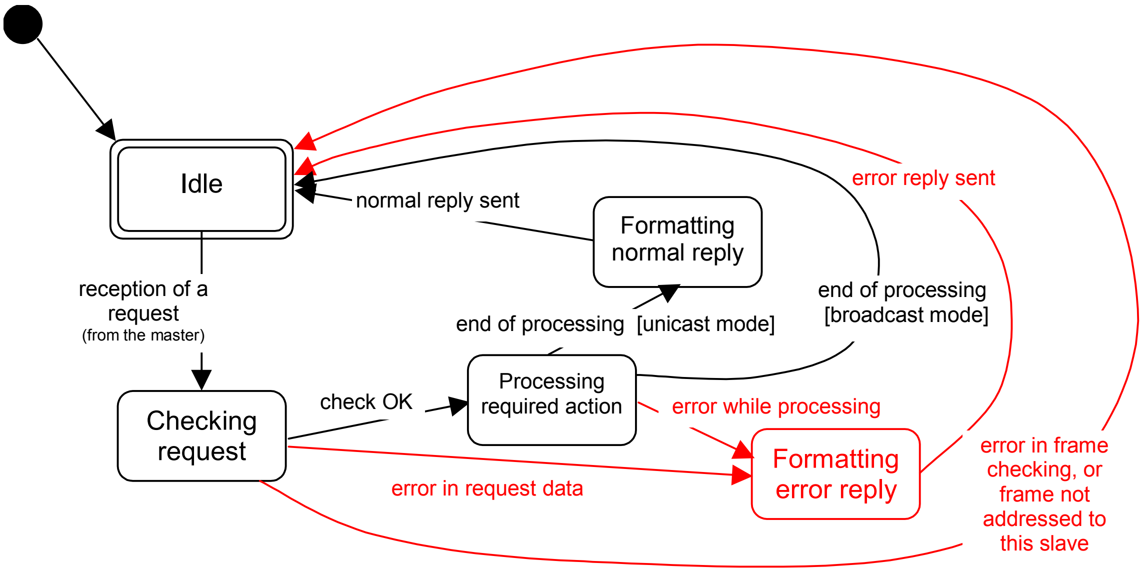


Figure 8: Slave state diagram

Some explanations about the above state diagram :

- State "Idle" = no pending request. This is the initial state after power-up.
- When a request is received, the slave checks the packet before performing the action requested in the packet. Different errors may occur : format error in the request, invalid action, … In case of error, a reply must be sent to the master.
- Once the required action has been completed, a unicast message requires that a reply must be formatted and sent to the master.
- If the slave detects an error in the received frame, no respond is returned to the master.
- MODBUS diagnostics counters are defined and should be managed by any slave in order to provide diagnostic information. These counters can be get using the Diagnostic MODBUS function (see Appendix A, and the MODBUS application protocol specification [1]).

2.4.3 Master / Slave communication time diagram

This following figure shows the time diagram of 3 typical scenarios of Master / Slave communications.

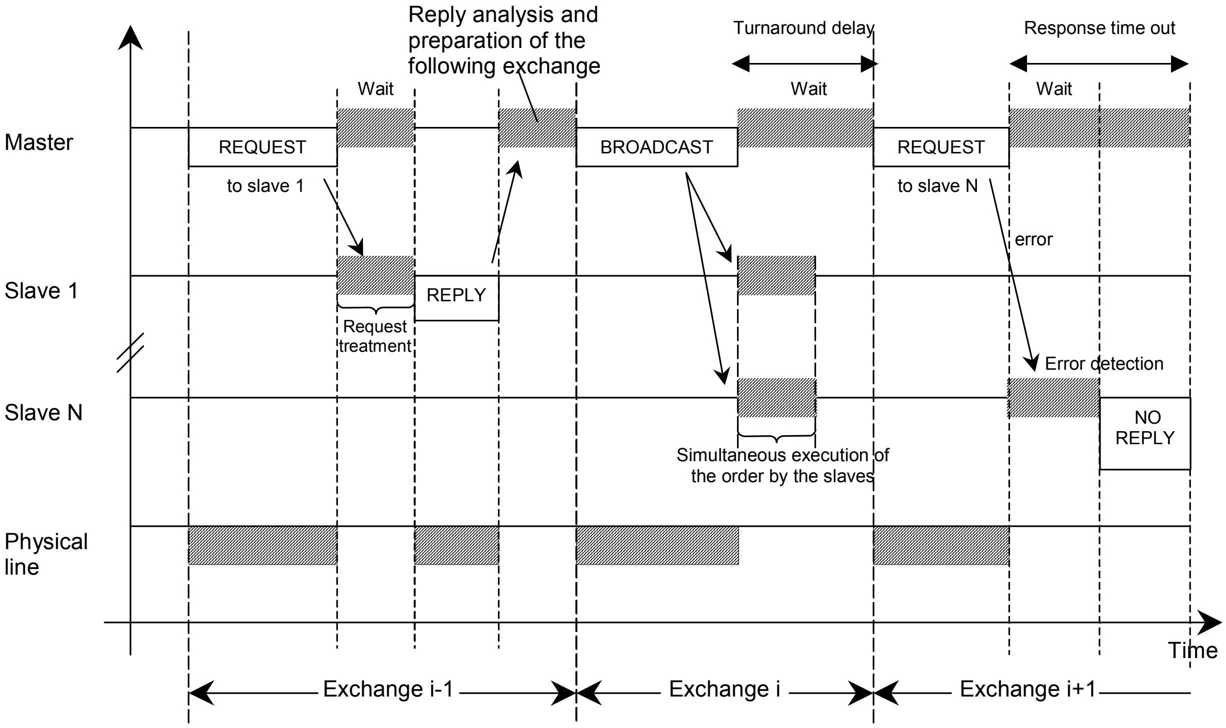


Figure 9: Master / Slave scenario time diagram

Remarks :

- the duration of the REQUEST, REPLY, BROACAST phases depends on the communication features (frame length and throughput).
- the duration of the WAIT and TREATMENT phases depends on the request processing time needed for the slave application.

2.5 The two serial Transmission Modes

Two different serial transmission modes are defined : The RTU mode and the ASCII mode.

It defines the bit contents of message fields transmitted serially on the line. It determines how information is packed into the message fields and decoded.

The transmission mode (and serial port parameters) must be the same for all devices on a MODBUS Serial Line.

Although the ASCII mode is required in some specific applications, interoperability between MODBUS devices can be reached only if each device has the same transmission mode : **All devices must implement the RTU Mode.** The ASCII transmission mode is an option.

Devices should be set up by the users to the desired transmission mode, RTU or ASCII. Default setup must be the RTU mode.

2.5.1 RTU Transmission Mode

When devices communicate on a MODBUS serial line using the RTU (Remote Terminal Unit) mode, each 8–bit byte in a message contains two 4–bit hexadecimal characters. The main advantage of this mode is that its greater character density allows better data throughput than ASCII mode for the same baud rate. Each message must be transmitted in a continuous stream of characters.

The format (11 bits) for each byte in RTU mode is :

Coding System:	8–bit binary
Bits per Byte:	1 start bit
	8 data bits, least significant bit sent first
	1 bit for parity completion
	1 stop bit

Even parity is required, other modes (odd parity, no parity) may also be used. In order to ensure a maximum compatibility with other products, it is recommended to support also No parity mode. The default parity mode must be even parity.

Remark : the use of no parity requires 2 stop bits.

How Characters are Transmitted Serially :

Each character or byte is sent in this order (left to right):

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

With Parity Checking

Start	1	2	3	4	5	6	7	8	Par	Stop

Figure 10: Bit Sequence in RTU mode

Devices may accept by configuration either Even, Odd, or No Parity checking. If No Parity is implemented, an additional stop bit is transmitted to fill out the character frame to a full 11-bit asynchronous character :

Without Parity Checking

Start	1	2	3	4	5	6	7	8	Stop	Stop

Figure 11: Bit Sequence in RTU mode (specific case of No Parity)

Frame Checking Field : Cyclical Redundancy Checking (CRC)

Frame description :

Slave Address	Function Code	Data	CRC
1 byte	1 byte	0 up to 252 byte(s)	2 bytes CRC Low CRC Hi

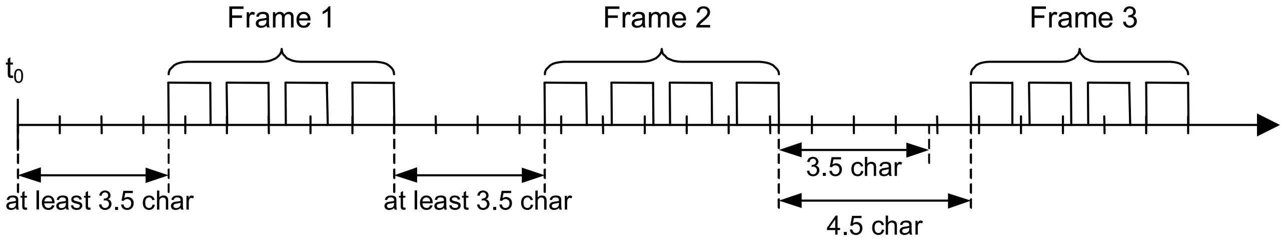
Figure 12: RTU Message Frame

➔ The maximum size of a MODBUS RTU frame is 256 bytes.

2.5.1.1 MODBUS Message RTU Framing

A MODBUS message is placed by the transmitting device into a frame that has a known beginning and ending point. This allows devices that receive a new frame to begin at the start of the message, and to know when the message is completed. Partial messages must be detected and errors must be set as a result.

In RTU mode, message frames are separated by a silent interval of at least 3.5 character times. In the following sections, this time interval is called t3,5.



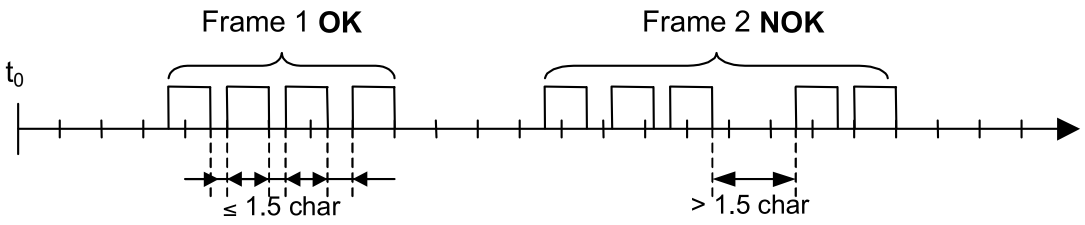
MODBUS message

Start	Address	Function	Data	CRC Check	End
≥ 3.5 char	8 bits	8 bits	N x 8 bits	16 bits	≥ 3.5 char

Figure 13: RTU Message Frame

The entire message frame must be transmitted as a continuous stream of characters.

If a silent interval of more than 1.5 character times occurs between two characters, the message frame is declared incomplete and should be discarded by the receiver.



Remark :

The implementation of RTU reception driver may imply the management of a lot of interruptions due to the $t_{1.5}$ and $t_{3.5}$ timers. With high communication baud rates, this leads to a heavy CPU load. Consequently these two timers must be strictly respected when the baud rate is equal or lower than 19200 Bps. For baud rates greater than 19200 Bps, fixed values for the 2 timers should be used: it is recommended to use a value of 750µs for the inter-character time-out ($t_{1.5}$) and a value of 1.750ms for inter-frame delay ($t_{3.5}$).

The following drawing provides a description of the RTU transmission mode state diagram. Both "master" and "slave" points of view are expressed in the same drawing :

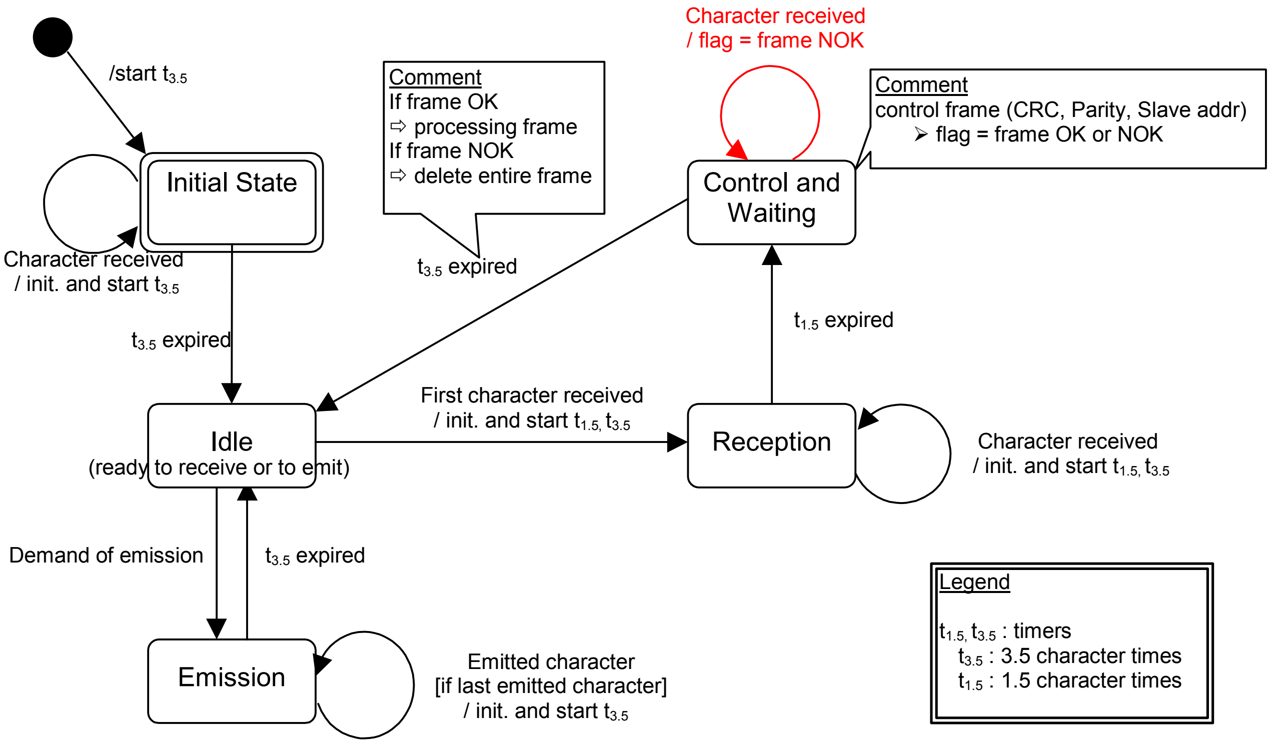


Figure 14: RTU transmission mode state diagram

<u>Some explanations about the above state diagram:</u>

- Transition from "Initial State" to "Idle" state needs $t_{3.5}$ time-out expiration : that insures inter-frame delay
- "Idle" state is the normal state when neither emission nor reception is active.
- In RTU mode, the communication link is declared in "idle" state when there is no transmission activity after a time interval equal to at least 3,5 characters.
- When the link is in idle state, each transmitted character detected on the link is identified as the **start of a frame**. The link goes to the "active" state. Then, the **end of frame** is identified when no more character is transmitted on the link after the time interval t3,5.
- After detection of the end of frame, the CRC calculation and checking is completed. Afterwards the address field is analysed to determine if the frame is for the device. If not the frame is discarded. In order to reduce the reception processing time the address field can be analysed as soon as it is received without waiting the end of frame. In this case the CRC will be calculated and checked only if the frame is addressed to the slave (broadcast frame included).

2.5.1.2 CRC Checking

The RTU mode includes an error–checking field that is based on a Cyclical Redundancy Checking (**CRC**) method performed on the message contents.

The CRC field checks the contents of the entire message. It is applied regardless of any parity checking method used for the individual characters of the message.

The CRC field contains a 16–bit value implemented as two 8–bit bytes.

The CRC field is appended to the message as the last field in the message. When this is done, the low–order byte of the field is appended first, followed by the high–order byte. The CRC high–order byte is the last byte to be sent in the message.

The CRC value is calculated by the sending device, which appends the CRC to the message. The receiving device recalculates a CRC during receipt of the message, and compares the calculated value to the actual value it received in the CRC field. If the two values are not equal, an error results.

The CRC calculation is started by first pre-loading a 16–bit register to all 1's. Then a process begins of applying successive 8–bit bytes of the message to the current contents of the register. Only the eight bits of data in each character are used for generating the CRC. Start and stop bits and the parity bit, do not apply to the CRC.

During generation of the CRC, each 8–bit character is exclusive ORed with the register contents. Then the result is shifted in the direction of the least significant bit (LSB), with a zero filled into the most significant bit (MSB) position. The LSB is extracted and examined. If the LSB was a 1, the register is then exclusive ORed with a preset, fixed value. If the LSB was a 0, no exclusive OR takes place.

This process is repeated until eight shifts have been performed. After the last (eight) shift, the next 8–bit byte is exclusive ORed with the register's current value, and the process repeats for eight more shifts as described above. The final content of the register, after all the bytes of the message have been applied, is the CRC value.

When the CRC is appended to the message, the low-order byte is appended first, followed by the high-order byte. A detailed example of CRC generation is contained in Appendix B.

2.5.2 The ASCII Transmission Mode

When devices are setup to communicate on a MODBUS serial line using ASCII (American Standard Code for Information Interchange) mode, each 8–bit byte in a message is sent as two ASCII characters. This mode is used when the physical communication link or the capabilities of the device does not allow the conformance with RTU mode requirements regarding timers management.

Remark : this mode is less efficient than RTU since each byte needs two characters.

➔ Example : The byte 0X5B is encoded as two characters : 0x35 and 0x42 (0x35 ="5", and 0x42 ="B" in ASCII).

The format (10 bits) for each byte in ASCII mode is :

Coding System:	Hexadecimal, ASCII characters 0–9, A–F One hexadecimal character contains 4-bits of data within each ASCII character of the message
Bits per Byte:	1 start bit 7 data bits, least significant bit sent first 1 bit for parity completion; 1 stop bit

Even parity is required, other modes (odd parity, no parity) may also be used. In order to ensure a maximum compatibility with other products, it is recommended to support also No parity mode. The default parity mode must be Even parity.

Remark : the use of no parity requires 2 stop bits.

How Characters are Transmitted Serially :

Each character or byte is sent in this order (left to right):

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

With Parity Checking

Start	1	2	3	4	5	6	7	Par	Stop

Figure 15: Bit Sequence in ASCII mode

Devices may accept by configuration either Even, Odd, or No Parity checking. If No Parity is implemented, an additional stop bit is transmitted to fill out the character frame :

Without Parity Checking

Start	1	2	3	4	5	6	7	Stop	Stop

Figure 16: Bit Sequence in ASCII mode (specific case of No Parity)

Frame Checking Field: Longitudinal Redundancy Checking (LRC)

2.5.2.1 MODBUS Message ASCII Framing

A MODBUS message is placed by the transmitting device into a frame that has a known beginning and ending point. This allows devices that receive a new frame to begin at the start of the message, and to know when the message is completed. Partial messages must be detected and errors must be set as a result.

The address field of a message frame contains two characters.

In ASCII mode, a message is delimited by specific characters as Start-of-frames and End-of-frames. A message must start with **a ‘colon’ (:)** character (ASCII 3A hex), and end with a **‘carriage return – line feed’** (CRLF) pair (ASCII 0D and 0A hex).

Remark : The LF character can be changed using a specific MODBUS application command (see MODBUS application protocol specification).

The allowable characters transmitted for all other fields are hexadecimal 0–9, A–F (ASCII coded). The devices monitor the bus continuously for the ‘colon’ character. When this character is received, each device decodes the next character until it detects the End-Of-Frame.

Intervals of up to one second may elapse between characters within the message. Unless the user has configured a longer timeout, an interval greater than 1 second means an error has occurred. Some Wide-Area-Network application may require a timeout in the 4 to 5 second range.

A typical message frame is shown below.

Start	Address	Function	Data	LRC	End
1 char :	2 chars	2 chars	0 up to 2x252 char(s)	2 chars	2 chars CR,LF

Figure 17: ASCII Message Frame

Remark : Each data byte needs two characters for encoding. Thus, to ensure compatibility at MODBUS application level between ASCII mode and RTU mode, the maximum data size for ASCII data field (2x252) is the double the maximum data size for RTU data field (252). Consequently, the maximum size of a MODBUS ASCII frame is 513 characters.

The ASCII framing requirements are synthesized in the following state diagram. Both "master" and "slave" points of view are expressed in the same drawing :

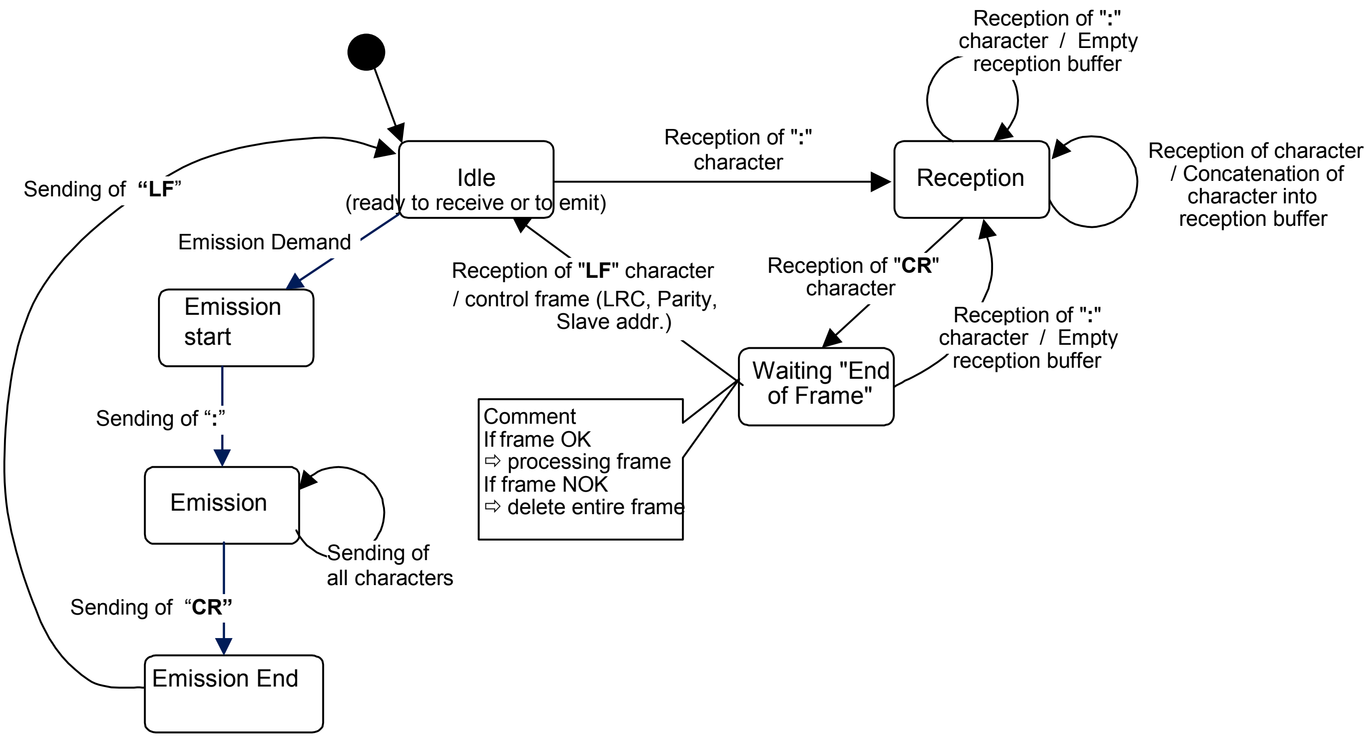


Figure 18: ASCII Transmission mode State diagram

Some explanations about the above state diagram :

- "Idle" state is the normal state when neither emission nor reception is active.
- Each reception of a ":" character means a beginning of a new message. If a message was in process of reception while receiving such a character, the current message is declared incomplete and it is discarded. A new reception buffer is then allocated.
- After detection of the end of frame, the LRC calculation and checking is completed. Afterwards the address field is analyzed to determine if the frame is for the device. If not the frame is discarded. In order to reduce the reception processing time the address field can be analyzed as soon as it is reserved without waiting the end of frame.

2.5.2.2 LRC Checking

In ASCII mode, messages include an error–checking field that is based on a Longitudinal Redundancy Checking (**LRC**) calculation that is performed on the message contents, exclusive of the beginning ‘colon’ and terminating CRLF pair characters. It is applied regardless of any parity checking method used for the individual characters of the message.

The LRC field is one byte, containing an 8–bit binary value. The LRC value is calculated by the device that emits, which appends the LRC to the message. The device that receives calculates an LRC during receipt of the message, and compares the calculated value to the actual value it received in the LRC field. If the two values are not equal, an error results.

The LRC is calculated by adding together successive 8–bit bytes of the message, discarding any carries, and then two’s complementing the result. It is performed on the bytes of the message, before the encoding of each byte in the two ASCII characters corresponding to the hexadecimal representation of each nibble. The computation does not include the 'colon' character that begins the message, and does not include the CRLF pair at the end of the message.
The resulting LRC is ASCII encoded into two bytes and placed at the end of the ASCII mode frame before the CRLF.

A detailed example of LRC generation is contained in Appendix B.

2.6 Error Checking Methods

The security of standard MODBUS Serial Line is based on two kinds of error checking :

- Parity checking (even or odd) should be applied to each character.
- Frame checking (LRC or CRC) must be applied to the entire message.

Both the character checking and message frame checking are generated in the device (master or slave) that emits and applied to the message contents before transmission. The device (slave or master) checks each character and the entire message frame during receipt.

The master is configured by the user to wait for a predetermined timeout interval (Response time-out) before aborting the transaction. This interval is set to be long enough for any slave to respond normally (unicast request). If the slave detects a transmission error, the message will not be acted upon. The slave will not construct a response to the master. Thus the timeout will expire and allow the master's program to handle the error. Note that a message addressed to a nonexistent slave device will also cause a timeout.

2.6.1 Parity Checking

Users may configure devices for Even (required) or Odd Parity checking, or for No Parity checking (recommended). This will determine how the parity bit will be set in each character.

If either Even or Odd Parity is specified, the quantity of 1 bits will be counted in the data portion of each character (seven data bits for ASCII mode, or eight for RTU). The parity bit will then be set to a 0 or 1 to result in an Even or Odd total of 1 bits.

For example, these eight data bits are contained in an RTU character frame:

1100 0101

The total quantity of 1 bits in the frame is four. If Even Parity is used, the frame's parity bit will be a 0, making the total quantity of 1 bits still an even number (four). If Odd Parity is used, the parity bit will be a 1, making an odd quantity (five).

When the message is transmitted, the parity bit is calculated and applied to the frame of each character. The device that receives counts the quantity of 1 bits and sets an error if they are not the same as configured for that device (all devices on the MODBUS Serial Line must be configured to use the same parity checking method).

Note that parity checking can only detect an error if an odd number of bits are picked up or dropped in a character frame during transmission. For example, if Odd Parity checking is employed, and two 1 bits are dropped from a character containing three 1 bits, the result is still an odd count of 1 bits.

If No Parity checking is specified, no parity bit is transmitted and no parity checking can be made. An additional stop bit is transmitted to fill out the character frame.

2.6.2 Frame Checking

Two kinds of frame checking is used depending on the transmission mode, RTU or ASCII.

- In RTU mode, messages include an error–checking field that is based on a Cyclical Redundancy Checking (CRC) method. The CRC field checks the contents of the entire message. It is applied regardless of any parity checking method used for the individual characters of the message.
- In ASCII mode, messages include an error–checking field that is based on a Longitudinal Redundancy Checking (LRC) method. The LRC field checks the contents of the message, exclusive of the beginning 'colon' and ending CRLF pair. It is applied regardless of any parity checking method used for the individual characters of the message.

The detailed information about error checking methods is contained in the previous sections.

3 Physical Layer

3.1 Preamble

A new MODBUS solution over serial line should implement an electrical interface in accordance with EIA/TIA-485 standard (also known as RS485 standard). This standard allows point to point and multipoint systems, in a "two-wire configuration". In addition, some devices may implement a "Four-Wire" RS485-Interface.

A device may also implement an RS232-Interface.

In such a MODBUS system, a Master Device and one or several Slave Devices communicate on a passive serial line.

On standard MODBUS system, all the devices are connected (in parallel) on a trunk cable constituted by 3 conductors. Two of those conductors (the "Two-Wire" configuration) form a balanced twisted pair, on which bi-directional data are transmitted, typically at the bit rate of 9600 bits per second.

Each device may be connected (see figure 19):

- either directly on the trunk cable, forming a daisy-chain,
- either on a passive Tap with a derivation cable,
- either on an active Tap with a specific cable.

Screw Terminals, RJ45, or D-shell 9 connectors may be used on devices to connect cables (see the chapter "Mechanical Interfaces").

3.2 Data Signaling Rates

9600 bps and 19.2 Kbps are required and 19.2 is the required default

Other baud rates may optionally be implemented : 1200, 2400, 4800, … 38400 bps, 56 Kbps, 115 Kbps, …

Every implemented baud rate must be respected better than 1% in transmission situation, and must accept an error of 2% in reception situation.

3.3 Electrical Interfaces

3.3.1 Multipoint Serial Bus Infrastructure

Figure 19 gives a general overview of the serial bus infrastructure in a MODBUS multipoint Serial Line system.

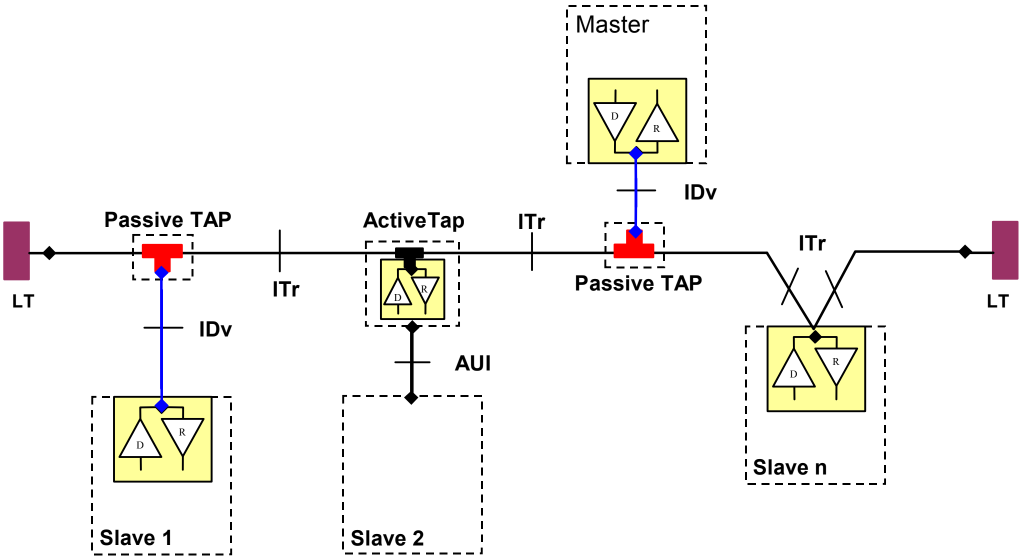


Figure 19 : Serial bus infrastructure

A multipoint MODBUS Serial Line bus is made of a principal cable (**the Trunk**), and possibly some **derivation** cables.
Line terminations are necessary at each extremity of the trunk cable for impedance adaptation (see § "Two-Wire MODBUS Definition" & "Optional Four-Wire MODBUS Definition" for details).

As shown in figure 19, different implementations may operate in the same MODBUS Serial Line system :

- the device integrates the communication transceiver and is connected to the trunk using a **Passive Tap** and a derivation cable (case of Slave 1 and Master) ;
- the device doesn't integrate the communication transceiver and is connected to the trunk using an **Active Tap** and a derivation cable (the active TAP integrates the transceiver) (case of Slave 2) ;
- the device is connected directly to the trunk cable, in a **Daisy-Chain** (case of Slave n)

The following conventions are adopted :

- The interface with the **trunk** is named **ITr** (Trunk Interface)
- The interface between the device and the **Passive Tap** is named **IDv** (Derivation Interface)
- The interface between the device and the **Active Tap** is named **AUI** (Attachment Unit Interface)

Remarks :

1. In some cases, the Tap may be connected directly to the IDv-socket or the AUI-socket of the device, without using a derivation cable.
2. A Tap may have several IDv sockets to connect several devices. Such a Tap is named **Distributor** when it is a passive one.
3. When using an active Tap, power supply of the Tap may be provided either via its AUI or ITr interface.

ITr and **IDv** interfaces are described in the following chapters (see § "Two-Wire MODBUS DEFINITION" & "Four-Wire MODBUS DEFINITION").

3.3.2 Two-Wire MODBUS Definition

A MODBUS solution over serial line should implement a “Two-Wire” electrical interface in accordance with EIA/TIA-485 standard.

On such a 2W-bus, at any time one driver only has the right for transmitting.

In fact a third conductor must also interconnect all the devices of the bus : the common.

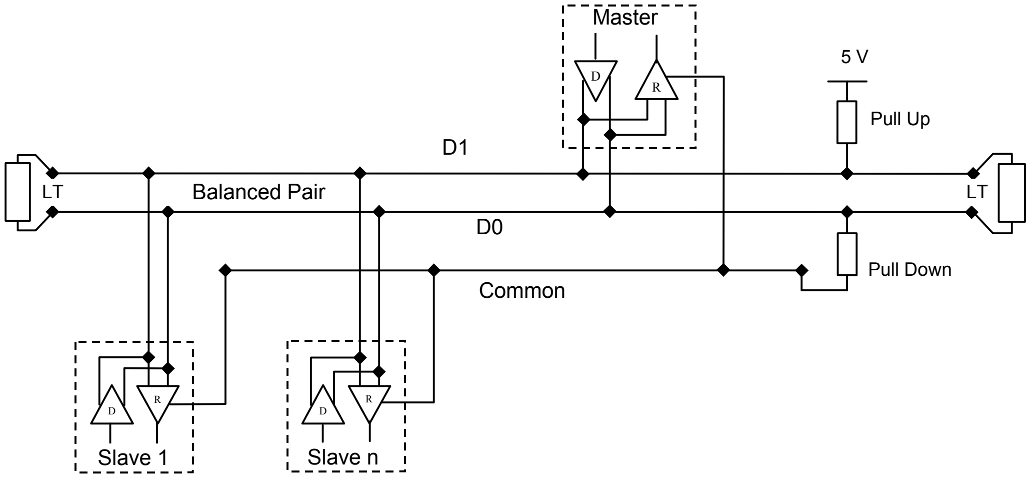


Figure 20: General 2-Wire Topology

2W-MODBUS Circuits Definition

Required Circuits		**For device**	**Required on device**	**EIA/TIA-485 name**	**Description**
on ITr	**on IDv**				
D1	D1	I/O	**X**	B/B’	**Transceiver terminal 1, V1 Voltage** (V1 > V0 for binary 1 [OFF] state)
D0	D0	I/O	**X**	A/A’	**Transceiver terminal 0, V0 Voltage** (V0 > V1 for binary 0 [ON] state)
Common	Common	--	**X**	C/C’	Signal and optional Power Supply Common

Notes :

- For Line Termination (LT), Pull Up and Pull Down resistors, please refer to section “Multipoint System requirements".
- D0, D1, and Common circuit names must be used in the documentation related to the device and the Tap (User Guide, Cabling Guide, …) to facilitate interoperability.
- Optional electrical interfaces may be added, for example :
  - **Power Supply :** 5..24 V D.C.
  - **Port mode control :** PMC circuit (TTL compatible). When needed, port mode may be controlled either by this external circuit and/or by another way (a switch on the device for example). In the first case while an open circuit PMC will ask for the 2W-MODBUS mode, a Low level on PMC will switch the port into 4W-MODBUS or RS232-MODBUS Mode, depending on the implementation.

3.3.3 Optional Four-Wire MODBUS Definition

Optionally, such MODBUS devices also permit to implement a **2-pair** bus (4 wires) of mono directional data. The data on the **master pair** (RXD1-RXD0) are only received by the slaves ; the data on the **slave pair** (TXD1-TXD0) are only received by the only master.

In fact a fifth conductor must also interconnect all the devices of the 4W-bus : the common.

In the same way as on a 2W-MODBUS, at any time one driver only has the right for emitting.

Such a device must implement, for each balanced pair, a driver and a transceiver **in accordance with EIA/ TIA-485**. (Sometimes this solution has been named "RS422", which is not correct : the RS422 standard does not support several drivers on one balanced pair.)

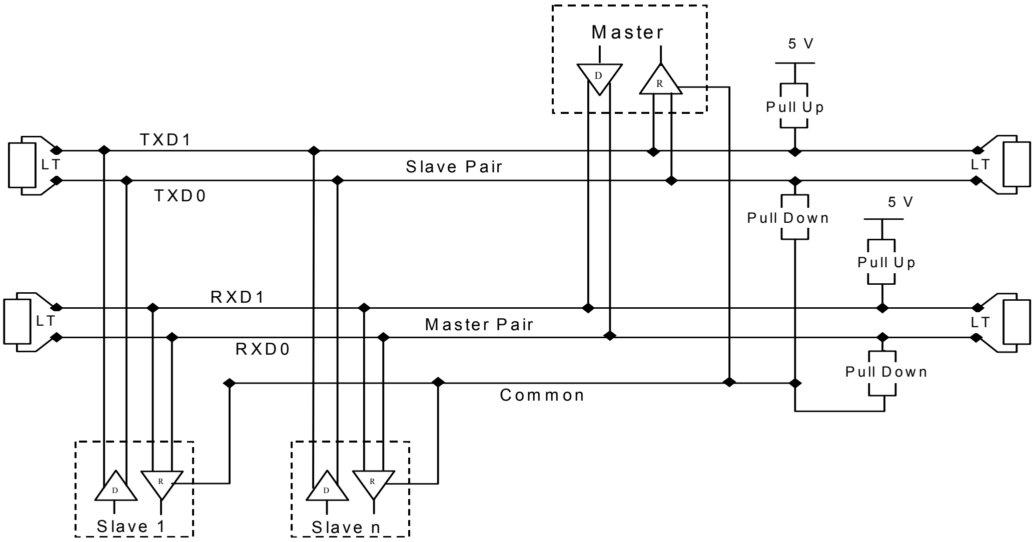


Figure 21: General 4-wire topology

Optional 4W-MODBUS Circuits Definition

Required Circuits		**For device**	**Required on device**	**EIA/TIA-485 name**	**Description for IDv**
on ITr	**on IDv**				
TXD1	TXD1	Out	**X**	B	**Generator terminal 1,** Vb Voltage (Vb > Va for binary 1 [OFF] state)
TXD0	TXD0	Out	**X**	A	**Generator terminal 0**, Va Voltage (Va > Vb for binary 0 [ON] state)
RXD1	RXD1	In	**(1)**	B'	**Receiver terminal 1**, Vb' Voltage (Vb' > Va' for binary 1 [OFF] state)
RXD0	RXD0	In	**(1)**	A'	**Receiver terminal 0**, Va' Voltage (Va' > Vb' for binary 0 [ON] state)
Common	Common	--	**X**	C/C'	Signal and optional Power Supply **Common**

Notes :

- For Line Termination (LT), Pull Up and Pull Down resistors, please refer to section "Multipoint System requirements".
- Those circuits **(1)** are required only if an 4W-MODBUS option is implemented.
- The name of the 5 required circuits must be used in the documentation related to the device and the Tap (User Guide, Cabling Guide, …) to facilitate interoperability.
- Optional electrical interfaces may be added, for example :
  - **Power Supply :** 5..24 V D.C.
  - **PMC circuit :** See above (In 2W-MODBUS Circuits Definition) the note about this optional circuit.

3.3.3.1 4W-Cabling System Important Topic

In such a 4W-MODBUS, Master Device and Slave Devices have IDv interfaces with the same 5 required circuits.
As the master has to :

- receive from the slave the data on the slave pair (TXD1-TXD0),
- and transmit on the master pair (RXD1-RXD0 , received by the slaves) ,

the 4W-cabling system must cross the two pairs of the bus between ITr and the IDv of the master :

	Signal on Master IDv		EIA/TIA-485 Name	**Circuit on ITr**
	Name	Type		
Slave Pair	RXD1	In	B'	TXD1
	RXD0	In	A'	TXD0
Master Pair	TXD1	Out	B	RXD1
	TXD0	Out	A	RXD0
	Common	--	C/C'	Common

This crossing may be implemented by crossed cables, but the connection of such crossed cables in a 2-wire system may cause damages. To connect a 4W master device (which have a MODBUS connector) a better solution is to use a Tap which includes the crossing function.

3.3.3.2 Compatibility between 4-Wire and 2-Wire cabling

In order to connect devices implementing a 2-Wire physical interface to an already existing 4-Wire system, the 4-Wire cabling system can be modified as described below :

- TxD0 signal shall be wired with the RxD0 signal, turning them to the D0 signal
- TxD1 signal shall be wired with the RxD1 signal, turning them to the D1 signal.
- Pull-up, Pull-down and line terminations resistors shall be re-arranged to correctly adapt the D0, D1 signals.

The figure hereafter gives an example where slaves 2 and 3 which use a 2-Wire interface can operate with the Master and the slave 1 which use a 4-Wire interface.

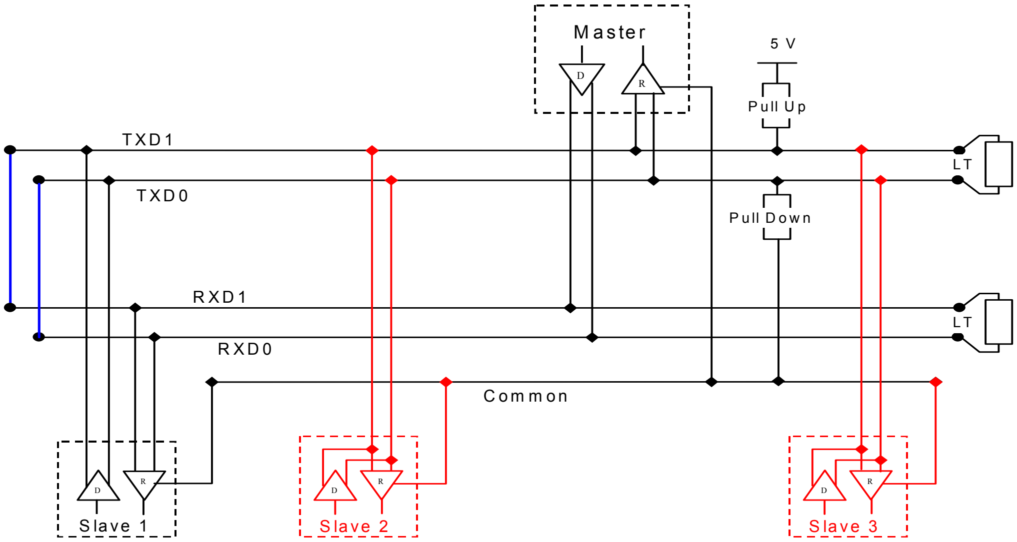


Figure 22 : Changing a 4-Wire cabling system into a 2-Wire cabling system

In order to connect devices implementing a 4-Wire physical interface to an already existing 2-Wire system, the 4-Wire interface of the new coming devices can be arranged as describe below :

On each 4-Wire device interface :

- TxD0 signal shall be wired with the RxD0 signal and then connected to the D0 signal of the trunk ;
- TxD1 signal shall be wired with the RxD1 signal and then connected to the D1 signal of the trunk.

The figure hereafter gives an example where slaves 2 and 3 which use a 4-Wire interface can operate with the Master and the slave 1 which use a 2-Wire interface.

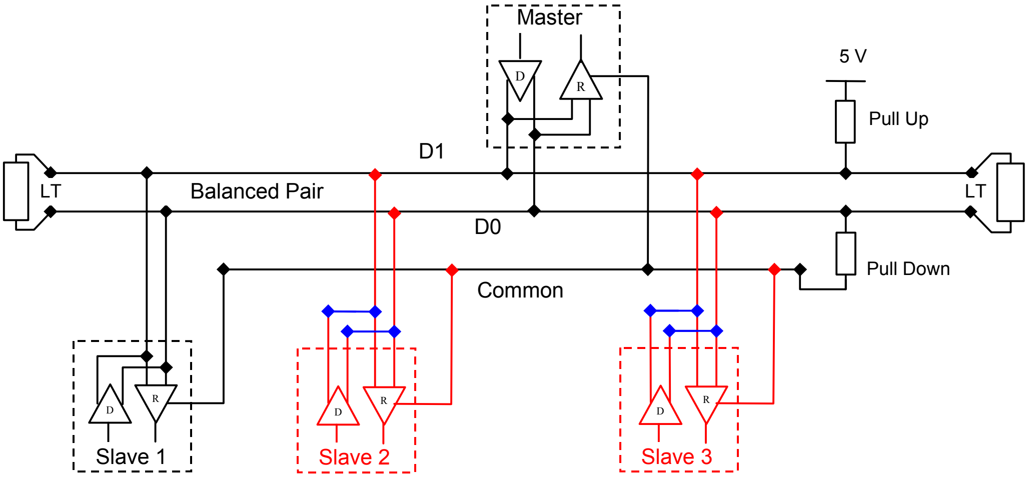


Figure 23 : Connecting devices with 4-Wire interface to a 2-Wire cabling system

3.3.4 RS232-MODBUS Definition

Some devices may implement an RS232-Interface between a DCE and a DTE.

Optional RS232-MODBUS Circuits Definition

Signal	**For DCE**	**Required on DCE (1)**	**Required on DTE (1)**	**Description**
Common	--	**X**	**X**	**Signal Common**
CTS	In			Clear to Send
DCD	--			Data Carrier Detected (from DCE to DTE)
DSR	In			Data Set Ready
DTR	Out			Data Terminal Ready
RTS	Out			Request to Send
RXD	In	**X**	**X**	**Received Data**
TXD	Out	**X**	**X**	**Transmitted Data**

Notes :

- "X" marked signals are required only if an RS232-MODBUS option is implemented.
- Signals are in accordance with EIA/ TIA-232.
- Each TXD must be wired with RXD of the other device ;
- RTS may be wired with CTS of the other device,
- DTR may be wired with DSR of the other device.
- Optional electrical interfaces may be added, for example :
  - **Power Supply :** 5..24 V D.C.
  - **PMC circuit :** See above (In 2W-MODBUS Circuits Definition) the note about this optional circuit.

3.3.5 RS232-MODBUS requirements

This optional MODBUS on Serial Line system should only be used for short length (typically less than 20m) point to point inter-connection.

Then, the EIA/TIA-232 standard must be respected :

⇒ circuits definition,

⇒ maximum wire capacitance to ground (2500 pF, then 25 m for a 100 pF/m cable).

Please refer to chapter "Cables" for the shield, and for the possibility to use Category 5 Cables.

Documentation of the device must indicate :

⇒ if the device must be considered as a DCE either as a DTE,

⇒ how optional circuits must work if such is the case.

3.4 Multipoint System requirements

For any EIA/ TIA-485 multipoint system, in either 2-wire or 4-wire configuration, the following requirements all apply.

3.4.1 Maximum number of devices without repeater

A figure of **32 devices** is always authorized on any RS485-MODBUS system without repeater.

Depending of :

- all the possible addresses,

- the figure of RS485 Unit Load used by the devices,

- and the line polarization in need be,

A RS485 system may implement a larger number of devices. Some devices allow the implementation of a RS485-MODBUS serial line with more than 32 devices, without repeater.

In this case these MODBUS devices must be documented to say how many of such devices are authorized without repeater.

The use of a **repeater** between two heavy loaded RS485-MODBUS is also possible.

3.4.2 Topology

An RS485-MODBUS configuration without repeater has one trunk cable, along which devices are connected, directly (daisy chaining) or by short derivation cables.

The trunk cable, also named “Bus”, can be long (see hereafter). Its two ends must be connected on Line Terminations.

The use of repeaters between several RS485-MODBUS is also possible.

3.4.3 Length

The end to end length of the **trunk cable** must be limited. The maximum length depends on the baud rate, the cable (Gauge, Capacitance or Characteristic Impedance), the number of loads on the daisy chain, and the network configuration *(2-wire or 4-wire)*.

For a maximum 9600 Baud Rate and AWG26 (or wider) gauge, the maximum length is 1000m. In the specific case shown in the figure 22 (4 Wire cabling used as a 2 Wire cabling system) the maximum length must be divided by two.

The **derivations** must be short, never more than 20m. If a multi-port tap is used with n derivations, each one must respect a maximum length of 40m divided by n.

3.4.4 Grounding Arrangements

The « Common » circuit (Signal and optional Power Supply Common) must be connected directly to protective ground, preferably at **one point only** for the entire bus. Generally this point is to choose on the master device or on its Tap.

3.4.5 Line Termination

A reflection in a transmission line is the result of an impedance discontinuity that a travelling wave sees as it propagates down the line. To minimize the reflections from the end of the RS485-cable it is required to place a Line Termination **near each of the 2 Ends** of the Bus.

It is important that the line be terminated at **both** ends since the propagation is bi-directional, but it is not allowed to place more than 2 LT on one passive D0-D1 balanced pair . Never place any LT on a derivation cable.

Each line termination must be connected between the two conductors of the balanced line : D0 and D1.

Line termination may be a 150 ohms value (0.5 W) resistor.

A serial capacitor (1 nF, 10 V minimum) with a 120 Ohms (0.25 W) resistor is a better choice when a polarization of the pair must be implemented (see here after).

In a 4W-system, each pair must be terminated at each end of the bus.

In an RS232 interconnections, no termination should be wired.

3.4.6 Line Polarization

When there is no data activity on an RS-485 balanced pair, the lines are not driven and, thus susceptible to external noise or interference. To insure that its receiver stays in a constant state, when no data signal is present, some devices need to bias the network.

Each MODBUS device must be documented to say :

- if the device needs a line polarization,
- if the device implements, or can implement, such a line polarization.

If one or several devices need polarization, **one** pair of resistors must be connected on the RS-485 balanced pair :

- a Pull-Up Resistor to a 5V Voltage on D1 circuit,
- a Pull-Down Resistor to the common circuit on D0 circuit.

The value of those resistors must be between 450 Ohms and 650 Ohms. 650 Ohms resistors value may allow a higher number of devices on the serial line bus.

In this case, a polarization of the pair must be implemented **at one location for the whole Serial Bus**. Generally this point is to choose on the master device or on its Tap. Other devices must not implement any polarization.

The maximum number of devices authorized on such a MODBUS Serial Line is reduced by 4 from a MODBUS without polarization.

3.5 Mechanical Interfaces

Screw Terminals may be used for both IDv and ITr connections. All information must be provided to the users about the exact location of each signal, with names in accordance with the previous chapter “Electrical Interface”.

If a RJ45 (or a mini-DIN or a D-Shell) **connector** is used on an equipment for a MODBUS mechanical interface, a **shielded female connector** must be chosen. Then the cable-end must have a shielded male connector.

3.5.1 Connectors pin-out for 2W-MODBUS

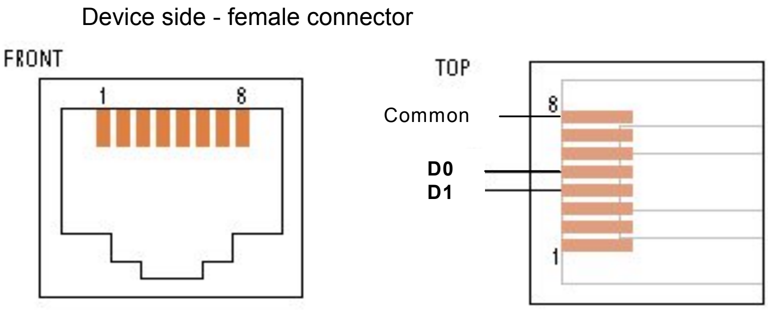


Figure 24: **2W- MODBUS on RJ45 connector (required pin-out)**

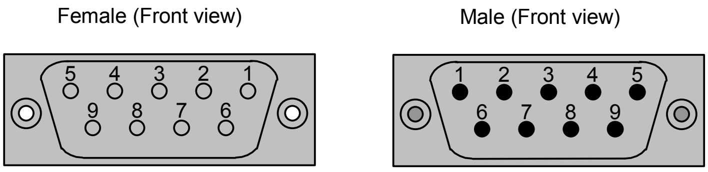


Figure 25: **D-shell 9-pin connector**

Screw type connectors can also be used.

If an RJ45 or a 9-pin D-shell connector is used for a standard MODBUS device, the pinouts hereafter must be respected for every implemented circuit.

2W-MODBUS RJ45 and 9-pin D-shell Pinouts

Pin on RJ45	Pin on D9-shell	Level of requirement	IDv Circuit	ITr Circuit	EIA/TIA-485 name	Description for IDv
3	3	optional	PMC	--	--	Port Mode Control
4	5	**required**	D1	D1	B/B’	**Transceiver terminal 1, V1 Voltage** (V1 > V0 for binary 1 [OFF] state)
5	9	**required**	D0	D0	A/A’	**Transceiver terminal 0, V0 Voltage** (V0 > V1 for binary 0 [ON] state)
7	2	recommended	VP	--	--	Positive 5...24 V D.C. Power Supply
8	1	**required**	Common	Common	C/C’	**Signal and Power Supply Common**

3.5.2 Connectors pin-out for optional 4W-MODBUS

Device side - female connector

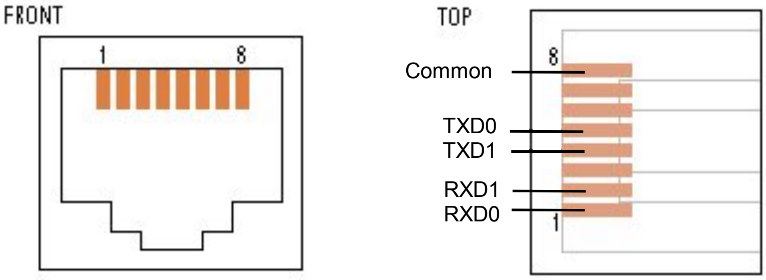


Figure 26: 4W- MODBUS on RJ45 connector (required pin-out)

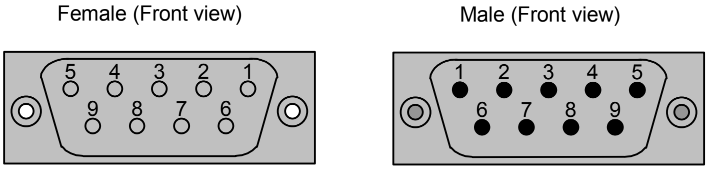


Figure 27: D-shell 9-pin connector

Screw type connectors can also be used.

If an RJ45 or a 9-pin D-shell connector is used for a 4W-MODBUS device, the pinouts hereafter must be respected for every implemented circuit.

Optional 4W-MODBUS RJ45 and 9-pin D-shell Pinouts

Pin on RJ45	Pin on D9-shell	Level of requirement	IDv Signal	ITr Signal	EIA/TIA-485 name	Description for IDv
1	8	**required**	RXD0	RXD0	A’	**Receiver terminal 0, Va’ Voltage** (Va’ > Vb’ for binary 0 [ON] state)
2	4	**required**	RXD1	RXD1	B’	**Receiver terminal 1, Vb’ Voltage** (Vb’ > Va’ for binary 1 [OFF] state)
3	3	optional	PMC	--	--	Port Mode Control
4	5	**required**	TXD1	TXD1	B	**Generator terminal 1, Vb Voltage** (Vb > Va for binary 1 [OFF] state)
5	9	**required**	TXD0	TXD0	A	**Generator terminal 0, Va Voltage** (Va > Vb for binary 0 [ON] state)
7	2	recommended	VP	--	--	Positive 5...24 V DC Power Supply
8	1	**required**	Common	Common	C/C’	**Signal and Power Supply Common**

Note : When both 2 and 4-Wire configurations are implemented on the same port, the **4W notations must be used.**

3.5.3 RJ45 and 9-pin D-shell Pinouts for optional RS232-MODBUS

If an RJ45 or a 9-pin D-shell connector is used for a RS232-MODBUS device, the pinouts hereafter must be respected for every implemented circuit.

DCE **Underlined** pins can be output			**Circuit**			**DTE** **Underlined** pins can be output		
Pin on RJ45	**Pin on D9-shell**	**Level of requirement**	**Name**	**Description**	**RS232 Source**	**Level of requirement**	**Pin on RJ45**	**Pin on D9-shell**
1	**2**	**required**	**TXD**	**Transmitted Data**	**DTE**	**required**	**2**	**3**
2	**3**	**required**	**RXD**	**Received Data**	**DCE**	**required**	**1**	**2**
3	7	optional	CTS	Clear to Send	DCE	optional	6	8
6	8	optional	RTS	Request to Send	DTE	optional	3	7
8	**5**	**required**	**Common**	**Signal Common**	**--**	**required**	**8**	**5**

Important Note : Some DCE Pinouts are crossed with DTE Pinouts with the same name :

A directly pin to pin wired cable (without any crossing) must be used between one DTE (a PC for example) and a DCE (a PLC for example).

3.6 Cables

A MODBUS over Serial Line Cable **must be shielded**. At one end of each cable its shield must be connected to protective ground. If a connector is used at this end, the shell of the connector is connected to the shield of the cable.

An RS485-MODBUS must use **a balanced pair** (for D0-D1) **and a third wire** (for the Common). In addition to that a second balanced pair must be used in a 4W-MODBUS system (for RXD0-RXD1).

If a connectorized 4 pairs Category 5 Cable is used, please remember to the user in the User Guides :

"Connection of a crossed cable in a 2-wire MODBUS system may cause damages".

To minimize errors in cabling, a Color Code is recommended for the wires in the RS485-MODBUS Cables :

	Signal Names	Recommended Color
	D1-*TXD1*	**yellow**
	D0-*TXD0*	**brown**
	Common	**grey**
4W (Optional)	*RXD0*	*white*
4W (Optional)	*RXD1*	*blue*

Figure 28: Color code for RS485-MODBUS wires

Note : Category 5 Cables use other colors.

For RS485-MODBUS, Wire Gauge must be chosen sufficiently wide to permit the maximum length (1000 m). AWG 24 is always sufficient for the MODBUS Data.

Category 5 cables may operate for RS485-MODBUS, to a maximum length of 600m.

For the balanced pairs used in an RS485-system, a **Characteristic Impedance** with a value higher than 100 Ohms may be preferred, especially for 19200 and higher baud rates.

3.7 Visual Diagnosis

For a visual diagnosis, communication status and device status must be indicated by LEDs :

LED	Level of requirement	State	Recommended colour
Communication	**required**	Switched ON during frame reception or sending. (2 LEDs for frame reception and frame sending, or 1 LED for both purposes.)	Yellow
Error	**recommended**	Switched ON : internal fault Flashing : Other faults (Communication fault or configuration error)	Red
Device status	**optional**	Switched ON : device powered	Green

4 Installation and Documentation

4.1 Installation

Product vendor should pay attention to give to the user of a MODBUS System or MODBUS Devices all useful information to prevent them **from any error in cabling** or bad utilization of cabling accessories :

- Some other Fieldbuses, CANopen for example, use the same connector types (D-shell, RJ45…) .
- Studies are conducted on Ethernet, with power supply on the same Balanced Pairs Cable.
- Some Products use for I/O circuits the same connector types (D-shell, RJ45…).

On these connectors, for the most part, **no foolproofing** is **available** (polarizing notch or other implementation) .

4.2 User Guide

The User Guide of any MODBUS Device or Cabling System Component must include in a non exhaustive manner one or two types of information:

4.2.1 For any MODBUS Product :

The following information should be documented :

- All the implemented requests.
- The operating modes.
- The visual diagnostics.
- The reachable registers and supported function codes.
- Installation rules.

- The required information in the following sections should also be documented :

⇒ "Two-Wire MODBUS Definition" (to mention the Required Circuits) ;
⇒ "Optional Four-Wire MODBUS Definition" (to mention the Required Circuits) ;
⇒ "Line Polarization" (to mention a possible Need or an Implementation) ;
⇒ "Cables" (special care of crossed cables).

- **A specific indication** relating to the devices addresses, is to be written in the form of an important warning :

"*It is of great importance to ensure at the time of the procedure of devices addressing, that there is not two devices with the same address. In such a case, an abnormal behavior of the whole serial bus can occur, the Master being then in the impossibility to communicate with all present slaves on the bus.*"

- A "**Getting Started**" chapter is highly recommended, with the documented description of a typical application example, for an easy start.

4.2.2 For a MODBUS Product with implemented Options :

The different optional parameters must be clearly detailed :

⇒ Optional serial Transmission mode ;
⇒ Optional Parity Checking ;
⇒ Optional Baud Rates ;
⇒ Optional Circuit(s) : Power Supply, Port Configuration ;
⇒ Optional Interface(s) ;
⇒ Maximum number of devices (without repeater) if greater than 32.

5 Implementation Classes

Each device on a MODBUS Serial Line must respect all the **mandatory** requirements of a same implementation class.
The following parameters are used to classify the MODBUS Serial Line devices :

- Addressing
- Broadcasting
- Transmission mode
- Baud rate
- Character format
- Electrical interface parameter

Two implementation classes are proposed, the Basic and the Regular classes.
The regular class must provide configuration capabilities.

	BASIC		**REGULAR**	**Default value**
Addressing	Slave : configurable address from 1 to 247	Master : to be able to address a slave from address 1 to 247	Same as Basic	-
Broadcast	Yes		Yes	-
Baud Rate	9600 (19200 is also recommended)		9600, 19200 + additional configurable baud rates	19200 (if implemented, else 9600)
Parity	EVEN		EVEN + possibility to configure NO and ODD parity	EVEN
Mode	RTU		RTU + ASCII	RTU
Electrical Interface	RS485 2W-cabling or RS232		RS485 2W-cabling (and 4W-cabling as an additional option) or RS232	RS485 2W-cabling
Connector Type	RJ 45 (recommended)			-

6 Appendix

6.1 Appendix A - Management of Serial Line Diagnostic Counters

6.1.1 General description

MODBUS Serial Line defines a list of diagnostic counters to allow performance and error management.

These counters are accessible using the MODBUS application protocol and its Diagnostic function (function code 08).

Each counter can be get by a sub-function code bound to the counter number. All counters can be cleared using the sub-function code 0x0A.

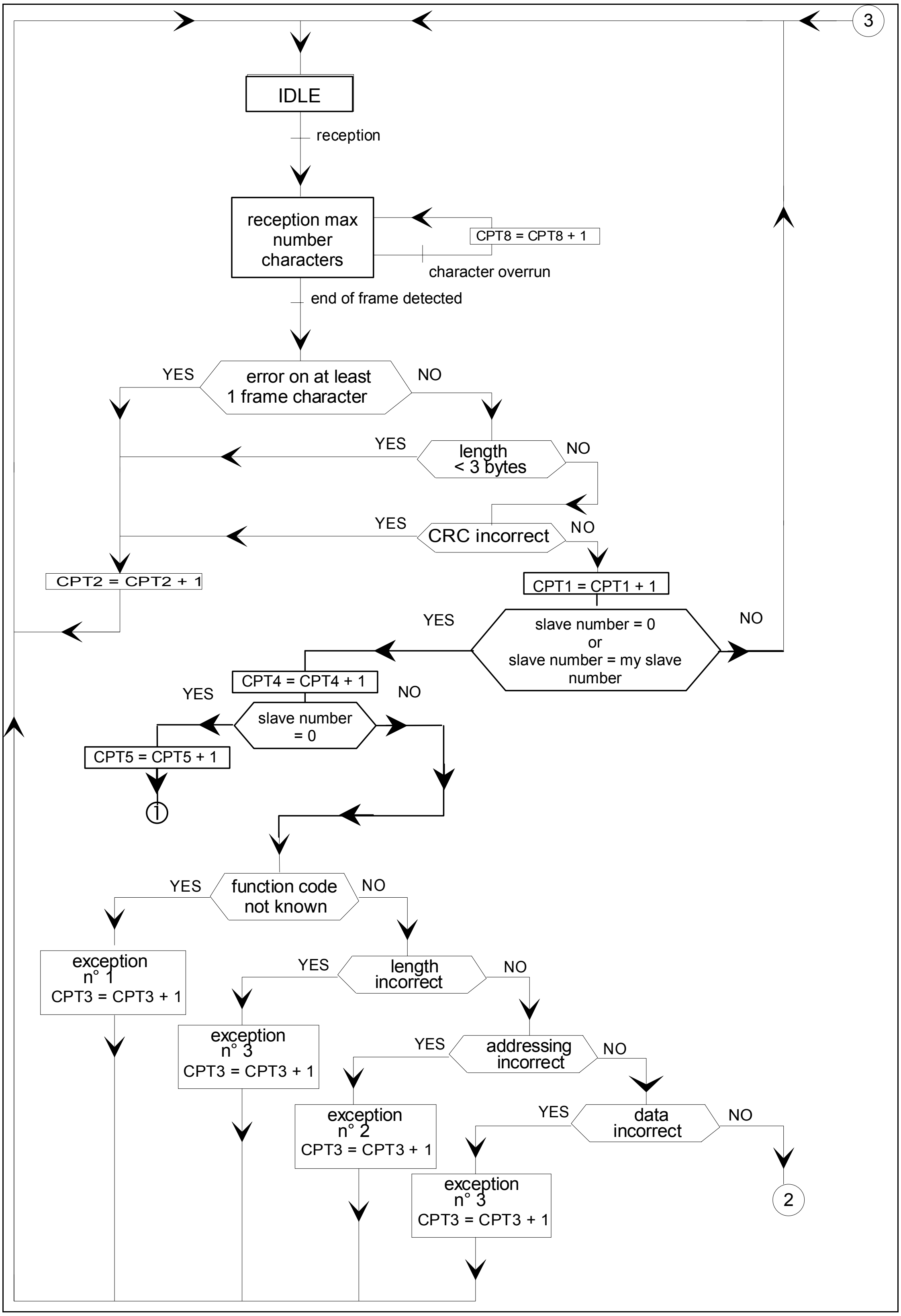
The format of the Diagnostic function is described in the MODBUS application protocol specification.

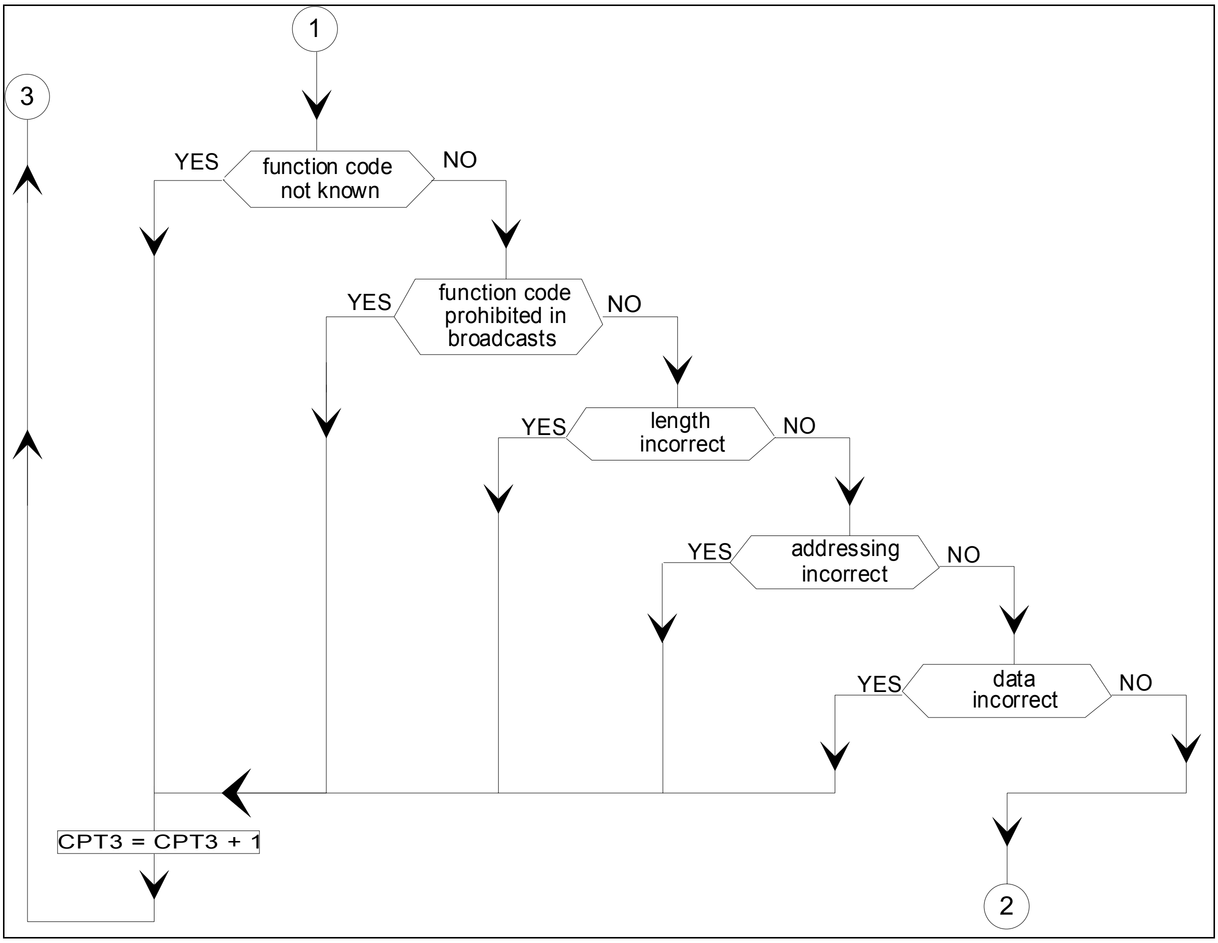
Herein is the list of diagnostics and associated sub-function codes supported by a serial line device.

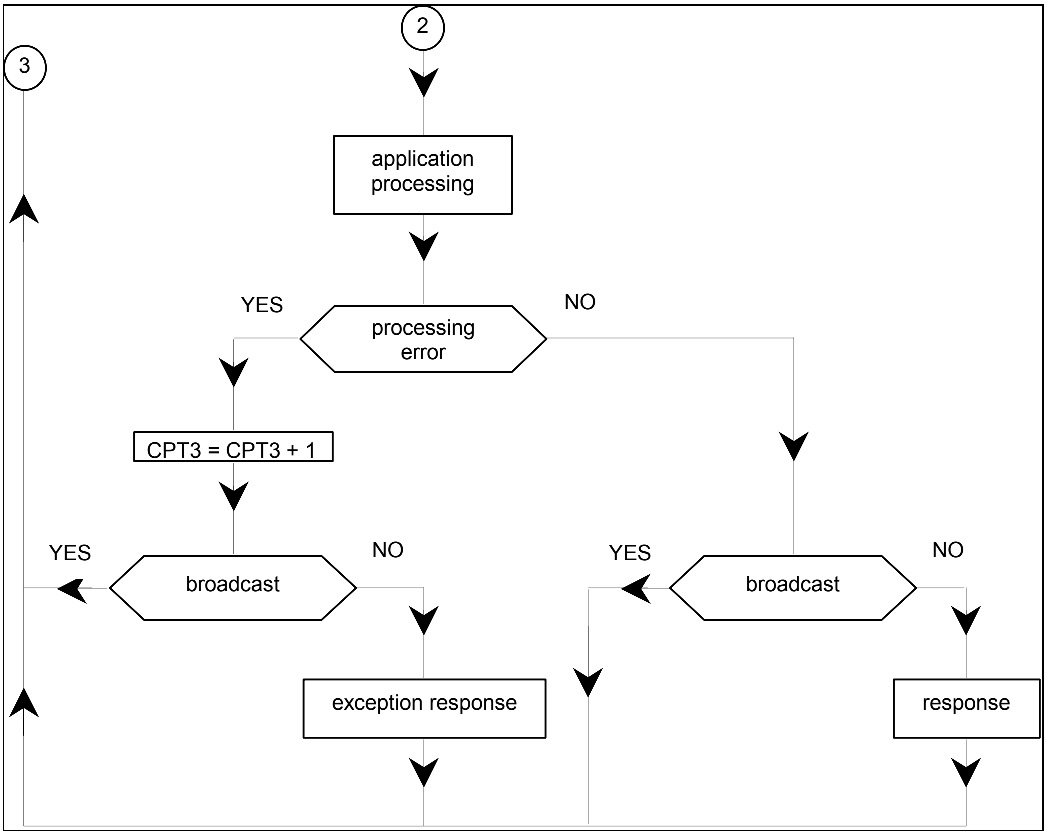
Sub-function code	Counter number	Counters Name	Comments (for diagram below)
Hex	Dec		
0x0B	1	Return Bus Message Count	Quantity of messages that the remote device has detected on the communications system since its last restart, clear counters operation, or power–up. Messages with bad CRC are not taken into account.
0x0C	2	Return Bus Communication Error Count	Quantity of CRC errors encountered by the remote device since its last restart, clear counters operation, or power–up. In case of an error detected on the character level, (overrun, parity error), or in case of a message length < 3 bytes, the receiving device is not able to calculate the CRC. In such cases, this counter is also incremented.
0x0D	3	Return Slave Exception Error Count	Quantity of MODBUS exception error detected by the remote device since its last restart, clear counters operation, or power–up. It comprises also the error detected in broadcast messages even if an exception message is not returned in this case. Exception errors are described and listed in "MODBUS Application Protocol Specification" document.
0xOE	4	Return Slave Message Count	Quantity of messages addressed to the remote device, including broadcast messages, that the remote device has processed since its last restart, clear counters operation, or power–up.
0x0F	5	Return Slave No Response Count	Quantity of messages received by the remote device for which it returned no response (neither a normal response nor an exception response), since its last restart, clear counters operation, or power–up. Then, this counter counts the number of broadcast messages it has received.
0x10	6	Return Slave NAK Count	Quantity of messages addressed to the remote device for which it returned a Negative Acknowledge (NAK) exception response, since its last restart, clear counters operation, or power–up. Exception responses are described and listed in "MODBUS Application Protocol Specification" document.
0x11	7	Return Slave Busy Count	Quantity of messages addressed to the remote device for which it returned a Slave Device Busy exception response, since its last restart, clear counters operation, or power–up. Exception responses are described and listed in "MODBUS Application Protocol Specification" document
0x12	8	Return Bus Character Overrun Count	Quantity of messages addressed to the remote device that it could not handle due to a character overrun condition, since its last restart, clear counters operation, or power–up. A character overrun is caused by data characters arriving at the port faster than they can be stored, or by the loss of a character due to a hardware malfunction.

6.1.2 Counters Management Diagram

The following diagrams describe when each previous counters must be incremented.




1
3
YES
function code not known
NO
YES
function code prohibited in broadcasts
NO
YES
length incorrect
NO
YES
addressing incorrect
NO
YES
data incorrect
NO
CPT3 = CPT3 + 1
2


2
3
application processing
YES
processing error
NO
CPT3 = CPT3 + 1
YES
broadcast
NO
YES
broadcast
NO
exception response
response

6.2 Appendix B - LRC/CRC Generation

6.2.1 LRC Generation

The Longitudinal Redundancy Checking (LRC) field is one byte, containing an 8–bit binary value. The LRC value is calculated by the transmitting device, which appends the LRC to the message. The device that receives recalculates an LRC during receipt of the message, and compares the calculated value to the actual value it received in the LRC field. If the two values are not equal, an error results.

The LRC is calculated by adding together successive 8–bit bytes in the message, discarding any carries, and then two's complementing the result. The LRC is an 8–bit field, therefore each new addition of a character that would result in a value higher than 255 decimal simply 'rolls over' the field's value through zero. Because there is no ninth bit, the carry is discarded automatically.

A procedure for generating an LRC is:

1. Add all bytes in the message, excluding the starting 'colon' and ending CRLF. Add them into an 8–bit field, so that carries will be discarded.
2. Subtract the final field value from FF hex (all 1's), to produce the ones–complement.
3. Add 1 to produce the twos–complement.

Placing the LRC into the Message

When the 8–bit LRC (2 ASCII characters) is transmitted in the message, the high–order character will be transmitted first, followed by the low–order character. For example, if the LRC value is 61 hex (0110 0001):

Colon	Addr	Func	Data Count	Data	Data	Data	Data	LRC Hi	LRC Lo	CR	LF
								"6" 0x36	"1" 0x31		

Figure 29: LRC Character Sequence

Example: an example of a C language function performing LRC generation is shown below.

The function takes two arguments:

unsigned char *auchMsg;	A pointer to the message buffer containing binary data to be used for generating the LRC,
unsigned short usDataLen;	The quantity of bytes in the message buffer.

LRC Generation Function

```
static unsigned char LRC(auchMsg, usDataLen)    /* the function returns the LRC as a type unsigned char */
unsigned char *auchMsg ;                        /*  message to calculate LRC upon */
unsigned short usDataLen ;                      /* quantity of bytes in message */
{
  unsigned char uchLRC = 0 ;                    /* LRC char initialized */
  while (usDataLen––)                           /* pass through message buffer */
  uchLRC += *auchMsg++ ;                        /* add buffer byte without carry */
  return ((unsigned char)(–((char)uchLRC))) ;   /* return twos complement */
}
```

6.2.2 CRC Generation

The Cyclical Redundancy Checking (CRC) field is two bytes, containing a 16–bit binary value. The CRC value is calculated by the transmitting device, which appends the CRC to the message. The device that receives recalculates a CRC during receipt of the message, and compares the calculated value to the actual value it received in the CRC field. If the two values are not equal, an error results.

The CRC is started by first preloading a 16–bit register to all 1's. Then a process begins of applying successive 8–bit bytes of the message to the current contents of the register. Only the eight bits of data in each character are used for generating the CRC. Start and stop bits and the parity bit, do not apply to the CRC.

During generation of the CRC, each 8–bit character is exclusive ORed with the register contents. Then the result is shifted in the direction of the least significant bit (LSB), with a zero filled into the most significant bit (MSB) position. The LSB is extracted and examined. If the LSB was a 1, the register is then exclusive ORed with a preset, fixed value. If the LSB was a 0, no exclusive OR takes place.

This process is repeated until eight shifts have been performed. After the last (eighth) shift, the next 8–bit character is exclusive ORed with the register's current value, and the process repeats for eight more shifts as described above. The final content of the register, after all the characters of the message have been applied, is the CRC value.

A procedure for generating a CRC is:

1. Load a 16–bit register with FFFF hex (all 1's). Call this the CRC register.
2. Exclusive OR the first 8–bit byte of the message with the low–order byte of the 16–bit CRC register, putting the result in the CRC register.
3. Shift the CRC register one bit to the right (toward the LSB), zero–filling the MSB. Extract and examine the LSB.
4. (If the LSB was 0): Repeat Step 3 (another shift).
   (If the LSB was 1): Exclusive OR the CRC register with the polynomial value 0xA001 (1010 0000 0000 0001).
5. Repeat Steps 3 and 4 until 8 shifts have been performed. When this is done, a complete 8–bit byte will have been processed.
6. Repeat Steps 2 through 5 for the next 8–bit byte of the message. Continue doing this until all bytes have been processed.
7. The final content of the CRC register is the CRC value.
8. When the CRC is placed into the message, its upper and lower bytes must be swapped as described below.

Placing the CRC into the Message

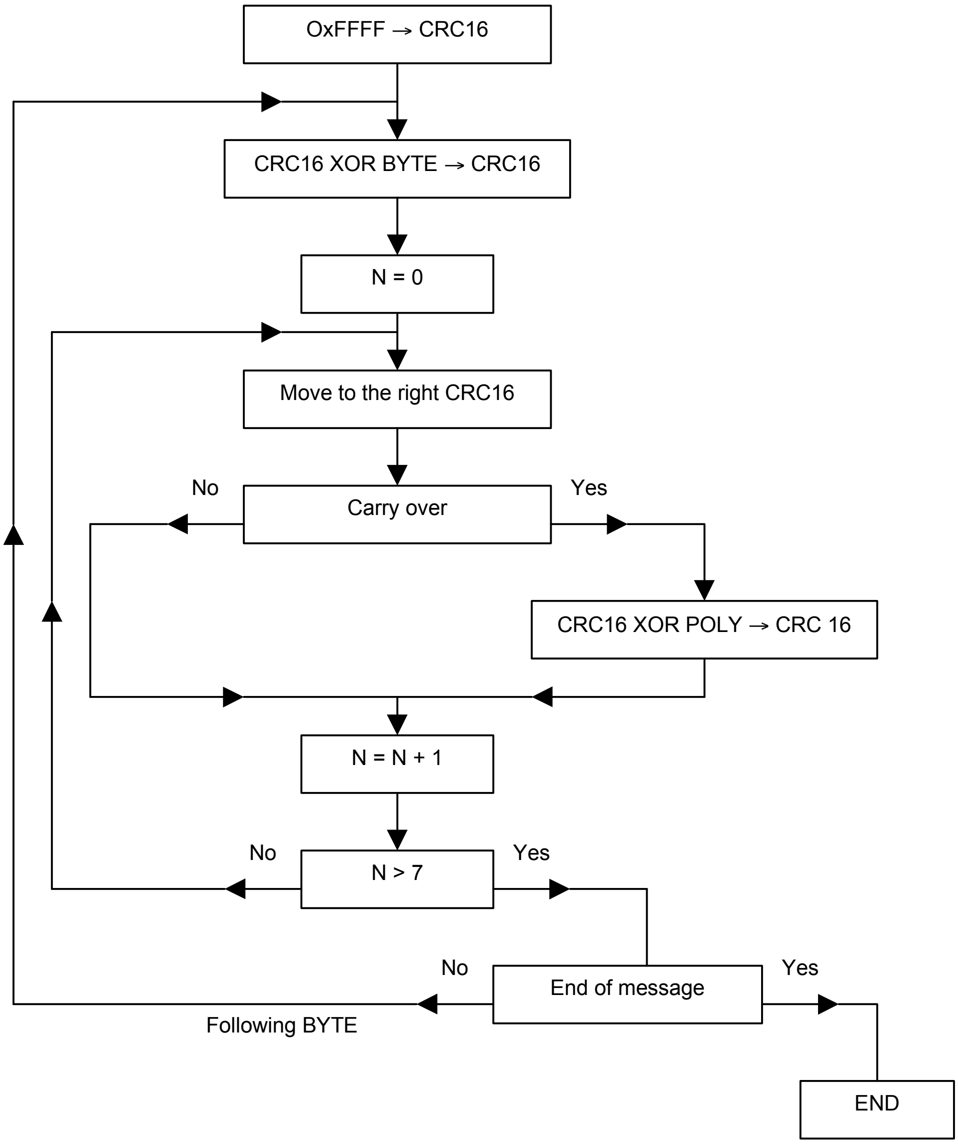
When the 16–bit CRC (two 8–bit bytes) is transmitted in the message, the low-order byte will be transmitted first, followed by the high-order byte.

For example, if the CRC value is 1241 hex (0001 0010 0100 0001):

Addr	Func	Data Count	Data	Data	Data	Data	CRC Lo	CRC Hi
							0x41	0x12

Figure 30: CRC Byte Sequence

Calculation algorithm of the CRC 16



XOR = exclusive or

N = number of information bits

POLY = calculation polynomial of the CRC 16 = 1010 0000 0000 0001

(Generating polynomial = $1 + x_2 + x_{15} + x_{16}$)

In the CRC 16, the 1st byte transmitted is the least significant one.

Example of CRC calculation (frame 02 07)

CRC register initialization		1111	1111	1111	1111
XOR 1st character		0000	0000	0000	0010
		1111	1111	1111	1101
	Move 1	0111	1111	1111	1110|1
Flag to 1, XOR polynomial		1010	0000	0000	0001
		1101	1111	1111	1111
	Move 2	0110	1111	1111	1111|1
Flag to 1, XOR polynomial		1010	0000	0000	0001
		1100	1111	1111	1110
	Move 3	0110	0111	1111	1111|0
	Move 4	0011	0011	1111	1111|1
		1010	0000	0000	0001
		1001	0011	1111	1110
	Move 5	0100	1001	1111	1111|0
	Move 6	0010	0100	1111	1111|1
		1010	0000	0000	0001
		1000	0100	1111	1110
	Move 7	0100	0010	0111	1111|0
	Move 8	0010	0001	0011	1111|1
		1010	0000	0000	0001
		1000	0001	0011	1110
XOR 2nd character		0000	0000	0000	0111
		1000	0001	0011	1001
	Move 1	0100	0000	1001	1100|1
		1010	0000	0000	0001
		1110	0000	1001	1101
	Move 2	0111	0000	0100	1110|1
		1010	0000	0000	0001
		1101	0000	0100	1111
	Move 3	0110	1000	0010	0111|1
		1010	0000	0000	0001
		1100	1000	0010	0110
	Move 4	0110	0100	0001	0011|0
	Move 5	0011	0010	0000	1001|1
		1010	0000	0000	0001
		1001	0010	0000	1000
	Move 6	0100	1001	0000	0100|0
	Move 7	0010	0100	1000	0010|0
	Move 8	0001	0010	0100	0001|0
		Most significant		least significant	

The CRC 16 of the frame is then: 4112

Example

An example of a C language function performing CRC generation is shown on the following pages. All of the possible CRC values are preloaded into two arrays, which are simply indexed as the function increments through the message buffer. One array contains all of the 256 possible CRC values for the high byte of the 16–bit CRC field, and the other array contains all of the values for the low byte.

Indexing the CRC in this way provides faster execution than would be achieved by calculating a new CRC value with each new character from the message buffer.

Note: This function performs the swapping of the high/low CRC bytes internally. The bytes are already swapped in the CRC value that is returned from the function.

Therefore the CRC value returned from the function can be directly placed into the message for transmission.

The function takes two arguments:

unsigned char *puchMsg;	A pointer to the message buffer containing binary data to be used for generating the CRC
unsigned short usDataLen;	The quantity of bytes in the message buffer.

CRC Generation Function

```
unsigned short CRC16 ( puchMsg, usDataLen )              /* The function returns the CRC as a unsigned short type  */
unsigned char *puchMsg ;                                 /* message to calculate CRC upon                          */
unsigned short usDataLen ;                               /* quantity of bytes in message                           */
{
        unsigned char uchCRCHi = 0xFF ;                  /* high byte of CRC initialized                           */
        unsigned char uchCRCLo = 0xFF ;                  /* low byte of CRC initialized                            */
        unsigned uIndex ;                                /* will index into CRC lookup table                       */

        while (usDataLen--)                              /* pass through message buffer                            */
        {
                uIndex = uchCRCLo ^ *puchMsg++ ;         /* calculate the CRC                                      */
                uchCRCLo = uchCRCHi ^ auchCRCHi[uIndex] ;
                uchCRCHi = auchCRCLo[uIndex] ;
        }
        return (uchCRCHi << 8 | uchCRCLo) ;
}
```

High-Order Byte Table

```
/* Table of CRC values for high–order byte */
static unsigned char auchCRCHi[] = {
    0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81,
    0x40, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0,
    0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01,
    0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01, 0xC0, 0x80, 0x41,
    0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81,
    0x40, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01, 0xC0,
    0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01,
    0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40,
    0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81,
    0x40, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0,
    0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01,
    0xC0, 0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41,
    0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81,
    0x40, 0x01, 0xC0, 0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0,
    0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01,
    0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81, 0x40, 0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41,
    0x00, 0xC1, 0x81, 0x40, 0x01, 0xC0, 0x80, 0x41, 0x01, 0xC0, 0x80, 0x41, 0x00, 0xC1, 0x81,
    0x40
} ;
```

Low-Order Byte Table

```
/* Table of CRC values for low–order byte */
static char auchCRCLo[] = {
    0x00, 0xC0, 0xC1, 0x01, 0xC3, 0x03, 0x02, 0xC2, 0xC6, 0x06, 0x07, 0xC7, 0x05, 0xC5, 0xC4,
    0x04, 0xCC, 0x0C, 0x0D, 0xCD, 0x0F, 0xCF, 0xCE, 0x0E, 0x0A, 0xCA, 0xCB, 0x0B, 0xC9, 0x09,
    0x08, 0xC8, 0xD8, 0x18, 0x19, 0xD9, 0x1B, 0xDB, 0xDA, 0x1A, 0x1E, 0xDE, 0xDF, 0x1F, 0xDD,
    0x1D, 0x1C, 0xDC, 0x14, 0xD4, 0xD5, 0x15, 0xD7, 0x17, 0x16, 0xD6, 0xD2, 0x12, 0x13, 0xD3,
    0x11, 0xD1, 0xD0, 0x10, 0xF0, 0x30, 0x31, 0xF1, 0x33, 0xF3, 0xF2, 0x32, 0x36, 0xF6, 0xF7,
    0x37, 0xF5, 0x35, 0x34, 0xF4, 0x3C, 0xFC, 0xFD, 0x3D, 0xFF, 0x3F, 0x3E, 0xFE, 0xFA, 0x3A,
    0x3B, 0xFB, 0x39, 0xF9, 0xF8, 0x38, 0x28, 0xE8, 0xE9, 0x29, 0xEB, 0x2B, 0x2A, 0xEA, 0xEE,
    0x2E, 0x2F, 0xEF, 0x2D, 0xED, 0xEC, 0x2C, 0xE4, 0x24, 0x25, 0xE5, 0x27, 0xE7, 0xE6, 0x26,
    0x22, 0xE2, 0xE3, 0x23, 0xE1, 0x21, 0x20, 0xE0, 0xA0, 0x60, 0x61, 0xA1, 0x63, 0xA3, 0xA2,
    0x62, 0x66, 0xA6, 0xA7, 0x67, 0xA5, 0x65, 0x64, 0xA4, 0x6C, 0xAC, 0xAD, 0x6D, 0xAF, 0x6F,
    0x6E, 0xAE, 0xAA, 0x6A, 0x6B, 0xAB, 0x69, 0xA9, 0xA8, 0x68, 0x78, 0xB8, 0xB9, 0x79, 0xBB,
    0x7B, 0x7A, 0xBA, 0xBE, 0x7E, 0x7F, 0xBF, 0x7D, 0xBD, 0xBC, 0x7C, 0xB4, 0x74, 0x75, 0xB5,
    0x77, 0xB7, 0xB6, 0x76, 0x72, 0xB2, 0xB3, 0x73, 0xB1, 0x71, 0x70, 0xB0, 0x50, 0x90, 0x91,
    0x51, 0x93, 0x53, 0x52, 0x92, 0x96, 0x56, 0x57, 0x97, 0x55, 0x95, 0x94, 0x54, 0x9C, 0x5C,
    0x5D, 0x9D, 0x5F, 0x9F, 0x9E, 0x5E, 0x5A, 0x9A, 0x9B, 0x5B, 0x99, 0x59, 0x58, 0x98, 0x88,
    0x48, 0x49, 0x89, 0x4B, 0x8B, 0x8A, 0x4A, 0x4E, 0x8E, 0x8F, 0x4F, 0x8D, 0x4D, 0x4C, 0x8C,
    0x44, 0x84, 0x85, 0x45, 0x87, 0x47, 0x46, 0x86, 0x82, 0x42, 0x43, 0x83, 0x41, 0x81, 0x80,
    0x40
};
```

6.3 Appendix E - References

ANSI/ TIA/ EIA-232-F-1997	**Interface Between Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange.**
ANSI/ TIA/ EIA-485-A-1998	**Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems.**
AWG	**"American Wire Gauge" is a standard method denoting wire diameter, it is used in the USA and in other countries; increasing gauge numbers give decreasing wire parameters. See for example D.G. Fink and H.W. Beaty, Standard Handbook for Electrical Engineers, 13th Edition, McGraw-Hill, 1993.**
MODBUS.org	**MODBUS application protocol specification**

MODBUS APPLICATION PROTOCOL SPECIFICATION
V1.1b3

CONTENTS

1 Introduction

1.1 Scope of this document

MODBUS is an application layer messaging protocol, positioned at level 7 of the OSI model, which provides client/server communication between devices connected on different types of buses or networks.

The industry's serial de facto standard since 1979, MODBUS continues to enable millions of automation devices to communicate. Today, support for the simple and elegant structure of MODBUS continues to grow. The Internet community can access MODBUS at a reserved system port 502 on the TCP/IP stack.

MODBUS is a request/reply protocol and offers services specified by **function codes**. MODBUS function codes are elements of MODBUS request/reply PDUs. The objective of this document is to describe the function codes used within the framework of MODBUS transactions.

MODBUS is an application layer messaging protocol for client/server communication between devices connected on different types of buses or networks.

It is currently implemented using:

- TCP/IP over Ethernet. See MODBUS Messaging Implementation Guide V1.0a.
- Asynchronous serial transmission over a variety of media (wire : EIA/TIA-232-E, EIA-422, EIA/TIA-485-A; fiber, radio, etc.)
- MODBUS PLUS, a high speed token passing network.

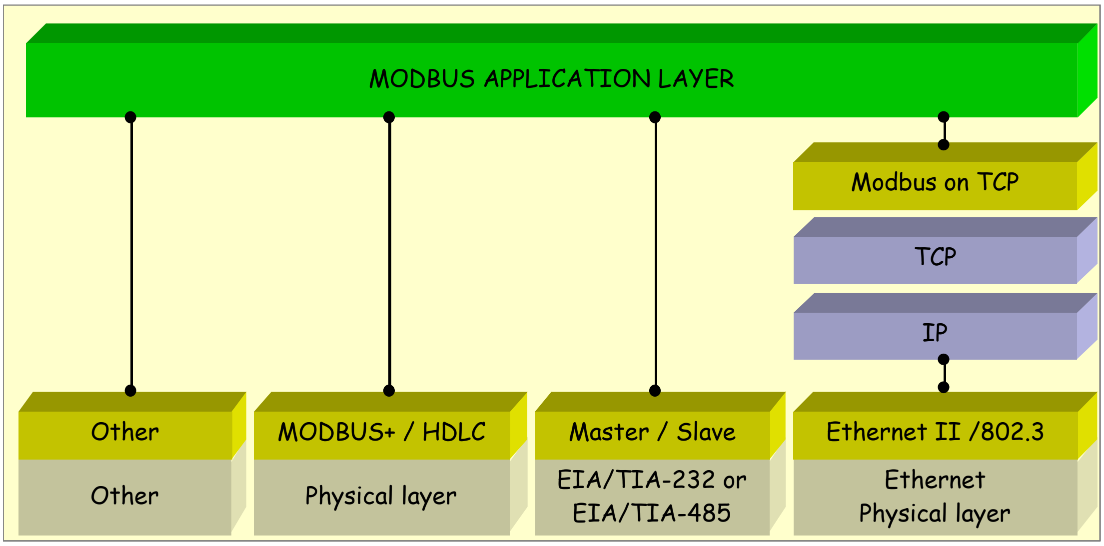


Figure 1: MODBUS communication stack

References

1. RFC 791, Internet Protocol, Sep81 DARPA

2 Abbreviations

ADU Application Data Unit
HDLC High level Data Link Control
HMI Human Machine Interface
IETF Internet Engineering Task Force
I/O Input/Output
IP Internet Protocol
MAC Media Access Control
MB MODBUS Protocol

MBAP	MODBUS Application Protocol
PDU	Protocol Data Unit
PLC	Programmable Logic Controller
TCP	Transmission Control Protocol

3 Context

The MODBUS protocol allows an easy communication within all types of network architectures.

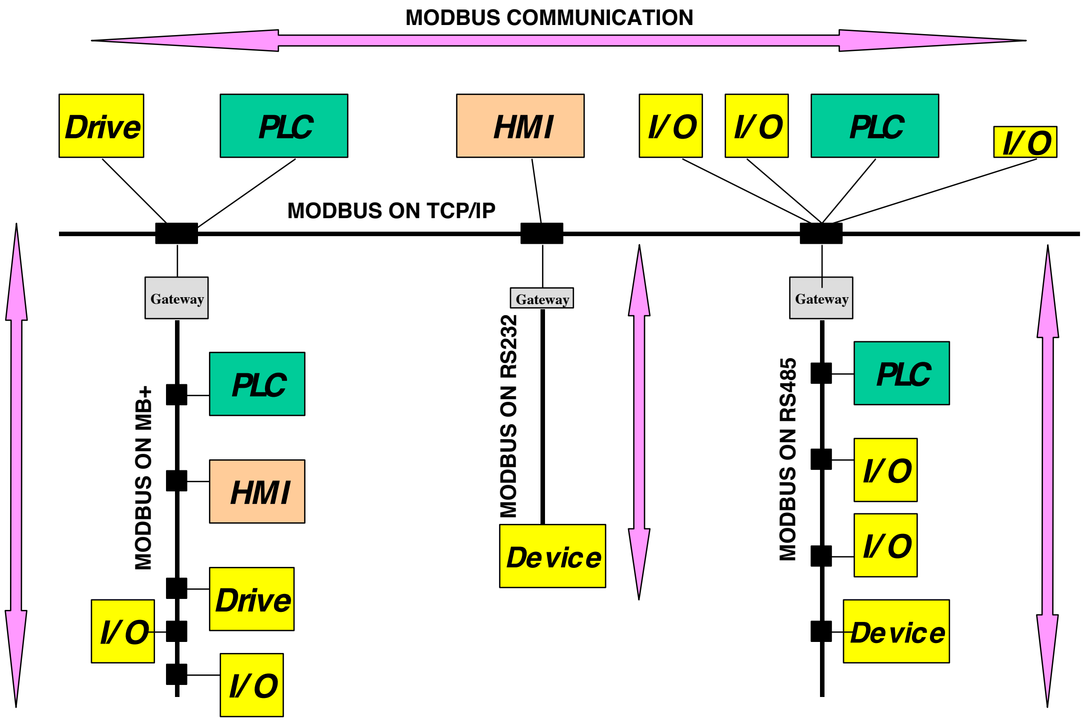


Figure 2: Example of MODBUS Network Architecture

Every type of devices (PLC, HMI, Control Panel, Driver, Motion control, I/O Device…) can use MODBUS protocol to initiate a remote operation.

The same communication can be done as well on serial line as on an Ethernet TCP/IP networks. Gateways allow a communication between several types of buses or network using the MODBUS protocol.

4 General description

4.1 Protocol description

The MODBUS protocol defines a simple protocol data unit **(PDU)** independent of the underlying communication layers. The mapping of MODBUS protocol on specific buses or network can introduce some additional fields on the application data unit **(ADU)**.

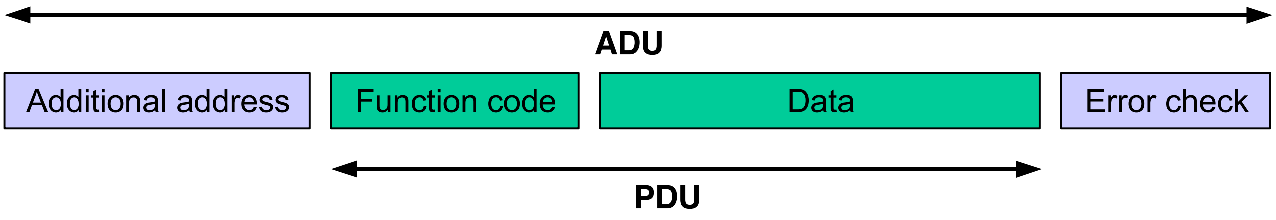


Figure 3: General MODBUS frame

The MODBUS application data unit is built by the client that initiates a MODBUS transaction. The function indicates to the server what kind of action to perform. The MODBUS application protocol establishes the format of a request initiated by a client.

The function code field of a MODBUS data unit is coded in one byte. Valid codes are in the range of 1 ... 255 decimal (the range 128 – 255 is reserved and used for exception responses). When a message is sent from a Client to a Server device the function code field tells the server what kind of action to perform. Function code "0" is not valid.

Sub-function codes are added to some function codes to define multiple actions.

The data field of messages sent from a client to server devices contains additional information that the server uses to take the action defined by the function code. This can include items like discrete and register addresses, the quantity of items to be handled, and the count of actual data bytes in the field.

The data field may be nonexistent (of zero length) in certain kinds of requests, in this case the server does not require any additional information. The function code alone specifies the action.

If no error occurs related to the MODBUS function requested in a properly received MODBUS ADU the data field of a response from a server to a client contains the data requested. If an error related to the MODBUS function requested occurs, the field contains an exception code that the server application can use to determine the next action to be taken.

For example a client can read the ON / OFF states of a group of discrete outputs or inputs or it can read/write the data contents of a group of registers.

When the server responds to the client, it uses the function code field to indicate either a normal (error-free) response or that some kind of error occurred (called an exception response). For a normal response, the server simply echoes to the request the original function code.

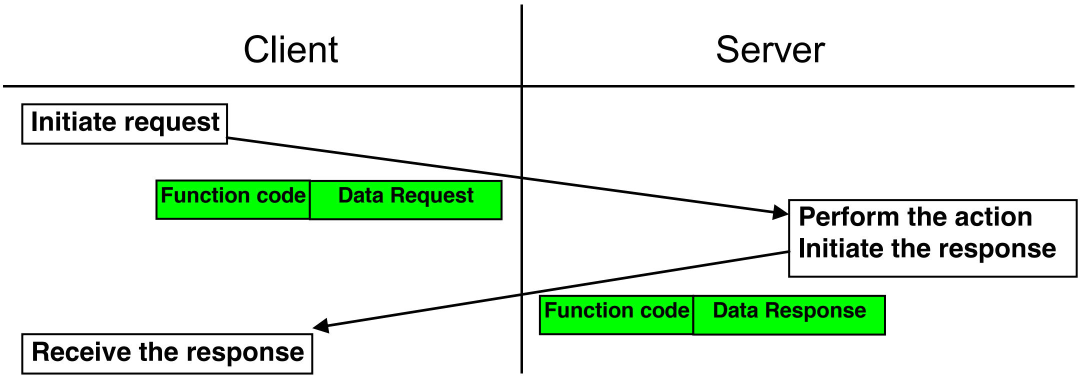


Figure 4: MODBUS transaction (error free)

For an exception response, the server returns a code that is equivalent to the original function code from the request PDU with its most significant bit set to logic 1.

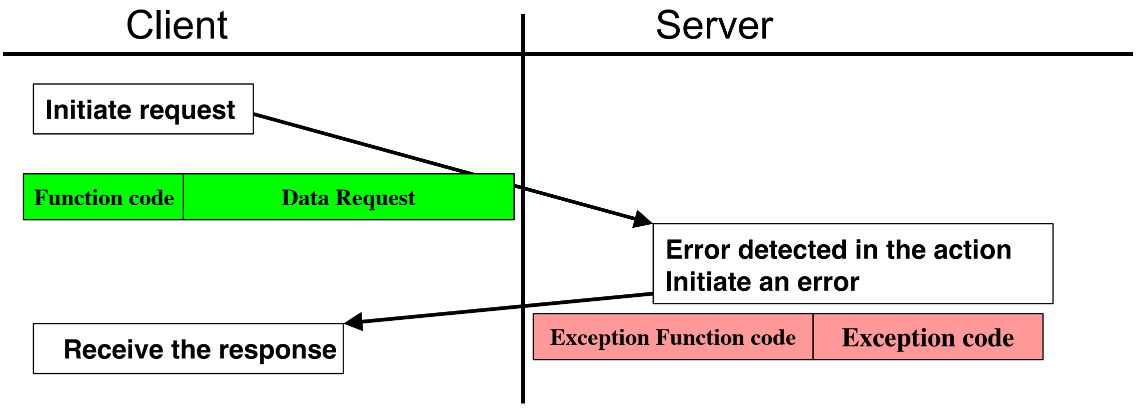


Figure 5: MODBUS transaction (exception response)

☞ **Note**: It is desirable to manage a time out in order not to indefinitely wait for an answer which will perhaps never arrive.

The size of the MODBUS PDU is limited by the size constraint inherited from the first MODBUS implementation on Serial Line network (max. RS485 ADU = 256 bytes).
Therefore:
MODBUS **PDU for serial line communication =** 256 - Server address (1 byte) - CRC (2 bytes) = **253 bytes**.

Consequently:
RS232 / RS485 **ADU** = 253 bytes + Server address (1 byte) + CRC (2 bytes) = **256 bytes**.
TCP MODBUS **ADU** = 253 bytes + MBAP (7 bytes) = **260 bytes**.

The MODBUS protocol defines three PDUs. They are :

- MODBUS Request PDU, mb_req_pdu
- MODBUS Response PDU, mb_rsp_pdu
- MODBUS Exception Response PDU, mb_excep_rsp_pdu

The mb_req_pdu is defined as:

mb_req_pdu = {function_code, request_data}, where
function_code = [1 byte] MODBUS function code,
request_data = [n bytes] This field is function code dependent and usually contains information such as variable references,
variable counts, data offsets, sub-function codes etc.

The mb_rsp_pdu is defined as:
mb_rsp_pdu = {function_code, response_data}, where
function_code = [1 byte] MODBUS function code
response_data = [n bytes] This field is function code dependent and usually contains information such as variable references,
variable counts, data offsets, sub-function codes, etc.

The mb_excep_rsp_pdu is defined as:
mb_excep_rsp_pdu = {exception-function_code, request_data}, where
exception-function_code = [1 byte] MODBUS function code + 0x80
exception_code = [1 byte] MODBUS Exception Code Defined in table
"MODBUS Exception Codes" (see section 7).

4.2 Data Encoding

- MODBUS uses a 'big-Endian' representation for addresses and data items. This means that when a numerical quantity larger than a single byte is transmitted, the most significant byte is sent first. So for example

Register size	value			
16 - bits	0x1234	the first byte sent is	0x12	then 0x34

☞ **Note**: For more details, see [1] .

4.3 MODBUS Data model

MODBUS bases its data model on a series of tables that have distinguishing characteristics. The four primary tables are:

Primary tables	Object type	Type of	Comments
Discretes Input	Single bit	Read-Only	This type of data can be provided by an I/O system.
Coils	Single bit	Read-Write	This type of data can be alterable by an application program.
Input Registers	16-bit word	Read-Only	This type of data can be provided by an I/O system
Holding Registers	16-bit word	Read-Write	This type of data can be alterable by an application program.

The distinctions between inputs and outputs, and between bit-addressable and word-addressable data items, do not imply any application behavior. It is perfectly acceptable, and very common, to regard all four tables as overlaying one another, if this is the most natural interpretation on the target machine in question.

For each of the primary tables, the protocol allows individual selection of 65536 data items, and the operations of read or write of those items are designed to span multiple consecutive data items up to a data size limit which is dependent on the transaction function code.

It's obvious that all the data handled via MODBUS (bits, registers) must be located in device application memory. But physical address in memory should not be confused with data reference. The only requirement is to link data reference with physical address.

MODBUS logical reference numbers, which are used in MODBUS functions, are unsigned integer indices starting at zero.

- **Implementation examples of MODBUS model**

The examples below show two ways of organizing the data in device. There are different organizations possible, but not all are described in this document. Each device can have its own organization of the data according to its application

Example 1 : Device having 4 separate blocks

The example below shows data organization in a device having digital and analog, inputs and outputs. Each block is separate because data from different blocks have no correlation. Each block is thus accessible with different MODBUS functions.

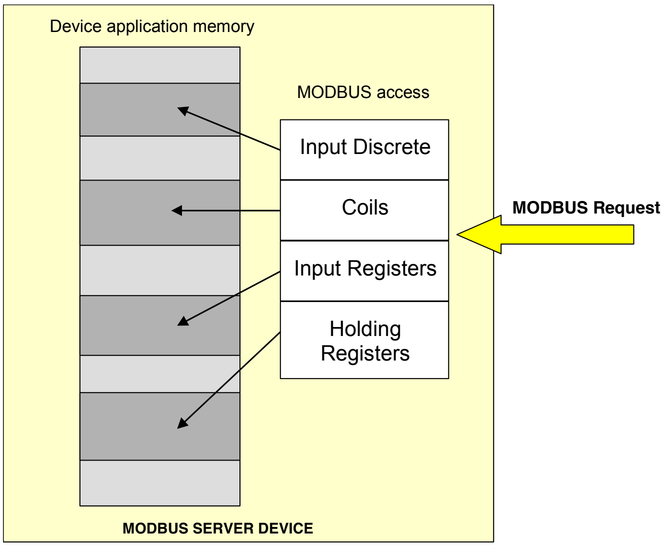


Figure 6 MODBUS Data Model with separate block

Example 2: Device having only 1 block

In this example, the device has only 1 data block. The same data can be reached via several MODBUS functions, either via a 16 bit access or via an access bit.

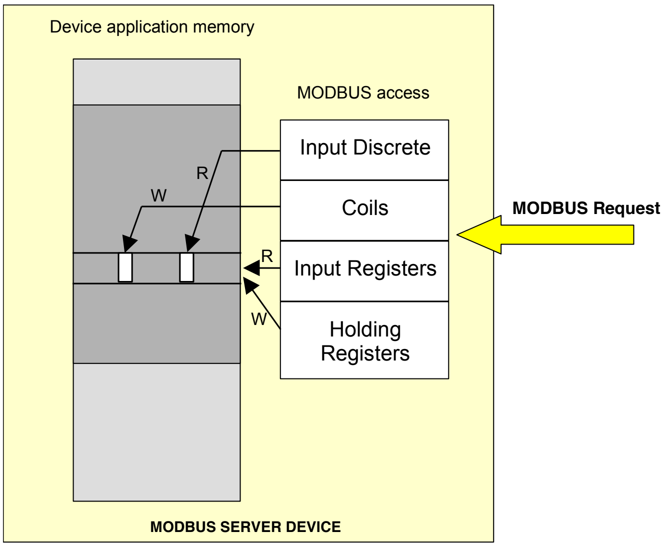


Figure 7 MODBUS Data Model with only 1 block

4.4 MODBUS Addressing model

The MODBUS application protocol defines precisely PDU addressing rules.

In a MODBUS PDU each data is addressed from 0 to 65535.

It also defines clearly a MODBUS data model composed of 4 blocks that comprises several elements numbered from 1 to n.

In the MODBUS data Model each element within a data block is numbered from 1 to n.

Afterwards the MODBUS data model has to be bound to the device application (IEC-61131 object, or other application model).

The pre-mapping between the MODBUS data model and the device application is totally vendor device specific.

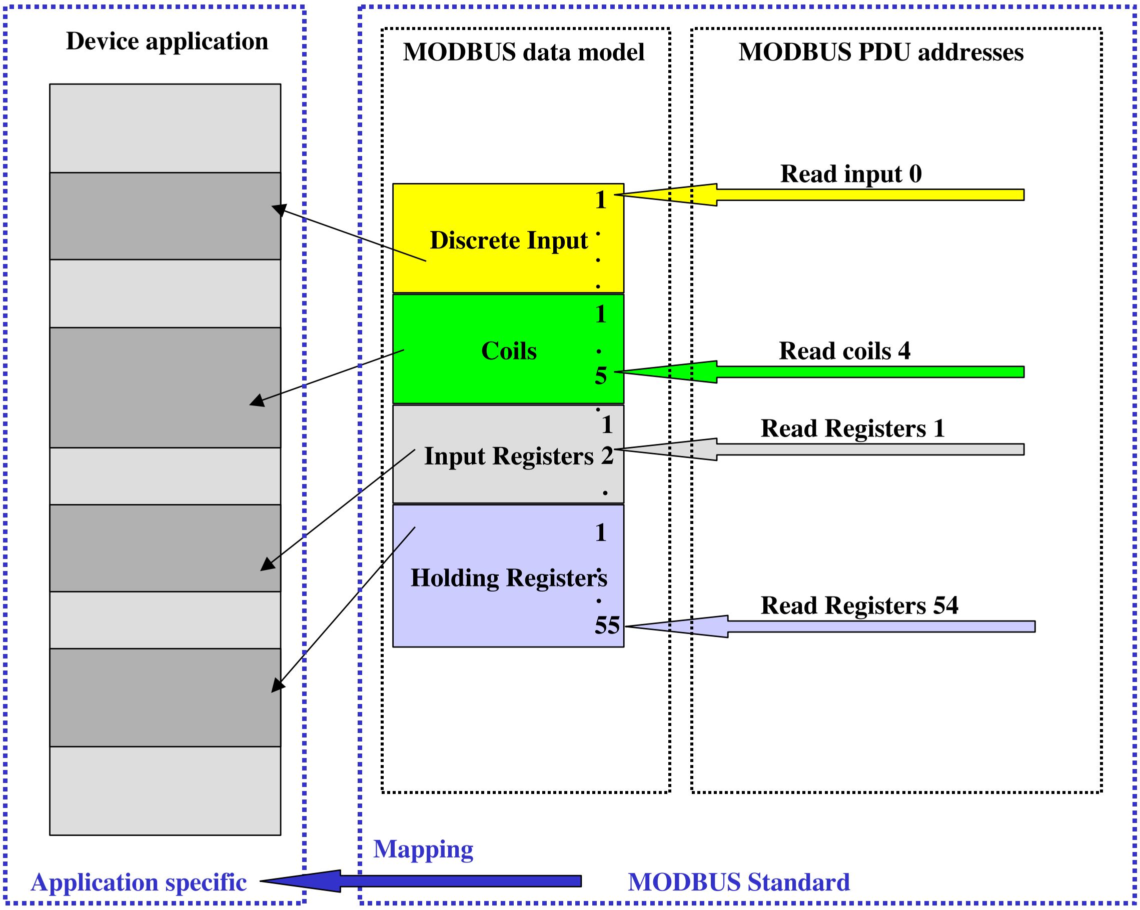


Figure 8 MODBUS Addressing model

The previous figure shows that a MODBUS data numbered X is addressed in the MODBUS PDU X-1.

4.5 Define MODBUS Transaction

The following state diagram describes the generic processing of a MODBUS transaction in server side.

V

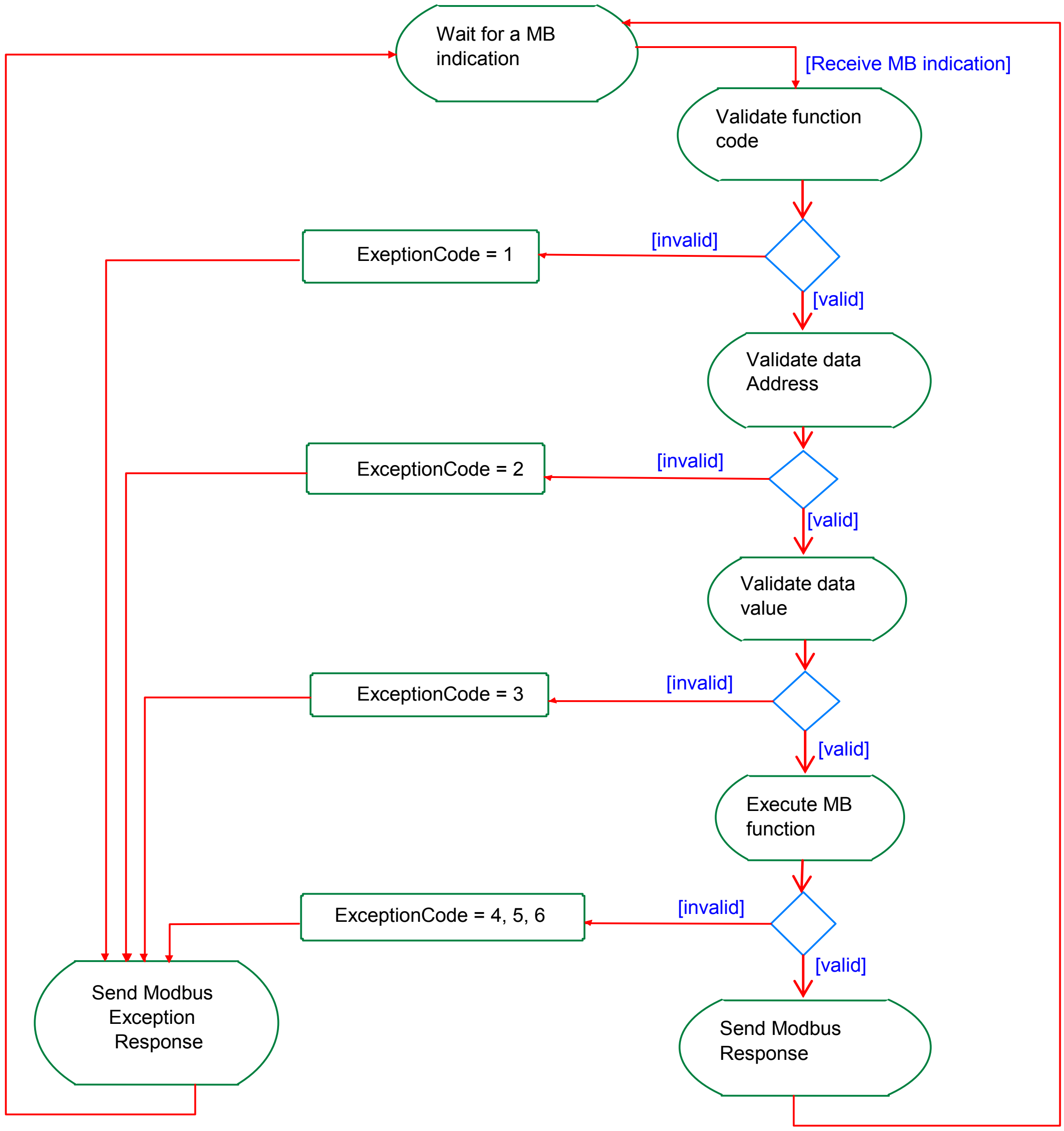


Figure 9 MODBUS Transaction state diagram

Once the request has been processed by a server, a MODBUS response using the adequate MODBUS server transaction is built.

Depending on the result of the processing two types of response are built :

- A positive MODBUS response :
  - the response function code = the request function code

- A MODBUS Exception response (see section 7):
  - the objective is to provide to the client relevant information concerning the error detected during the processing ;
  - the exception function code = the request function code + 0x80 ;
  - an exception code is provided to indicate the reason of the error.

5 Function Code Categories

There are three categories of MODBUS Functions codes. They are :

Public Function Codes

- Are well defined function codes ,
- guaranteed to be unique,
- validated by the MODBUS.org community,
- publicly documented
- have available conformance test,
- includes both defined public assigned function codes as well as unassigned function codes reserved for future use.

User-Defined Function Codes

- there are two ranges of user-defined function codes, i.e. 65 to 72 and from 100 to 110 decimal.
- user can select and implement a function code that is not supported by the specification.
- there is no guarantee that the use of the selected function code will be unique
- if the user wants to re-position the functionality as a public function code, he must initiate an RFC to introduce the change into the public category and to have a new public function code assigned.
- MODBUS Organization, Inc expressly reserves the right to develop the proposed RFC.

Reserved Function Codes

- Function Codes currently used by some companies for legacy products and that are not available for public use.
- Informative Note: The reader is asked refer to Annex A (Informative) MODBUS RESERVED FUNCTION CODES, SUBCODES AND MEI TYPES.

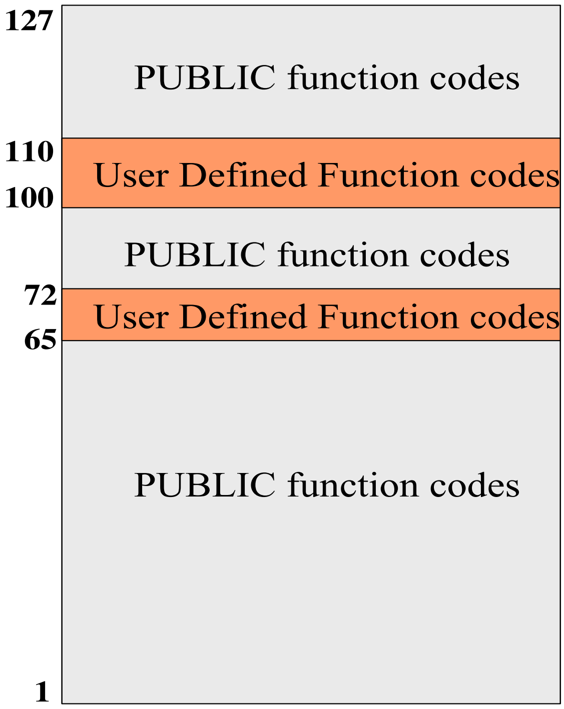


Figure 10 MODBUS Function Code Categories

5.1 Public Function Code Definition

				Function Codes			
				code	*Sub code*	*(hex)*	*Section*
Data Access	**Bit access**	Physical Discrete Inputs	Read Discrete Inputs	**02**		**02**	6.2
		Internal Bits Or Physical coils	Read Coils	**01**		**01**	6.1
			Write Single Coil	**05**		**05**	6.5
			Write Multiple Coils	**15**		**0F**	6.11
	16 bits access	Physical Input Registers	Read Input Register	**04**		**04**	6.4
		Internal Registers Or Physical Output Registers	Read Holding Registers	**03**		**03**	6.3
			Write Single Register	**06**		**06**	6.6
			Write Multiple Registers	**16**		**10**	6.12
			Read/Write Multiple Registers	**23**		**17**	6.17
			Mask Write Register	**22**		**16**	6.16
			Read FIFO queue	**24**		**18**	6.18
	File record access		Read File record	**20**		**14**	6.14
			Write File record	**21**		**15**	6.15
Diagnostics			Read Exception status	**07**		**07**	6.7
			Diagnostic	**08**	**00-18,20**	**08**	6.8
			Get Com event counter	**11**		**OB**	6.9
			Get Com Event Log	**12**		**0C**	6.10
			Report Server ID	**17**		**11**	6.13
			Read device Identification	**43**	**14**	**2B**	6.21
Other			Encapsulated Interface Transport	**43**	**13,14**	**2B**	6.19
			CANopen General Reference	**43**	**13**	**2B**	6.20

6 Function codes descriptions

6.1 01 (0x01) Read Coils

This function code is used to read from 1 to 2000 contiguous status of coils in a remote device. The Request PDU specifies the starting address, i.e. the address of the first coil specified, and the number of coils. In the PDU Coils are addressed starting at zero. Therefore coils numbered 1-16 are addressed as 0-15.

The coils in the response message are packed as one coil per bit of the data field. Status is indicated as 1= ON and 0= OFF. The LSB of the first data byte contains the output addressed in the query. The other coils follow toward the high order end of this byte, and from low order to high order in subsequent bytes.

If the returned output quantity is not a multiple of eight, the remaining bits in the final data byte will be padded with zeros (toward the high order end of the byte). The Byte Count field specifies the quantity of complete bytes of data.

Request

Function code	1 Byte	**0x01**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of coils	2 Bytes	1 to 2000 (0x7D0)

Response

Function code	1 Byte	**0x01**
Byte count	1 Byte	**N***
Coil Status	**n** Byte	n = N or N+1

***N** = Quantity of Outputs / 8, if the remainder is different of 0 ⇒ N = N+1

Error

Function code	1 Byte	**Function code + 0x80**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to read discrete outputs 20–38:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**01**	Function	**01**
Starting Address Hi	**00**	Byte Count	**03**
Starting Address Lo	**13**	Outputs status 27-20	**CD**
Quantity of Outputs Hi	**00**	Outputs status 35-28	**6B**
Quantity of Outputs Lo	**13**	Outputs status 38-36	**05**

The status of outputs 27–20 is shown as the byte value CD hex, or binary 1100 1101. Output 27 is the MSB of this byte, and output 20 is the LSB.

By convention, bits within a byte are shown with the MSB to the left, and the LSB to the right. Thus the outputs in the first byte are '27 through 20', from left to right. The next byte has outputs '35 through 28', left to right. As the bits are transmitted serially, they flow from LSB to MSB: 20 . . . 27, 28 . . . 35, and so on.

In the last data byte, the status of outputs 38-36 is shown as the byte value 05 hex, or binary 0000 0101. Output 38 is in the sixth bit position from the left, and output 36 is the LSB of this byte. The five remaining high order bits are zero filled.

☞ **Note**: The five remaining bits (toward the high order end) are zero filled.

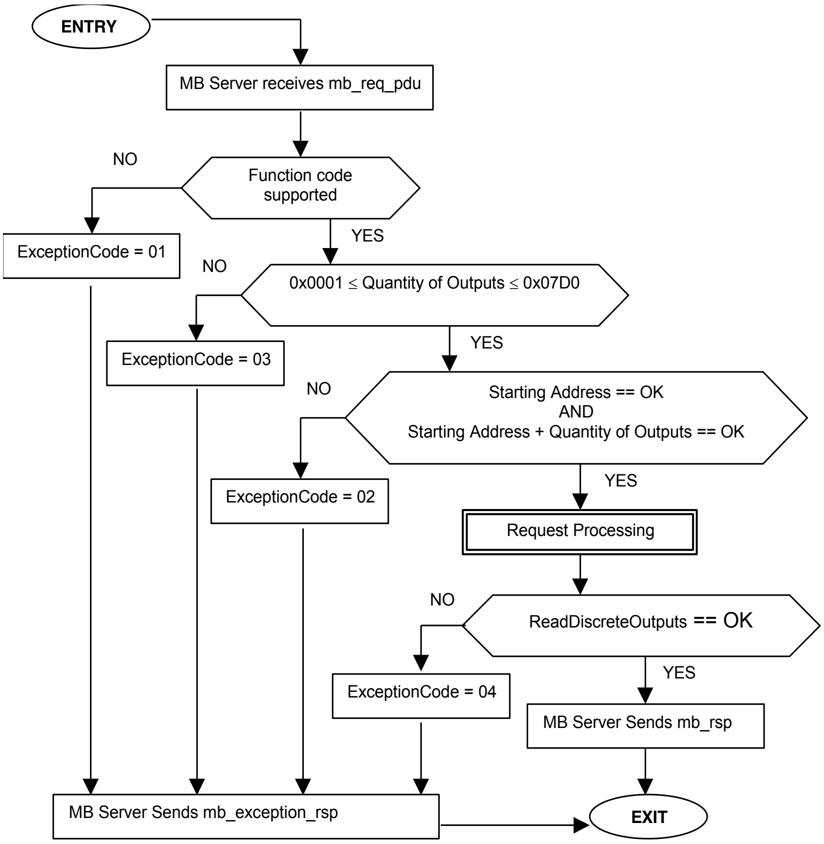


Figure 11: Read Coils state diagram

6.2 02 (0x02) Read Discrete Inputs

This function code is used to read from 1 to 2000 contiguous status of discrete inputs in a remote device. The Request PDU specifies the starting address, i.e. the address of the first input specified, and the number of inputs. In the PDU Discrete Inputs are addressed starting at zero. Therefore Discrete inputs numbered 1-16 are addressed as 0-15.

The discrete inputs in the response message are packed as one input per bit of the data field. Status is indicated as 1= ON; 0= OFF. The LSB of the first data byte contains the input addressed in the query. The other inputs follow toward the high order end of this byte, and from low order to high order in subsequent bytes.

If the returned input quantity is not a multiple of eight, the remaining bits in the final data byte will be padded with zeros (toward the high order end of the byte). The Byte Count field specifies the quantity of complete bytes of data.

Request

Function code	1 Byte	**0x02**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Inputs	2 Bytes	1 to 2000 (0x7D0)

Response

Function code	1 Byte	**0x02**
Byte count	1 Byte	**N***
Input Status	**N*** x 1 Byte	

*__N__ = Quantity of Inputs / 8 if the remainder is different of 0 ⇒ N = N+1

Error

Error code	1 Byte	**0x82**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to read discrete inputs 197 – 218:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**02**	Function	**02**
Starting Address Hi	**00**	Byte Count	**03**
Starting Address Lo	**C4**	Inputs Status 204-197	**AC**
Quantity of Inputs Hi	**00**	Inputs Status 212-205	**DB**
Quantity of Inputs Lo	**16**	Inputs Status 218-213	**35**

The status of discrete inputs 204–197 is shown as the byte value AC hex, or binary 1010 1100. Input 204 is the MSB of this byte, and input 197 is the LSB.

The status of discrete inputs 218–213 is shown as the byte value 35 hex, or binary 0011 0101. Input 218 is in the third bit position from the left, and input 213 is the LSB.

Note: The two remaining bits (toward the high order end) are zero filled.

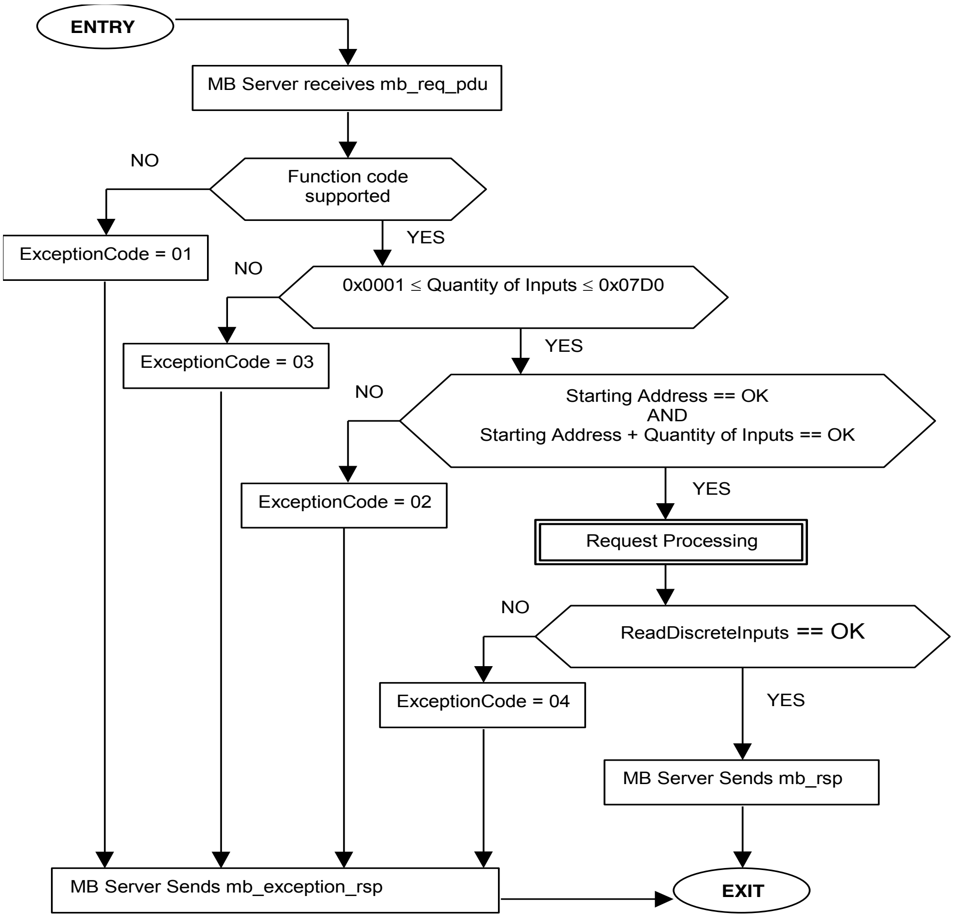


Figure 12: Read Discrete Inputs state diagram

6.3 03 (0x03) Read Holding Registers

This function code is used to read the contents of a contiguous block of holding registers in a remote device. The Request PDU specifies the starting register address and the number of registers. In the PDU Registers are addressed starting at zero. Therefore registers numbered 1-16 are addressed as 0-15.

The register data in the response message are packed as two bytes per register, with the binary contents right justified within each byte. For each register, the first byte contains the high order bits and the second contains the low order bits.

Request

Function code	1 Byte	**0x03**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Registers	2 Bytes	1 to 125 (0x7D)

Response

Function code	1 Byte	**0x03**
Byte count	1 Byte	2 x **N***
Register value	**N*** x 2 Bytes	

***N** = Quantity of Registers

Error

Error code	1 Byte	**0x83**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to read registers 108 – 110:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**03**	Function	**03**
Starting Address Hi	**00**	Byte Count	**06**
Starting Address Lo	**6B**	Register value Hi (108)	**02**
No. of Registers Hi	**00**	Register value Lo (108)	**2B**
No. of Registers Lo	**03**	Register value Hi (109)	**00**
		Register value Lo (109)	**00**
		Register value Hi (110)	**00**
		Register value Lo (110)	**64**

The contents of register 108 are shown as the two byte values of 02 2B hex, or 555 decimal. The contents of registers 109–110 are 00 00 and 00 64 hex, or 0 and 100 decimal, respectively.

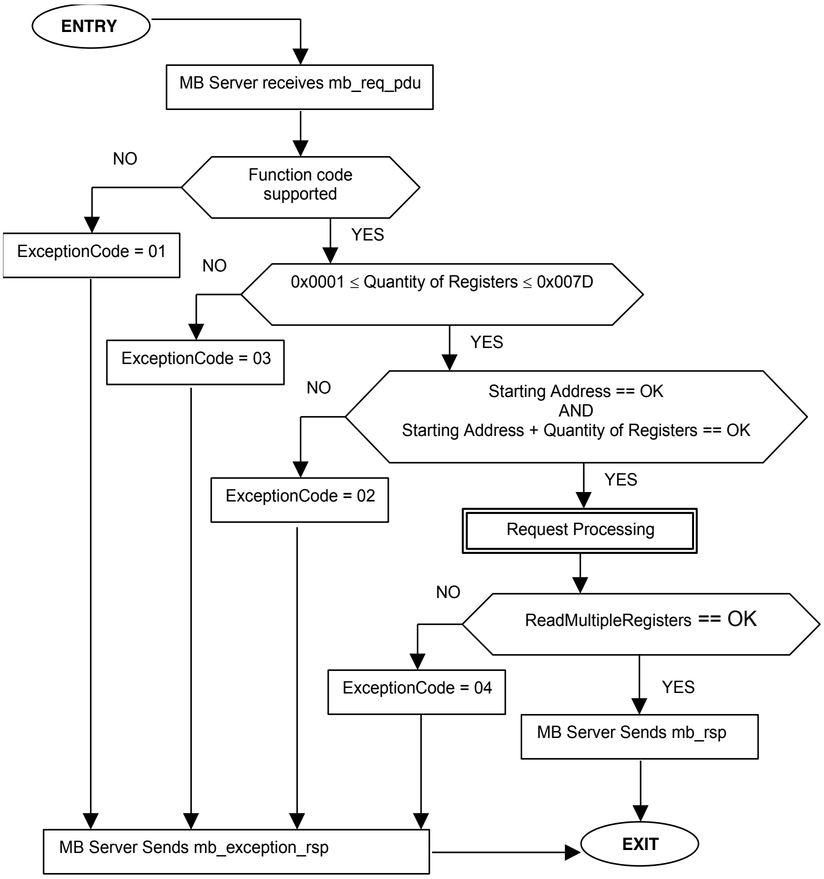


Figure 13: Read Holding Registers state diagram

6.4 04 (0x04) Read Input Registers

This function code is used to read from 1 to 125 contiguous input registers in a remote device. The Request PDU specifies the starting register address and the number of registers. In the PDU Registers are addressed starting at zero. Therefore input registers numbered 1-16 are addressed as 0-15.

The register data in the response message are packed as two bytes per register, with the binary contents right justified within each byte. For each register, the first byte contains the high order bits and the second contains the low order bits.

Request

Function code	1 Byte	**0x04**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Input Registers	2 Bytes	0x0001 to 0x007D

Response

Function code	1 Byte	**0x04**
Byte count	1 Byte	2 x **N***
Input Registers	**N*** x 2 Bytes	

***N** = Quantity of Input Registers

Error

Error code	1 Byte	**0x84**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to read input register 9:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**04**	Function	**04**
Starting Address Hi	**00**	Byte Count	**02**
Starting Address Lo	**08**	Input Reg. 9 Hi	**00**
Quantity of Input Reg. Hi	**00**	Input Reg. 9 Lo	**0A**

Quantity of Input Reg. Lo	**01**	

The contents of input register 9 are shown as the two byte values of 00 0A hex, or 10 decimal.

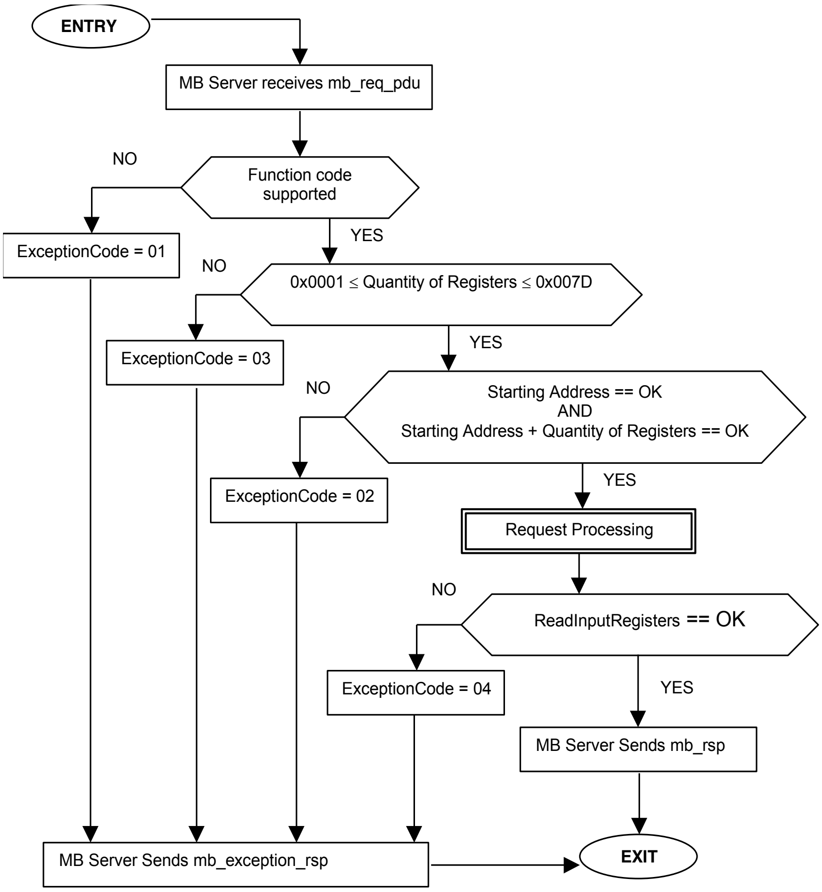


Figure 14: Read Input Registers state diagram

6.5 05 (0x05) Write Single Coil

This function code is used to write a single output to either ON or OFF in a remote device.

The requested ON/OFF state is specified by a constant in the request data field. A value of FF 00 hex requests the output to be ON. A value of 00 00 requests it to be OFF. All other values are illegal and will not affect the output.

The Request PDU specifies the address of the coil to be forced. Coils are addressed starting at zero. Therefore coil numbered 1 is addressed as 0. The requested ON/OFF state is specified by a constant in the Coil Value field. A value of 0XFF00 requests the coil to be ON. A value of 0X0000 requests the coil to be off. All other values are illegal and will not affect the coil.

The normal response is an echo of the request, returned after the coil state has been written.

Request

Function code	1 Byte	**0x05**
Output Address	2 Bytes	0x0000 to 0xFFFF
Output Value	2 Bytes	0x0000 or 0xFF00

Response

Function code	1 Byte	**0x05**
Output Address	2 Bytes	0x0000 to 0xFFFF

Output Value	2 Bytes	0x0000 or 0xFF00

Error

Error code	1 Byte	**0x85**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to write Coil 173 ON:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**05**	Function	**05**
Output Address Hi	**00**	Output Address Hi	**00**
Output Address Lo	**AC**	Output Address Lo	**AC**
Output Value Hi	**FF**	Output Value Hi	**FF**
Output Value Lo	**00**	Output Value Lo	**00**

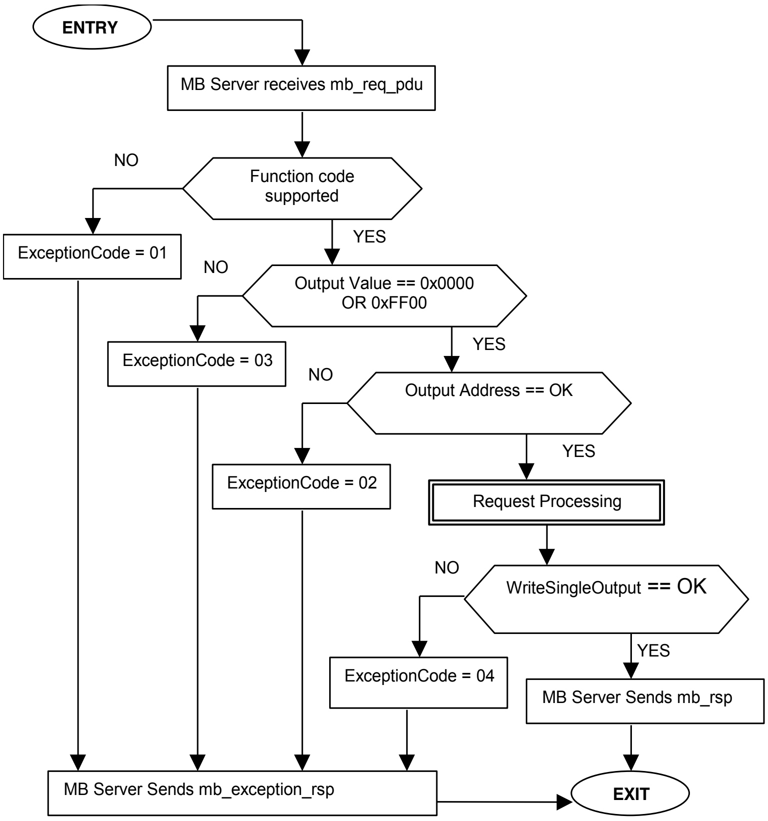


Figure 15: Write Single Output state diagram

6.6 06 (0x06) Write Single Register

This function code is used to write a single holding register in a remote device.

The Request PDU specifies the address of the register to be written. Registers are addressed starting at zero. Therefore register numbered 1 is addressed as 0.

The normal response is an echo of the request, returned after the register contents have been written.

Request

Function code	1 Byte	**0x06**
Register Address	2 Bytes	0x0000 to 0xFFFF
Register Value	2 Bytes	0x0000 to 0xFFFF

Response

Function code	1 Byte	**0x06**
Register Address	2 Bytes	0x0000 to 0xFFFF
Register Value	2 Bytes	0x0000 to 0xFFFF

Error

Error code	1 Byte	**0x86**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to write register 2 to 00 03 hex:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**06**	Function	**06**
Register Address Hi	**00**	Register Address Hi	**00**
Register Address Lo	**01**	Register Address Lo	**01**
Register Value Hi	**00**	Register Value Hi	**00**
Register Value Lo	**03**	Register Value Lo	**03**

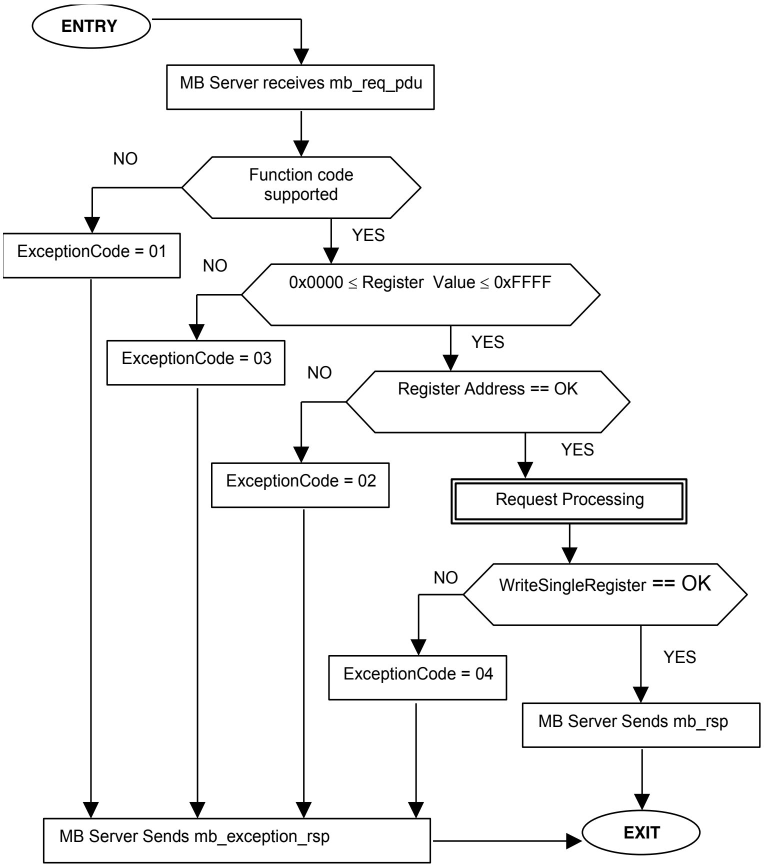


Figure 16: Write Single Register state diagram

6.7 07 (0x07) Read Exception Status (Serial Line only)

This function code is used to read the contents of eight Exception Status outputs in a remote device.

The function provides a simple method for accessing this information, because the Exception Output references are known (no output reference is needed in the function).

The normal response contains the status of the eight Exception Status outputs. The outputs are packed into one data byte, with one bit per output. The status of the lowest output reference is contained in the least significant bit of the byte.

The contents of the eight Exception Status outputs are device specific.

Request

Function code	1 Byte	**0x07**

Response

Function code	1 Byte	**0x07**
Output Data	1 Byte	0x00 to 0xFF

Error

Error code	1 Byte	**0x87**
Exception code	1 Byte	01 or 04

Here is an example of a request to read the exception status:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**07**	Function	**07**
		Output Data	**6D**

In this example, the output data is 6D hex (0110 1101 binary). Left to right, the outputs are OFF–ON–ON–OFF–ON–ON–OFF–ON. The status is shown from the highest to the lowest addressed output.

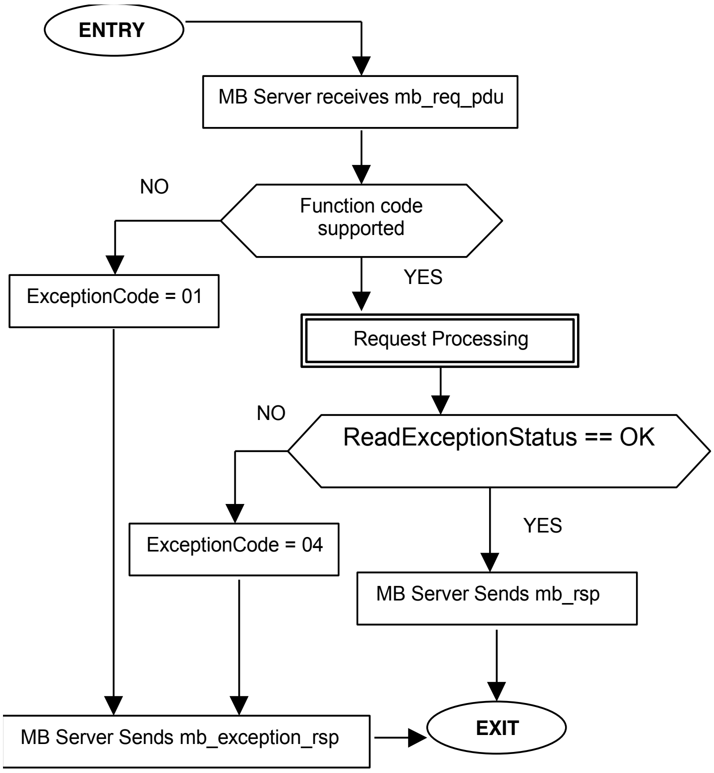


Figure 17: Read Exception Status state diagram

6.8 08 (0x08) Diagnostics (Serial Line only)

MODBUS function code 08 provides a series of tests for checking the communication system between a client device and a server, or for checking various internal error conditions within a server.

The function uses a two–byte sub-function code field in the query to define the type of test to be performed. The server echoes both the function code and sub-function code in a normal response. Some of the diagnostics cause data to be returned from the remote device in the data field of a normal response.

In general, issuing a diagnostic function to a remote device does not affect the running of the user program in the remote device. User logic, like discrete and registers, is not accessed by the diagnostics. Certain functions can optionally reset error counters in the remote device.

A server device can, however, be forced into 'Listen Only Mode' in which it will monitor the messages on the communications system but not respond to them. This can affect the outcome of your application program if it depends upon any further exchange of data with the remote device. Generally, the mode is forced to remove a malfunctioning remote device from the communications system.

The following diagnostic functions are dedicated to serial line devices.

The normal response to the Return Query Data request is to loopback the same data. The function code and sub-function codes are also echoed.

Request

Function code	1 Byte	**0x08**
Sub-function	2 Bytes	
Data	N x 2 Bytes	

Response

Function code	1 Byte	**0x08**
Sub-function	2 Bytes	
Data	N x 2 Bytes	

Error

Error code	1 Byte	**0x88**
Exception code	1 Byte	01 or 03 or 04

6.8.1 Sub-function codes supported by the serial line devices

Here the list of sub-function codes supported by the serial line devices. Each sub-function code is then listed with an example of the data field contents that would apply for that diagnostic.

Sub-function code		Name
Hex	Dec	
00	00	Return Query Data
01	01	Restart Communications Option
02	02	Return Diagnostic Register
03	03	Change ASCII Input Delimiter
04	04	Force Listen Only Mode
	05.. 09	RESERVED
0A	10	Clear Counters and Diagnostic Register
0B	11	Return Bus Message Count
0C	12	Return Bus Communication Error Count
0D	13	Return Bus Exception Error Count
0E	14	Return Server Message Count
0F	15	Return Server No Response Count
10	16	Return Server NAK Count
11	17	Return Server Busy Count
12	18	Return Bus Character Overrun Count
13	19	RESERVED
14	20	Clear Overrun Counter and Flag
N.A.	21 ... 65535	RESERVED

00 Return Query Data

The data passed in the request data field is to be returned (looped back) in the response. The entire response message should be identical to the request.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 00	Any	Echo Request Data

01 Restart Communications Option

The remote device serial line port must be initialized and restarted, and all of its communications event counters are cleared. If the port is currently in Listen Only Mode, no response is returned. This function is the only one that brings the port out of Listen Only Mode. If the port is not currently in Listen Only Mode, a normal response is returned. This occurs before the restart is executed.

When the remote device receives the request, it attempts a restart and executes its power–up confidence tests. Successful completion of the tests will bring the port online.

A request data field contents of FF 00 hex causes the port's Communications Event Log to be cleared also. Contents of 00 00 leave the log as it was prior to the restart.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 01	00 00	Echo Request Data
00 01	FF 00	Echo Request Data

02 Return Diagnostic Register

The contents of the remote device's 16–bit diagnostic register are returned in the response.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 02	00 00	Diagnostic Register Contents

03 Change ASCII Input Delimiter

The character 'CHAR' passed in the request data field becomes the end of message delimiter for future messages (replacing the default LF character). This function is useful in cases of a Line Feed is not required at the end of ASCII messages.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 03	CHAR 00	Echo Request Data

04 Force Listen Only Mode

Forces the addressed remote device to its Listen Only Mode for MODBUS communications. This isolates it from the other devices on the network, allowing them to continue communicating without interruption from the addressed remote device. No response is returned.

When the remote device enters its Listen Only Mode, all active communication controls are turned off. The Ready watchdog timer is allowed to expire, locking the controls off. While the device is in this mode, any MODBUS messages addressed to it or broadcast are monitored, but no actions will be taken and no responses will be sent.

The only function that will be processed after the mode is entered will be the Restart Communications Option function (function code 8, sub-function 1).

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 04	00 00	No Response Returned

10 (0A Hex) Clear Counters and Diagnostic Register

The goal is to clear all counters and the diagnostic register. Counters are also cleared upon power–up.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 0A	00 00	Echo Request Data

11 (0B Hex) Return Bus Message Count

The response data field returns the quantity of messages that the remote device has detected on the communications system since its last restart, clear counters operation, or power–up.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 0B	00 00	Total Message Count

12 (0C Hex) Return Bus Communication Error Count

The response data field returns the quantity of CRC errors encountered by the remote device since its last restart, clear counters operation, or power–up.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 0C	00 00	CRC Error Count

13 (0D Hex) Return Bus Exception Error Count

The response data field returns the quantity of MODBUS exception responses returned by the remote device since its last restart, clear counters operation, or power–up.

Exception responses are described and listed in section 7 .

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 0D	00 00	Exception Error Count

14 (0E Hex) Return Server Message Count

The response data field returns the quantity of messages addressed to the remote device, or broadcast, that the remote device has processed since its last restart, clear counters operation, or power–up.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 0E	00 00	Server Message Count

15 (0F Hex) Return Server No Response Count

The response data field returns the quantity of messages addressed to the remote device for which it has returned no response (neither a normal response nor an exception response), since its last restart, clear counters operation, or power–up.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 0F	00 00	Server No Response Count

16 (10 Hex) Return Server NAK Count

The response data field returns the quantity of messages addressed to the remote device for which it returned a Negative Acknowledge (NAK) exception response, since its last restart, clear counters operation, or power–up. Exception responses are described and listed in section 7 .

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 10	00 00	Server NAK Count

17 (11 Hex) Return Server Busy Count

The response data field returns the quantity of messages addressed to the remote device for which it returned a Server Device Busy exception response, since its last restart, clear counters operation, or power–up.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 11	00 00	Server Device Busy Count

18 (12 Hex) Return Bus Character Overrun Count

The response data field returns the quantity of messages addressed to the remote device that it could not handle due to a character overrun condition, since its last restart, clear counters operation, or power–up. A character overrun is caused by data characters arriving at the port faster than they can be stored, or by the loss of a character due to a hardware malfunction.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 12	00 00	Server Character Overrun Count

20 (14 Hex) Clear Overrun Counter and Flag

Clears the overrun error counter and reset the error flag.

Sub-function	**Data Field (Request)**	**Data Field (Response)**
00 14	00 00	Echo Request Data

6.8.2 Example and state diagram

Here is an example of a request to remote device to Return Query Data. This uses a sub-function code of zero (00 00 hex in the two–byte field). The data to be returned is sent in the two–byte data field (A5 37 hex).

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**08**	Function	**08**
Sub-function Hi	**00**	Sub-function Hi	**00**
Sub-function Lo	**00**	Sub-function Lo	**00**
Data Hi	**A5**	Data Hi	**A5**
Data Lo	**37**	Data Lo	**37**

The data fields in responses to other kinds of queries could contain error counts or other data requested by the sub-function code.

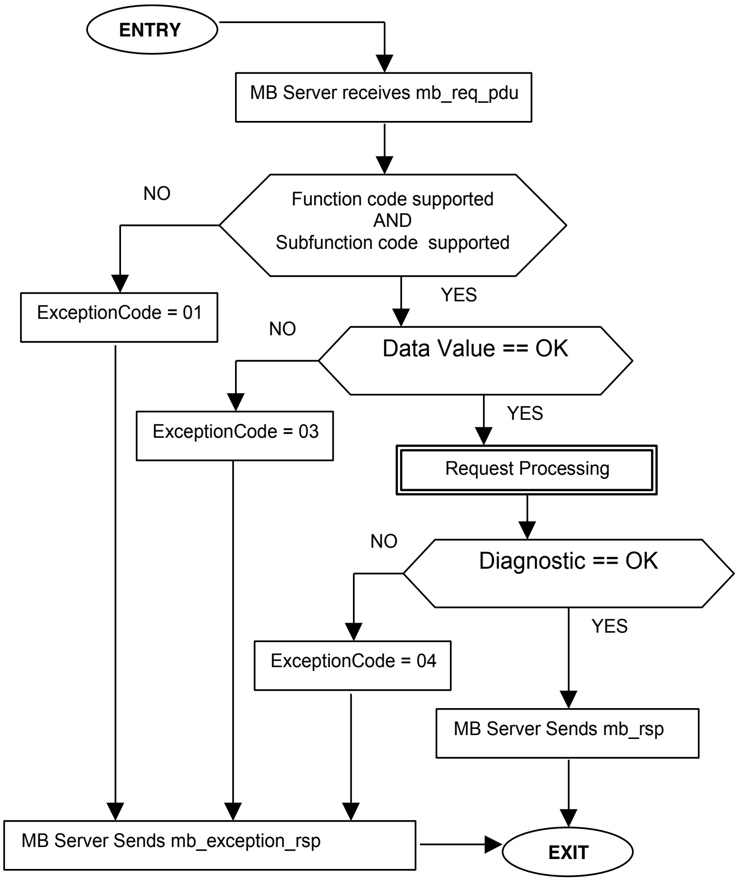


Figure 18: Diagnostic state diagram

6.9 11 (0x0B) Get Comm Event Counter (Serial Line only)

This function code is used to get a status word and an event count from the remote device's communication event counter.

By fetching the current count before and after a series of messages, a client can determine whether the messages were handled normally by the remote device.

The device's event counter is incremented once for each successful message completion. It is not incremented for exception responses, poll commands, or fetch event counter commands.

The event counter can be reset by means of the Diagnostics function (code 08), with a sub-function of Restart Communications Option (code 00 01) or Clear Counters and Diagnostic Register (code 00 0A).

The normal response contains a two–byte status word, and a two–byte event count. The status word will be all ones (FF FF hex) if a previously–issued program command is still being processed by the remote device (a busy condition exists). Otherwise, the status word will be all zeros.

Request

Function code	1 Byte	**0x0B**

Response

Function code	1 Byte	**0x0B**
Status	2 Bytes	0x0000 to 0xFFFF
Event Count	2 Bytes	0x0000 to 0xFFFF

Error

Error code	1 Byte	**0x8B**
Exception code	1 Byte	01 or 04

Here is an example of a request to get the communications event counter in remote device:

Request	Response

Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**0B**	Function	**0B**
		Status Hi	**FF**
		Status Lo	**FF**
		Event Count Hi	**01**
		Event Count Lo	**08**

In this example, the status word is FF FF hex, indicating that a program function is still in progress in the remote device. The event count shows that 264 (01 08 hex) events have been counted by the device.

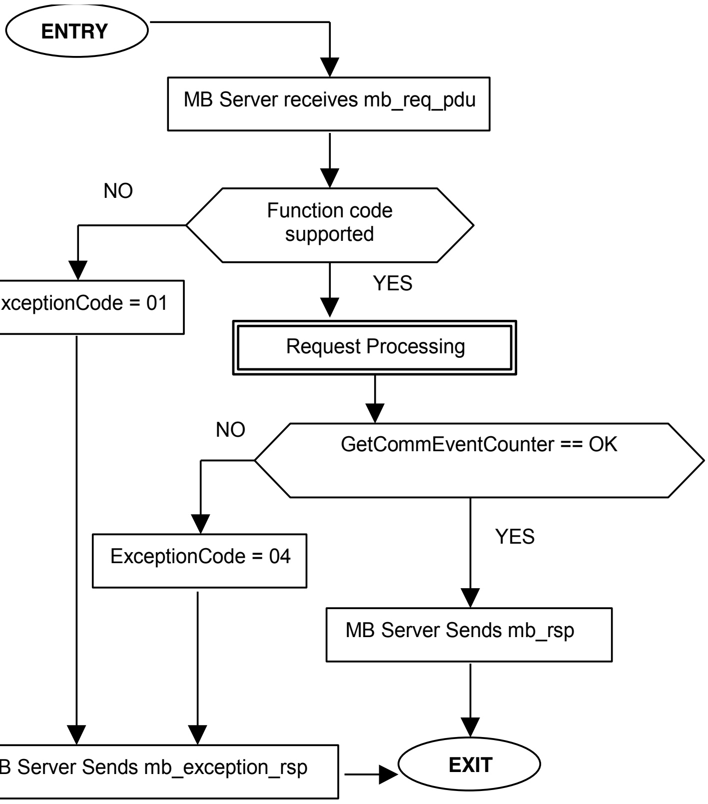


Figure 19: Get Comm Event Counter state diagram

6.10 12 (0x0C) Get Comm Event Log (Serial Line only)

This function code is used to get a status word, event count, message count, and a field of event bytes from the remote device.

The status word and event counts are identical to that returned by the Get Communications Event Counter function (11, 0B hex).

The message counter contains the quantity of messages processed by the remote device since its last restart, clear counters operation, or power–up. This count is identical to that returned by the Diagnostic function (code 08), sub-function Return Bus Message Count (code 11, 0B hex).

The event bytes field contains 0-64 bytes, with each byte corresponding to the status of one MODBUS send or receive operation for the remote device. The remote device enters the events into the field in chronological order. Byte 0 is the most recent event. Each new byte flushes the oldest byte from the field.

The normal response contains a two–byte status word field, a two–byte event count field, a two–byte message count field, and a field containing 0-64 bytes of events. A byte count field defines the total length of the data in these four fields.

Request

Function code	1 Byte	**0x0C**

Response

Function code	1 Byte	**0x0C**
Byte Count	1 Byte	**N***
Status	2 Bytes	0x0000 to 0xFFFF
Event Count	2 Bytes	0x0000 to 0xFFFF
Message Count	2 Bytes	0x0000 to 0xFFFF
Events	(**N**-6) x 1 Byte	

***N** = Quantity of Events + 3 x 2 Bytes, (Length of Status, Event Count and Message Count)

Error

Error code	1 Byte	**0x8C**
Exception code	1 Byte	01 or 04

Here is an example of a request to get the communications event log in remote device:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**0C**	Function	**0C**
		Byte Count	**08**
		Status Hi	**00**
		Status Lo	**00**
		Event Count Hi	**01**
		Event Count Lo	**08**
		Message Count Hi	**01**
		Message Count Lo	**21**
		Event 0	**20**
		Event 1	**00**

In this example, the status word is 00 00 hex, indicating that the remote device is not processing a program function. The event count shows that 264 (01 08 hex) events have been counted by the remote device. The message count shows that 289 (01 21 hex) messages have been processed.

The most recent communications event is shown in the Event 0 byte. Its content (20 hex) show that the remote device has most recently entered the Listen Only Mode.

The previous event is shown in the Event 1 byte. Its contents (00 hex) show that the remote device received a Communications Restart.

The layout of the response's event bytes is described below.

What the Event Bytes Contain

An event byte returned by the Get Communications Event Log function can be any one of four types. The type is defined by bit 7 (the high–order bit) in each byte. It may be further defined by bit 6. This is explained below.

- **Remote device MODBUS Receive Event**

  The remote device stores this type of event byte when a query message is received. It is stored before the remote device processes the message. This event is defined by bit 7 set to logic '1'. The other bits will be set to a logic '1' if the corresponding condition is TRUE. The bit layout is:

Bit	**Contents**
0	Not Used
1	Communication Error
2	Not Used
3	Not Used
4	Character Overrun

5	Currently in Listen Only Mode
6	Broadcast Received
7	1

- **Remote device MODBUS Send Event**

The remote device stores this type of event byte when it finishes processing a request message. It is stored if the remote device returned a normal or exception response, or no response. This event is defined by bit 7 set to a logic '0', with bit 6 set to a '1'. The other bits will be set to a logic '1' if the corresponding condition is TRUE. The bit layout is:

Bit	**Contents**
0	Read Exception Sent (Exception Codes 1-3)
1	Server Abort Exception Sent (Exception Code 4)
2	Server Busy Exception Sent (Exception Codes 5-6)
3	Server Program NAK Exception Sent (Exception Code 7)
4	Write Timeout Error Occurred
5	Currently in Listen Only Mode
6	1
7	0

- **Remote device Entered Listen Only Mode**

The remote device stores this type of event byte when it enters the Listen Only Mode. The event is defined by a content of 04 hex.

- **Remote device Initiated Communication Restart**

The remote device stores this type of event byte when its communications port is restarted. The remote device can be restarted by the Diagnostics function (code 08), with sub-function Restart Communications Option (code 00 01).

That function also places the remote device into a 'Continue on Error' or 'Stop on Error' mode. If the remote device is placed into 'Continue on Error' mode, the event byte is added to the existing event log. If the remote device is placed into 'Stop on Error' mode, the byte is added to the log and the rest of the log is cleared to zeros.

The event is defined by a content of zero.

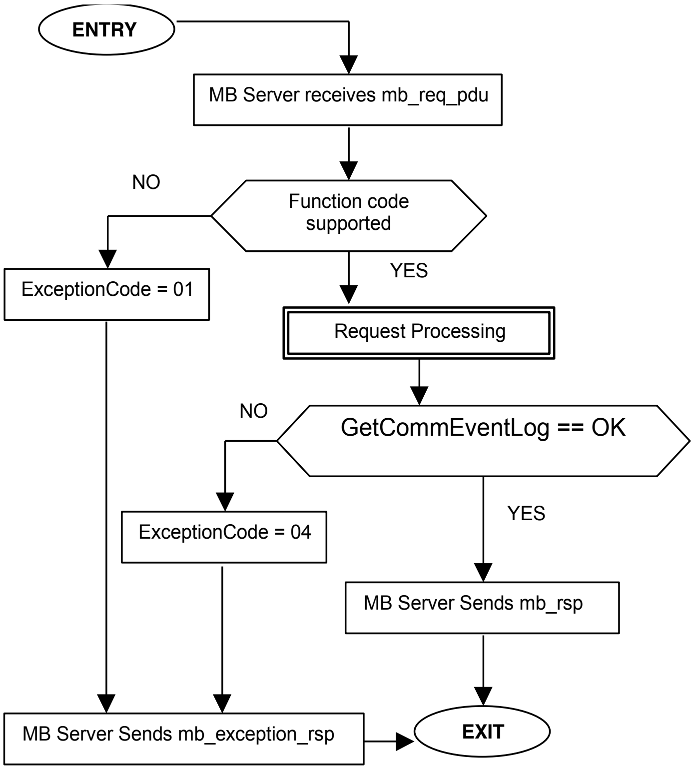


Figure 20: Get Comm Event Log state diagram

6.11 15 (0x0F) Write Multiple Coils

This function code is used to force each coil in a sequence of coils to either ON or OFF in a remote device. The Request PDU specifies the coil references to be forced. Coils are addressed starting at zero. Therefore coil numbered 1 is addressed as 0.

The requested ON/OFF states are specified by contents of the request data field. A logical '1' in a bit position of the field requests the corresponding output to be ON. A logical '0' requests it to be OFF.

The normal response returns the function code, starting address, and quantity of coils forced.

Request PDU

Function code	1 Byte	**0x0F**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Outputs	2 Bytes	0x0001 to 0x07B0
Byte Count	1 Byte	**N***
Outputs Value	**N*** x 1 Byte	

*__N__ = Quantity of Outputs / 8, if the remainder is different of 0 ⇒ N = N+1

Response PDU

Function code	1 Byte	**0x0F**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Outputs	2 Bytes	0x0001 to 0x07B0

Error

Error code	1 Byte	**0x8F**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to write a series of 10 coils starting at coil 20:

The request data contents are two bytes: CD 01 hex (1100 1101 0000 0001 binary). The binary bits correspond to the outputs in the following way:

Bit:	1	1	0	0	1	1	0	1	0	0	0	0	0	0	0	1
Output:	27	26	25	24	23	22	21	20	–	–	–	–	–	–	29	28

The first byte transmitted (CD hex) addresses outputs 27-20, with the least significant bit addressing the lowest output (20) in this set.

The next byte transmitted (01 hex) addresses outputs 29-28, with the least significant bit addressing the lowest output (28) in this set. Unused bits in the last data byte should be zero–filled.

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**0F**	Function	**0F**
Starting Address Hi	**00**	Starting Address Hi	**00**
Starting Address Lo	**13**	Starting Address Lo	**13**
Quantity of Outputs Hi	**00**	Quantity of Outputs Hi	**00**
Quantity of Outputs Lo	**0A**	Quantity of Outputs Lo	**0A**
Byte Count	**02**		
Outputs Value Hi	**CD**		
Outputs Value Lo	**01**		

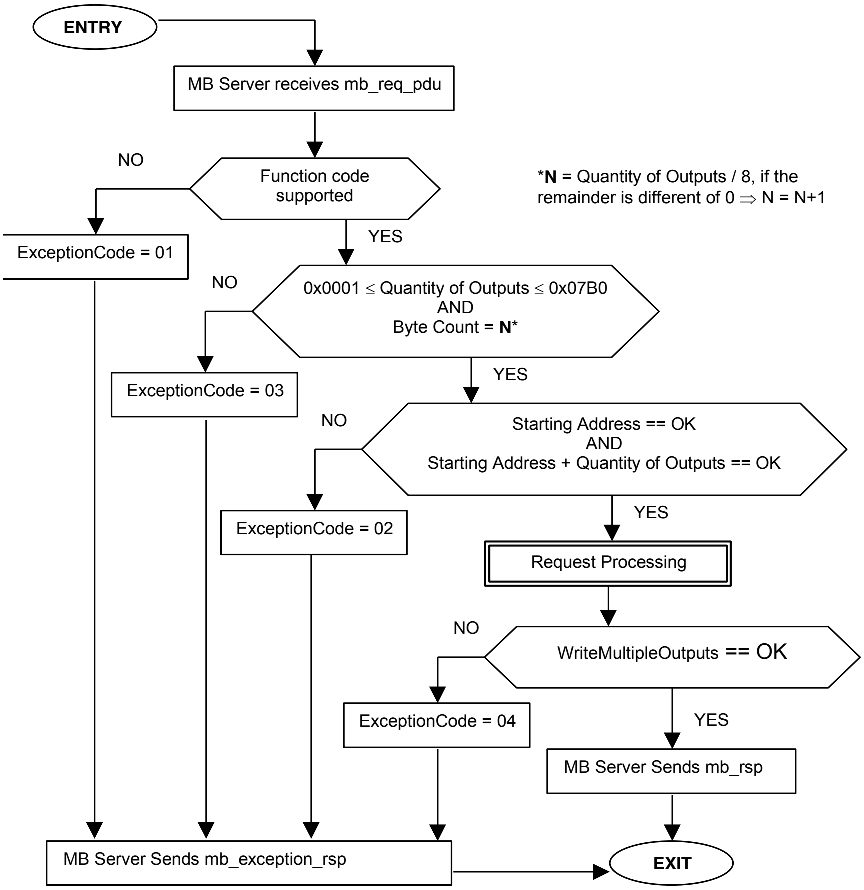


Figure 21: Write Multiple Outputs state diagram

6.12 16 (0x10) Write Multiple registers

This function code is used to write a block of contiguous registers (1 to 123 registers) in a remote device.

The requested written values are specified in the request data field. Data is packed as two bytes per register.

The normal response returns the function code, starting address, and quantity of registers written.

Request

Function code	1 Byte	**0x10**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Registers	2 Bytes	0x0001 to 0x007B
Byte Count	1 Byte	2 x **N***
Registers Value	**N*** x 2 Bytes	value

***N** = Quantity of Registers

Response

Function code	1 Byte	**0x10**
Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity of Registers	2 Bytes	1 to 123 (0x7B)

Error

Error code	1 Byte	**0x90**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to write two registers starting at 2 to 00 0A and 01 02 hex:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**10**	Function	**10**
Starting Address Hi	**00**	Starting Address Hi	**00**
Starting Address Lo	**01**	Starting Address Lo	**01**

Quantity of Registers Hi	**00**	Quantity of Registers Hi	**00**
Quantity of Registers Lo	**02**	Quantity of Registers Lo	**02**
Byte Count	**04**		
Registers Value Hi	**00**		
Registers Value Lo	**0A**		
Registers Value Hi	**01**		
Registers Value Lo	**02**		

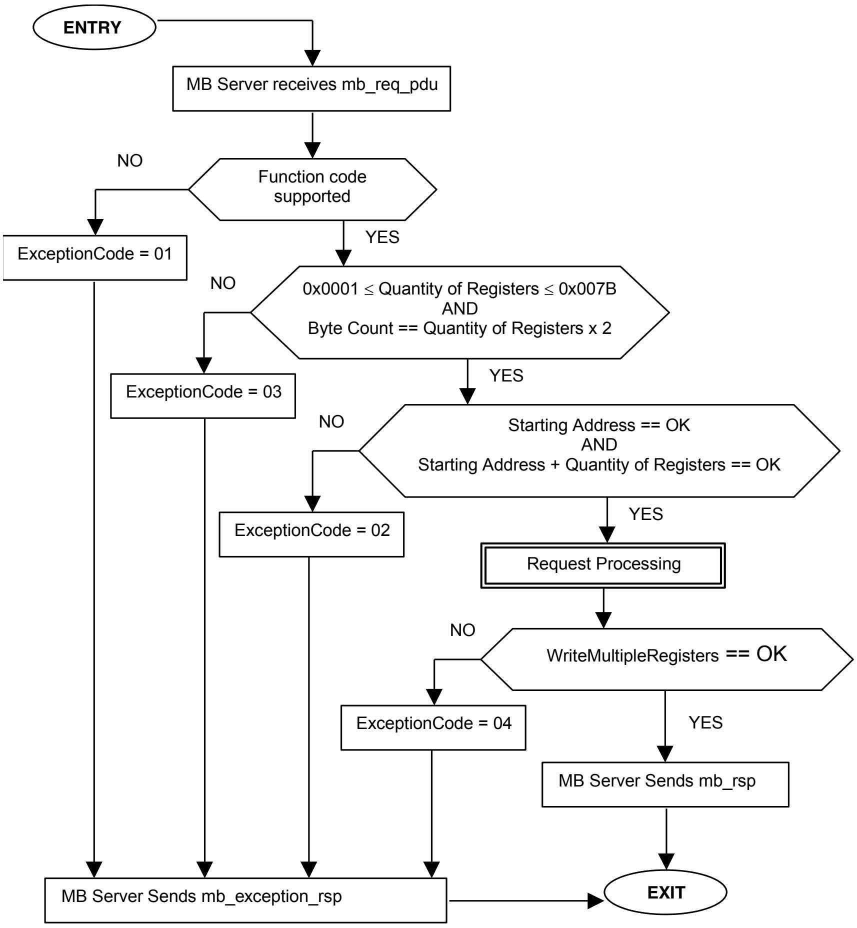


Figure 22: Write Multiple Registers state diagram

6.13 17 (0x11) Report Server ID (Serial Line only)

This function code is used to read the description of the type, the current status, and other information specific to a remote device.

The format of a normal response is shown in the following example. The data contents are specific to each type of device.

Request

Function code	1 Byte	**0x11**

Response

Function code	1 Byte	**0x11**
Byte Count	1 Byte	
Server ID	*device specific*	
Run Indicator Status	1 Byte	0x00 = OFF, 0xFF = ON
Additional Data		

Error

Error code	1 Byte	**0x91**
Exception code	1 Byte	01 or 04

Here is an example of a request to report the ID and status:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**11**	Function	**11**
		Byte Count	Device Specific
		Server ID	Device Specific
		Run Indicator Status	0x00 or 0xFF
		Additional Data	Device Specific

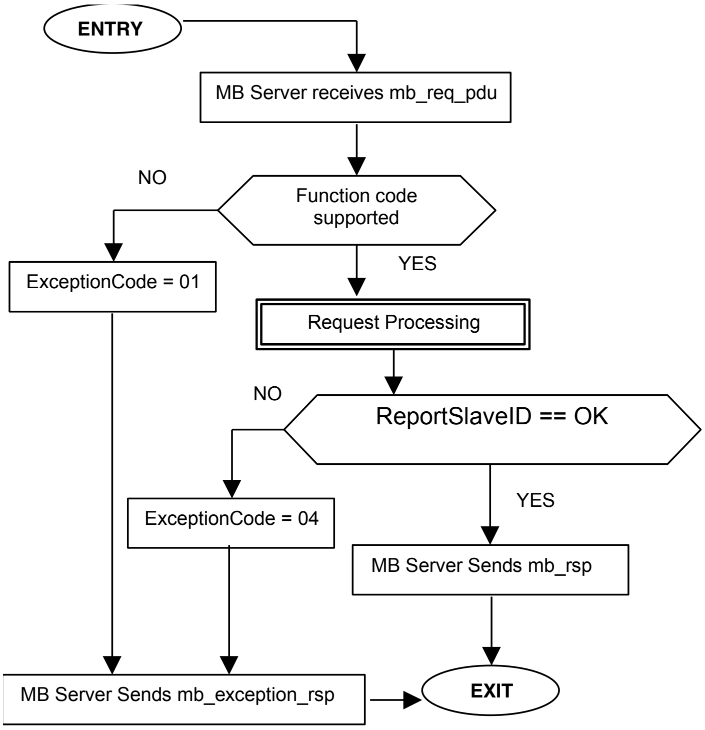


Figure 23: Report server ID state diagram

6.14 20 (0x14) Read File Record

This function code is used to perform a file record read. All Request Data Lengths are provided in terms of number of bytes and all Record Lengths are provided in terms of registers.

A file is an organization of records. Each file contains 10000 records, addressed 0000 to 9999 decimal or 0X0000 to 0X270F. For example, record 12 is addressed as 12.

The function can read multiple groups of references. The groups can be separating (non-contiguous), but the references within each group must be sequential.

Each group is defined in a separate ‘sub-request’ field that contains 7 bytes:

The reference type: 1 byte (must be specified as 6)
The File number: 2 bytes
The starting record number within the file: 2 bytes
The length of the record to be read: 2 bytes.

The quantity of registers to be read, combined with all other fields in the expected response, must not exceed the allowable length of the MODBUS PDU : 253 bytes.

The normal response is a series of ‘sub-responses’, one for each ‘sub-request’. The byte count field is the total combined count of bytes in all ‘sub-responses’. In addition, each ‘sub-response’ contains a field that shows its own byte count.

Request

Function code	1 Byte	**0x14**
Byte Count	1 Byte	0x07 to 0xF5 bytes
Sub-Req. x, Reference Type	1 Byte	06
Sub-Req. x, File Number	2 Bytes	0x0001 to 0xFFFF

Sub-Req. x, Record Number	2 Bytes	0x0000 to 0x270F
Sub-Req. x, Record Length	2 Bytes	**N**
Sub-Req. x+1, ...		

Response

Function code	1 Byte	**0x14**
Resp. data Length	1 Byte	0x07 to 0xF5
Sub-Req. x, File Resp. length	1 Byte	0x07 to 0xF5
Sub-Req. x, Reference Type	1 Byte	6
Sub-Req. x, Record Data	**N** x 2 Bytes	
Sub-Req. x+1, ...		

Error

Error code	1 Byte	**0x94**
Exception code	1 Byte	01 or 02 or 03 or 04 or 08

While it is allowed for the File Number to be in the range 1 to 0xFFFF, it should be noted that interoperability with legacy equipment may be compromised if the File Number is greater than 10 (0x0A).

Here is an example of a request to read two groups of references from remote device:

- Group 1 consists of two registers from file 4, starting at register 1 (address 0001).
- Group 2 consists of two registers from file 3, starting at register 9 (address 0009).

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**14**	Function	**14**
Byte Count	**0E**	Resp. Data length	**0C**
Sub-Req. 1, Ref. Type	**06**	Sub-Req. 1, File resp. length	**05**
Sub-Req. 1, File Number Hi	**00**	Sub-Req. 1, Ref. Type	**06**
Sub-Req. 1, File Number Lo	**04**	Sub-Req. 1, Register.Data Hi	**0D**
Sub-Req. 1, Record number Hi	**00**	Sub-Req. 1, Register.DataLo	**FE**
Sub-Req. 1, Record number Lo	**01**	Sub-Req. 1, Register.Data Hi	**00**
Sub-Req. 1, Record Length Hi	**00**	Sub-Req. 1, Register.DataLo	**20**
Sub-Req. 1, Record Length Lo	**02**	Sub-Req. 2, File resp. length	**05**
Sub-Req. 2, Ref. Type	**06**	Sub-Req. 2, Ref. Type	**06**
Sub-Req. 2, File Number Hi	**00**	Sub-Req. 2, Register.Data H	**33**
Sub-Req. 2, File Number Lo	**03**	Sub-Req. 2, Register.DataLo	**CD**
Sub-Req. 2, Record number Hi	**00**	Sub-Req. 2, Register.Data Hi	**00**
Sub-Req. 2, Record number Lo	**09**	Sub-Req. 2, Register.DataLo	**40**
Sub-Req. 2, Record Length Hi	**00**		
Sub-Req. 2, Record Length Lo	**02**		

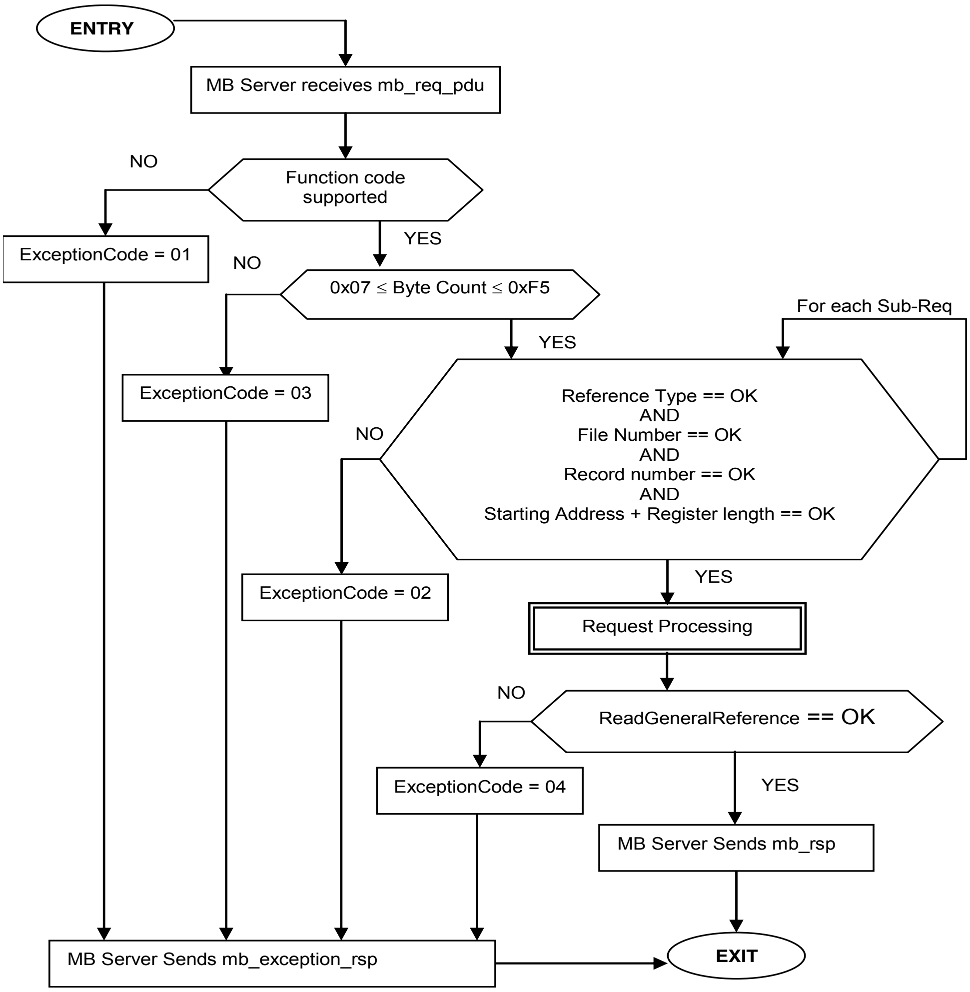


Figure 24: Read File Record state diagram

6.15 21 (0x15) Write File Record

This function code is used to perform a file record write. All Request Data Lengths are provided in terms of number of bytes and all Record Lengths are provided in terms of the number of 16-bit words.

A file is an organization of records. Each file contains 10000 records, addressed 0000 to 9999 decimal or 0X0000 to 0X270F. For example, record 12 is addressed as 12.

The function can write multiple groups of references. The groups can be separate, i.e. non–contiguous, but the references within each group must be sequential.

Each group is defined in a separate 'sub-request' field that contains 7 bytes plus the data:

The reference type: 1 byte (must be specified as 6)
The file number: 2 bytes
The starting record number within the file: 2 bytes
The length of the record to be written: 2 bytes
The data to be written: 2 bytes per register.

The quantity of registers to be written, combined with all other fields in the request, must not exceed the allowable length of the MODBUS PDU : 253bytes.

The normal response is an echo of the request.

Request

Function code	1 Byte	**0x15**
Request data length	1 Byte	0x09 to 0xFB
Sub-Req. x, Reference Type	1 Byte	06
Sub-Req. x, File Number	2 Bytes	0x0001 to 0xFFFF
Sub-Req. x, Record Number	2 Bytes	0x0000 to 0x270F

Sub-Req. x, Record length	2 Bytes	**N**
Sub-Req. x, Record data	**N** x 2 Bytes	
Sub-Req. x+1, ...		

Response

Function code	1 Byte	**0x15**
Response Data length	1 Byte	0x09 to 0xFB
Sub-Req. x, Reference Type	1 Byte	06
Sub-Req. x, File Number	2 Bytes	0x0001 to 0xFFFF
Sub-Req. x, Record number	2 Bytes	0x0000 to 0x270F
Sub-Req. x, Record length	2 Bytes	**N**
Sub-Req. x, Record Data	**N** x 2 Bytes	
Sub-Req. x+1, ...		

Error

Error code	1 Byte	**0x95**
Exception code	1 Byte	01 or 02 or 03 or 04 or 08

While it is allowed for the File Number to be in the range 1 to 0xFFFF, it should be noted that interoperability with legacy equipment may be compromised if the File Number is greater than 10 (0x0A).

Here is an example of a request to write one group of references into remote device:

- The group consists of three registers in file 4, starting at register 7 (address 0007).

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**15**	Function	**15**
Request Data length	**0D**	Request Data length	**0D**
Sub-Req. 1, Ref. Type	**06**	Sub-Req. 1, Ref. Type	**06**
Sub-Req. 1, File Number Hi	**00**	Sub-Req. 1, File Number Hi	**00**
Sub-Req. 1, File Number Lo	**04**	Sub-Req. 1, File Number Lo	**04**
Sub-Req. 1, Record number Hi	**00**	Sub-Req. 1, Record number Hi	**00**
Sub-Req. 1, Record number Lo	**07**	Sub-Req. 1, Record number Lo	**07**
Sub-Req. 1, Record length Hi	**00**	Sub-Req. 1, Record length Hi	**00**
Sub-Req. 1, Record length Lo	**03**	Sub-Req. 1, Record length Lo	**03**
Sub-Req. 1, Register Data Hi	**06**	Sub-Req. 1, Register Data Hi	**06**
Sub-Req. 1, Register Data Lo	**AF**	Sub-Req. 1, Register Data Lo	**AF**
Sub-Req. 1, Register Data Hi	**04**	Sub-Req. 1, Register Data Hi	**04**
Sub-Req. 1, Register Data Lo	**BE**	Sub-Req. 1, Register Data Lo	**BE**
Sub-Req. 1, Register Data Hi	**10**	Sub-Req. 1, Register Data Hi	**10**
Sub-Req. 1, Register Data Lo	**0D**	Sub-Req. 1, Register Data Lo	**0D**

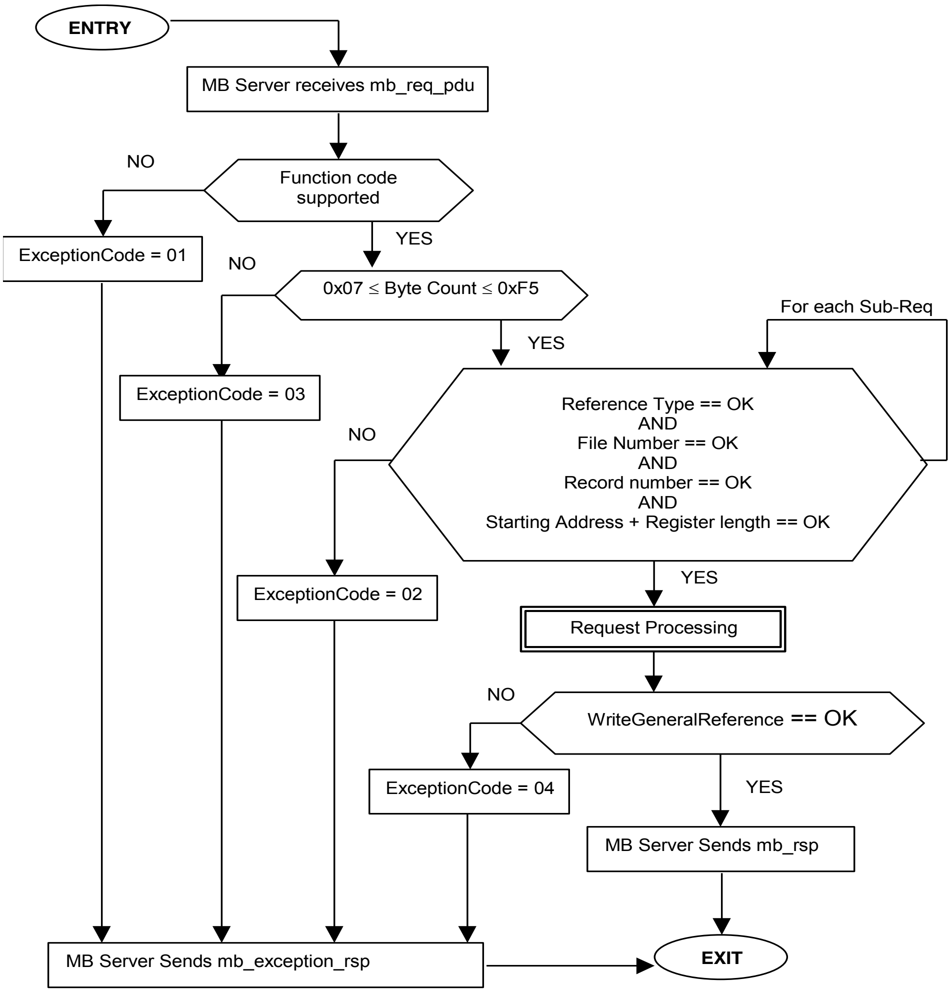


Figure 25: Write File Record state diagram

6.16 22 (0x16) Mask Write Register

This function code is used to modify the contents of a specified holding register using a combination of an AND mask, an OR mask, and the register's current contents. The function can be used to set or clear individual bits in the register.

The request specifies the holding register to be written, the data to be used as the AND mask, and the data to be used as the OR mask. Registers are addressed starting at zero. Therefore registers 1-16 are addressed as 0-15.

The function’s algorithm is:

Result = (Current Contents AND And_Mask) OR (Or_Mask AND (NOT And_Mask))

For example:

	Hex	**Binary**
Current Contents=	12	0001 0010
And_Mask =	F2	1111 0010
Or_Mask =	25	0010 0101
(NOT And_Mask)=	0D	0000 1101
Result =	17	0001 0111

☞ **Note**:

- If the Or_Mask value is zero, the result is simply the logical ANDing of the current contents and And_Mask. If the And_Mask value is zero, the result is equal to the Or_Mask value.
- The contents of the register can be read with the Read Holding Registers function (function code 03). They could, however, be changed subsequently as the controller scans its user logic program.

The normal response is an echo of the request. The response is returned after the register has been written.

Request

Function code	1 Byte	**0x16**
Reference Address	2 Bytes	0x0000 to 0xFFFF
And_Mask	2 Bytes	0x0000 to 0xFFFF
Or_Mask	2 Bytes	0x0000 to 0xFFFF

Response

Function code	1 Byte	**0x16**
Reference Address	2 Bytes	0x0000 to 0xFFFF
And_Mask	2 Bytes	0x0000 to 0xFFFF
Or_Mask	2 Bytes	0x0000 to 0xFFFF

Error

Error code	1 Byte	**0x96**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a Mask Write to register 5 in remote device, using the above mask values.

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**16**	Function	**16**
Reference address Hi	**00**	Reference address Hi	**00**
Reference address Lo	**04**	Reference address Lo	**04**
And_Mask Hi	**00**	And_Mask Hi	**00**
And_Mask Lo	**F2**	And_Mask Lo	**F2**
Or_Mask Hi	**00**	Or_Mask Hi	**00**
Or_Mask Lo	**25**	Or_Mask Lo	**25**

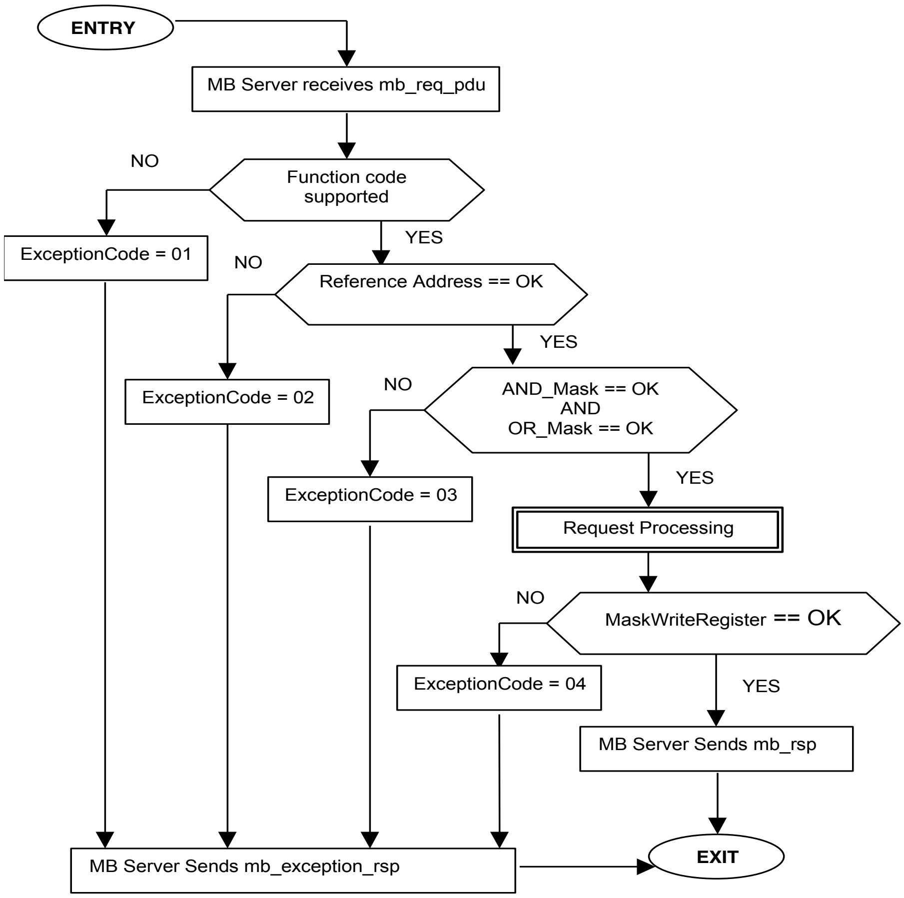


Figure 26: Mask Write Holding Register state diagram

6.17 23 (0x17) Read/Write Multiple registers

This function code performs a combination of one read operation and one write operation in a single MODBUS transaction. The write operation is performed before the read.

Holding registers are addressed starting at zero. Therefore holding registers 1-16 are addressed in the PDU as 0-15.

The request specifies the starting address and number of holding registers to be read as well as the starting address, number of holding registers, and the data to be written. The byte count specifies the number of bytes to follow in the write data field.

The normal response contains the data from the group of registers that were read. The byte count field specifies the quantity of bytes to follow in the read data field.

Request

Function code	1 Byte	**0x17**
Read Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity to Read	2 Bytes	0x0001 to 0x007D
Write Starting Address	2 Bytes	0x0000 to 0xFFFF
Quantity to Write	2 Bytes	0x0001 to 0X0079
Write Byte Count	1 Byte	2 x **N***
Write Registers Value	**N***x 2 Bytes	

***N** = Quantity to Write

Response

Function code	1 Byte	**0x17**
Byte Count	1 Byte	2 x **N'***
Read Registers value	**N'*** x 2 Bytes	

***N'** = Quantity to Read

Error

Error code	1 Byte	**0x97**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of a request to read six registers starting at register 4, and to write three registers starting at register 15:

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**17**	Function	**17**
Read Starting Address Hi	**00**	Byte Count	**0C**
Read Starting Address Lo	**03**	Read Registers value Hi	**00**
Quantity to Read Hi	**00**	Read Registers value Lo	**FE**
Quantity to Read Lo	**06**	Read Registers value Hi	**0A**
Write Starting Address Hi	**00**	Read Registers value Lo	**CD**
Write Starting address Lo	**0E**	Read Registers value Hi	**00**
Quantity to Write Hi	**00**	Read Registers value Lo	**01**
Quantity to Write Lo	**03**	Read Registers value Hi	**00**
Write Byte Count	**06**	Read Registers value Lo	**03**
Write Registers Value Hi	**00**	Read Registers value Hi	**00**
Write Registers Value Lo	**FF**	Read Registers value Lo	**0D**
Write Registers Value Hi	**00**	Read Registers value Hi	**00**
Write Registers Value Lo	**FF**	Read Registers value Lo	**FF**
Write Registers Value Hi	**00**		
Write Registers Value Lo	**FF**		

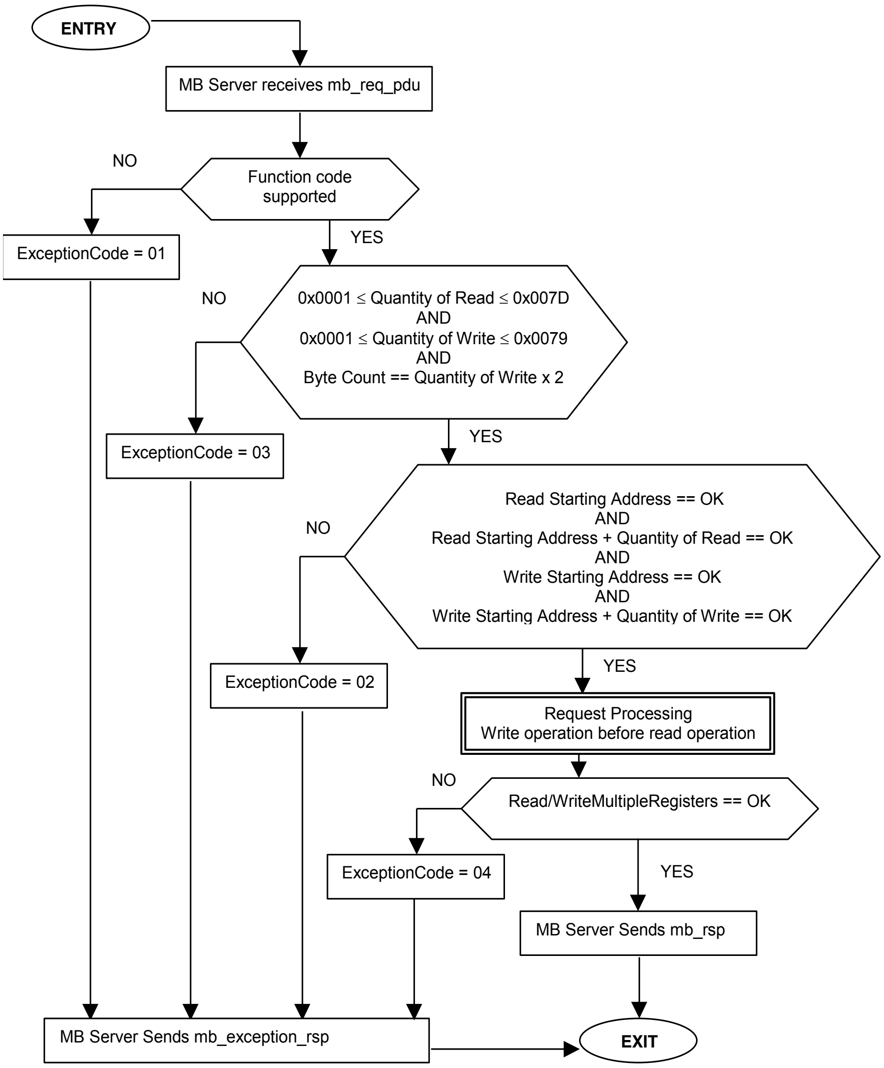


Figure 27: Read/Write Multiple Registers state diagram

6.18 24 (0x18) Read FIFO Queue

This function code allows to read the contents of a First-In-First-Out (FIFO) queue of register in a remote device. The function returns a count of the registers in the queue, followed by the queued data. Up to 32 registers can be read: the count, plus up to 31 queued data registers. The queue count register is returned first, followed by the queued data registers.

The function reads the queue contents, but does not clear them.

In a normal response, the byte count shows the quantity of bytes to follow, including the queue count bytes and value register bytes (but not including the error check field).

The queue count is the quantity of data registers in the queue (not including the count register).

If the queue count exceeds 31, an exception response is returned with an error code of 03 (Illegal Data Value).

Request

Function code	1 Byte	**0x18**
FIFO Pointer Address	2 Bytes	0x0000 to 0xFFFF

Response

Function code	1 Byte	**0x18**
Byte Count	2 Bytes	
FIFO Count	2 Bytes	≤ 31
FIFO Value Register	**N*** x 2 Bytes	

***N** = FIFO Count

Error

Error code	1 Byte	**0x98**
Exception code	1 Byte	01 or 02 or 03 or 04

Here is an example of Read FIFO Queue request to remote device. The request is to read the queue starting at the pointer register 1246 (0x04DE):

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**18**	Function	**18**
FIFO Pointer Address Hi	**04**	Byte Count Hi	**00**
FIFO Pointer Address Lo	**DE**	Byte Count Lo	**06**
		FIFO Count Hi	**00**
		FIFO Count Lo	**02**
		FIFO Value Register Hi	**01**
		FIFO Value Register Lo	**B8**
		FIFO Value Register Hi	**12**
		FIFO Value Register Lo	**84**

In this example, the FIFO pointer register (1246 in the request) is returned with a queue count of 2. The two data registers follow the queue count. These are:

1247 (contents 440 decimal -- 0x01B8); and 1248 (contents 4740 -- 0x1284).

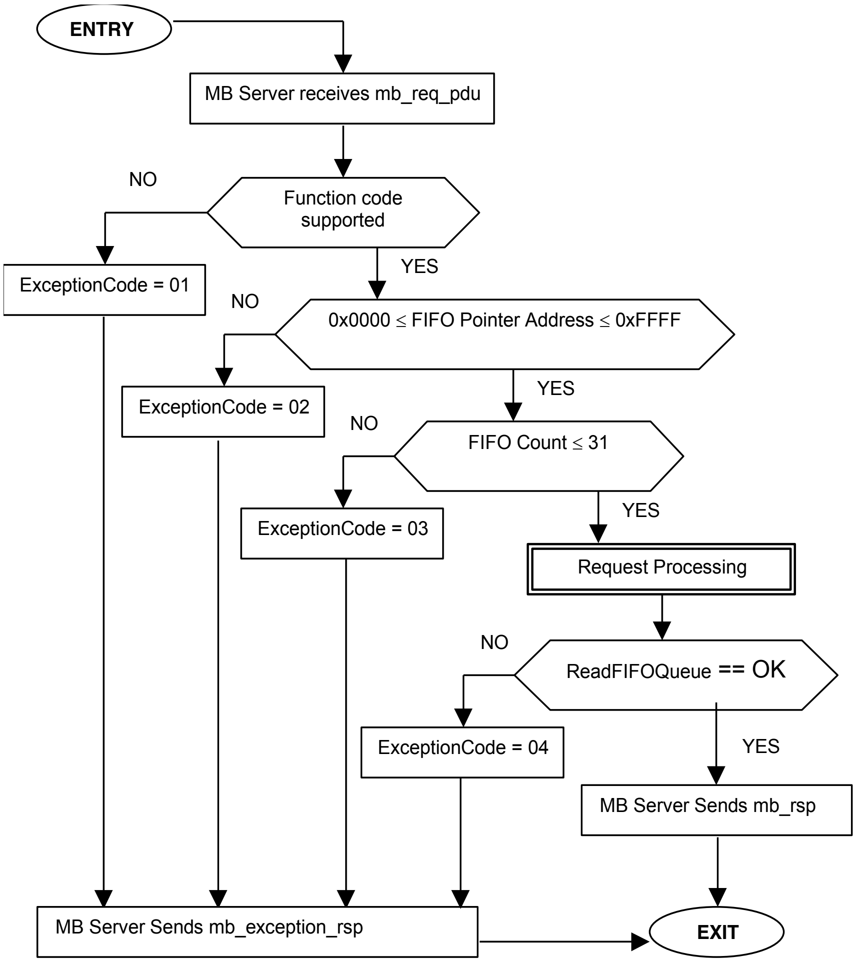


Figure 28: Read FIFO Queue state diagram

6.19 43 (0x2B) Encapsulated Interface Transport

Informative Note: The user is asked to refer to Annex A (Informative) MODBUS RESERVED FUNCTION CODES, SUBCODES AND MEI TYPES.

Function Code 43 and its MEI Type 14 for Device Identification is one of two Encapsulated Interface Transport currently available in this Specification. The following function codes and MEI Types shall not be part of this published Specification and these function codes and MEI Types are specifically reserved: 43/0-12 and 43/15-255.

The MODBUS Encapsulated Interface (MEI)Transport is a mechanism for tunneling service requests and method invocations, as well as their returns, inside MODBUS PDUs.
The primary feature of the MEI Transport is the encapsulation of method invocations or service requests that are part of a defined interface as well as method invocation returns or service responses.

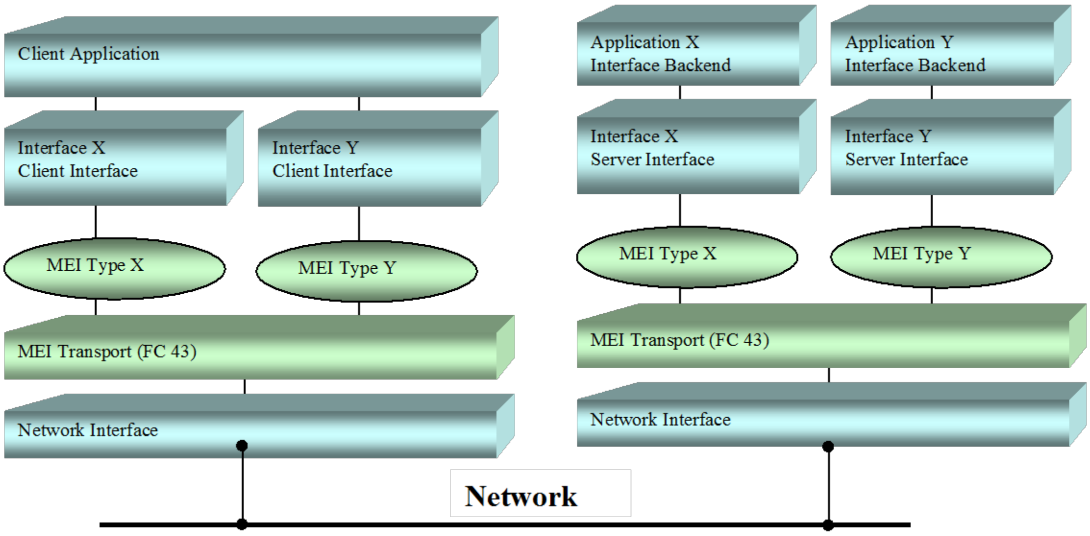


Figure 29: MODBUS encapsulated Interface Transport

The **Network Interface** can be any communication stack used to send MODBUS PDUs, such as TCP/IP, or serial line.

A **MEI Type** is a MODBUS Assigned Number and therefore will be unique, the value between 0 to 255 are Reserved according to Annex A (Informative) except for MEI Type 13 and MEI Type 14.

The MEI Type is used by MEI Transport implementations to dispatch a method invocation to the indicated interface.

Since the MEI Transport service is interface agnostic, any specific behavior or policy required by the interface must be provided by the interface, e.g. MEI transaction processing, MEI interface error handling, etc.

Request

Function code	1 Byte	**0x2B**
MEI Type*	1 Byte	0x0D or 0x0E
MEI type specific data	n Bytes	

* MEI = MODBUS Encapsulated Interface

Response

Function code	1 Byte	**0x2B**
MEI Type	1 byte	echo of MEI Type in Request
MEI type specific data	n Bytes	

Error

Function code	1 Byte	**0xAB :** **Fc 0x2B + 0x80**
Exception code	1 Byte	01 or 02 or 03 or 04

As an example see Read device identification request.

6.20 43 / 13 (0x2B / 0x0D) CANopen General Reference Request and Response PDU

The CANopen General reference Command is an encapsulation of the services that will be used to access (read from or write to) the entries of a CAN-Open Device Object Dictionary as well as controlling and monitoring the CANopen system, and devices.

The MEI Type 13 (0x0D) is a MODBUS Assigned Number licensed to CiA for the CANopen General Reference.

The system is intended to work within the limitations of existing MODBUS networks. Therefore, the information needed to query or modify the object dictionaries in the system is mapped into the format of a MODBUS message. The PDU will have the 253 Byte limitation in both the Request and the Response message.

Informative: Please refer to Annex B for a reference to a specification that provides information on MEI Type 13.

6.21 43 / 14 (0x2B / 0x0E) Read Device Identification

This function code allows reading the identification and additional information relative to the physical and functional description of a remote device, only.

The Read Device Identification interface is modeled as an address space composed of a set of addressable data elements. The data elements are called objects and an object Id identifies them.

The interface consists of 3 categories of objects :

- Basic Device Identification. All objects of this category are mandatory : VendorName, Product code, and revision number.
- Regular Device Identification. In addition to Basic data objects, the device provides additional and optional identification and description data objects. All of the objects of this category are defined in the standard but their implementation is optional .
- Extended Device Identification. In addition to regular data objects, the device provides additional and optional identification and description private data about the physical device itself. All of these data are device dependent.

Object Id	Object Name / Description	Type	M/O	category
0x00	VendorName	ASCII String	**Mandatory**	**Basic**
0x01	ProductCode	ASCII String	**Mandatory**	
0x02	MajorMinorRevision	ASCII String	**Mandatory**	
0x03	VendorUrl	ASCII String	Optional	**Regular**
0x04	ProductName	ASCII String	Optional	
0x05	ModelName	ASCII String	Optional	
0x06	UserApplicationName	ASCII String	Optional	
0x07 … 0x7F	*Reserved*		Optional	
0x80 … 0xFF	*Private objects may be* ***optionally*** *defined.* *The range [0x80 – 0xFF] is Product dependant.*	device dependant	Optional	**Extended**

Request

Function code	1 Byte	**0x2B**
MEI Type*	1 Byte	0x0E
Read Device ID code	1 Byte	01 / 02 / 03 / 04
Object Id	1 Byte	0x00 to 0xFF

* MEI = MODBUS Encapsulated Interface

Response

Function code	1 Byte	**0x2B**
MEI Type	1 byte	0x0E
Read Device ID code	1 Byte	01 / 02 / 03 / 04
Conformity level	1 Byte	0x01 or 0x02 or 0x03 or 0x81 or 0x82 or 0x83
More Follows	1 Byte	00 / FF
Next Object Id	1 Byte	Object ID number
Number of objects	1 Byte	
List Of		
Object ID	1 Byte	
Object length	1 Byte	
Object Value	Object length	Depending on the object ID

Error

Function code	1 Byte	**0xAB :** **Fc 0x2B + 0x80**

Exception code	1 Byte	01 or 02 or 03 or 04

Request parameters description :

A MODBUS Encapsulated Interface assigned number 14 identifies the Read identification request.

The parameter " Read Device ID code " allows to define four access types :

01: request to get the basic device identification (stream access)
02: request to get the regular device identification (stream access)
03: request to get the extended device identification (stream access)
04: request to get one specific identification object (individual access)

An exception code 03 is sent back in the response if the Read device ID code is illegal.

In case of a response that does not fit into a single response, several transactions (request/response) must be done. The Object Id byte gives the identification of the first object to obtain. For the first transaction, the client must set the Object Id to 0 to obtain the beginning of the device identification data. For the following transactions, the client must set the Object Id to the value returned by the server in its previous response.

Remark : An object is indivisible, therefore any object must have a size consistent with the size of transaction response.

If the Object Id does not match any known object, the server responds as if object 0 were pointed out (restart at the beginning).

In case of an individual access: ReadDevId code 04***,*** the Object Id in the request gives the identification of the object to obtain, and if the Object Id doesn't match to any known object, the server returns an exception response with exception code = 02 (Illegal data address).

If the server device is asked for a description level (readDevice Code)higher that its conformity level , It must respond in accordance with its actual conformity level.

Response parameter description :

Function code :	Function code 43 (decimal) 0x2B (hex)
MEI Type	14 (0x0E) MEI Type assigned number for Device Identification Interface
ReadDevId code :	Same as request ReadDevId code : 01, 02, 03 or 04
Conformity Level	Identification conformity level of the device and type of supported access 0x01: basic identification (stream access only) 0x02: regular identification (stream access only) 0x03: extended identification (stream access only) 0x81: basic identification (stream access and individual access) 0x82: regular identification (stream access and individual access) 0x83: extended identification(stream access and individual access)
More Follows	***In case of ReadDevId codes 01, 02 or 03 (stream access),*** If the identification data doesn't fit into a single response, several request/response transactions may be required. 0x00 : no more Object are available 0xFF : other identification Object are available and further MODBUS transactions are required ***In case of ReadDevId code 04 (individual access),*** this field must be set to 00.
Next Object Id	If "MoreFollows = FF", identification of the next Object to be asked for. If "MoreFollows = 00", must be set to 00 (useless)
Number Of Objects	Number of identification Object returned in the response (for an individual access, Number Of Objects = 1)
Object0.Id	Identification of the first Object returned in the PDU (stream access) or the requested Object (individual access)

Object0.Length	Length of the first Object in byte
Object0.Value	Value of the first Object (Object0.Length bytes)
…	
ObjectN.Id	Identification of the last Object (within the response)
ObjectN.Length	Length of the last Object in byte
ObjectN.Value	Value of the last Object (ObjectN.Length bytes)

Example of a Read Device Identification request for "Basic device identification" : In this example all information are sent in one response PDU.

Request		**Response**	
Field Name	*Value*	*Field Name*	*Value*
Function	**2B**	Function	**2B**
MEI Type	**0E**	MEI Type	**0E**
Read Dev Id code	**01**	Read Dev Id Code	**01**
Object Id	**00**	Conformity Level	**01**
		More Follows	**00**
		NextObjectId	**00**
		Number Of Objects	**03**
		Object Id	**00**
		Object Length	**16**
		Object Value	**" Company identification"**
		Object Id	**01**
		Object Length	**0D**
		Object Value	**" Product code XX"**
		Object Id	**02**
		Object Length	**05**
		Object Value	**"V2.11"**

In case of a device that required several transactions to send the response the following transactions is intiated.

First transaction :

Request		**Response**	
Field Name	*Value*	*Field Name*	*Value*
Function	**2B**	Function	**2B**
MEI Type	**0E**	MEI Type	**0E**
Read Dev Id code	**01**	Read Dev Id Code	**01**
Object Id	**00**	Conformity Level	**01**
		More Follows	**FF**
		NextObjectId	**02**
		Number Of Objects	**03**
		Object Id	**00**
		Object Length	**16**
		Object Value	**" Company identification"**
		Object Id	**01**
		Object Length	**1C**
		Object Value	**" Product code XXXXXXXXXXXXXXXX"**

Second transaction :

Request		**Response**	
Field Name	*Value*	*Field Name*	*Value*
Function	**2B**	Function	**2B**
MEI Type	**0E**	MEI Type	**0E**
Read Dev Id code	**01**	Read Dev Id Code	**01**
Object Id	**02**	Conformity Level	**01**
		More Follows	**00**
		NextObjectId	**00**
		Number Of Objects	**03**
		Object Id	**02**
		Object Length	**05**
		Object Value	**"V2.11"**

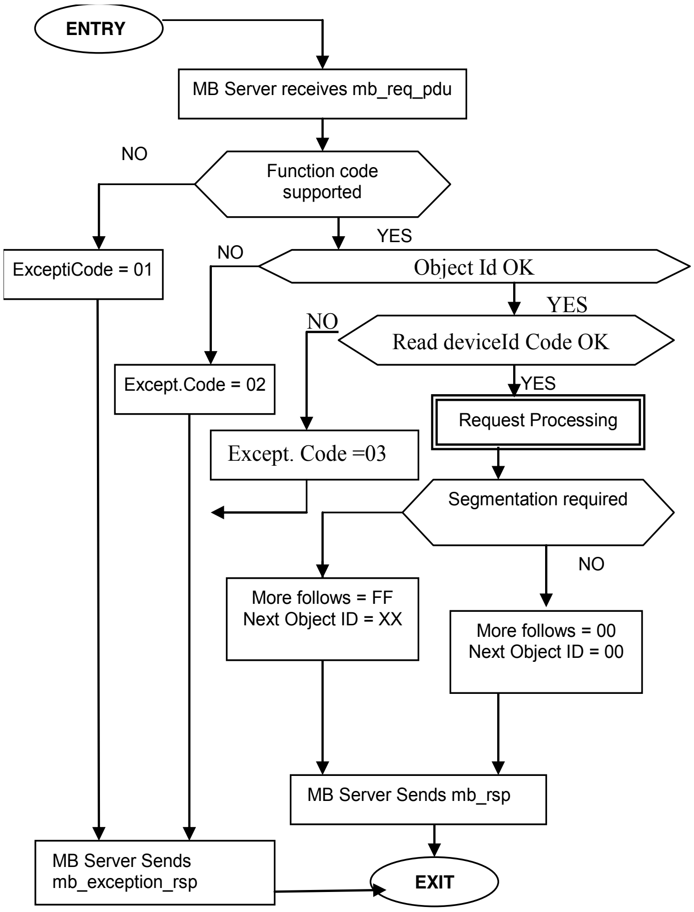


Figure 30: Read Device Identification state diagram

7 MODBUS Exception Responses

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

- If the server device receives the request without a communication error, and can handle the query normally, it returns a normal response.
- If the server does not receive the request due to a communication error, no response is returned. The client program will eventually process a timeout condition for the request.
- If the server receives the request, but detects a communication error (parity, LRC, CRC, ...), no response is returned. The client program will eventually process a timeout condition for the request.
- If the server receives the request without a communication error, but cannot handle it (for example, if the request is to read a non–existent output or register), the server will return an exception response informing the client of 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 server echoes the function code of the original request 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 server sets the MSB of the function code to 1. This makes the function code value in an exception response exactly 80 hexadecimal higher than the value would be for a normal response.

With the function code's MSB set, the client'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 server may return data or statistics in the data field (any information that was requested in the request). In an exception response, the server returns an exception code in the data field. This defines the server condition that caused the exception.

Example of a client request and server exception response

Request		**Response**	
Field Name	*(Hex)*	*Field Name*	*(Hex)*
Function	**01**	Function	**81**
Starting Address Hi	**04**	Exception Code	**02**
Starting Address Lo	**A1**		
Quantity of Outputs Hi	**00**		
Quantity of Outputs Lo	**01**		

In this example, the client addresses a request to server device. The function code (01) is for a Read Output Status operation. It requests the status of the output at address 1185 (04A1 hex). Note that only that one output is to be read, as specified by the number of outputs field (0001).

If the output address is non–existent in the server device, the server will return the exception response with the exception code shown (02). This specifies an illegal data address for the server.

A listing of exception codes begins on the next page.

MODBUS Exception Codes		
Code	**Name**	**Meaning**
01	ILLEGAL FUNCTION	The function code received in the query is not an allowable action for the server. This may be because the function code is only applicable to newer devices, and was not implemented in the unit selected. It could also indicate that the server is in the wrong state to process a request of this type, for example because it is unconfigured and is being asked to return register values.
02	ILLEGAL DATA ADDRESS	The data address received in the query is not an allowable address for the server. More specifically, the combination of reference number and transfer length is invalid. For a controller with 100 registers, the PDU addresses the first register as 0, and the last one as 99. If a request is submitted with a starting register address of 96 and a quantity of registers of 4, then this request will successfully operate (address-wise at least) on registers 96, 97, 98, 99. If a request is submitted with a starting register address of 96 and a quantity of registers of 5, then this request will fail with Exception Code 0x02 "Illegal Data Address" since it attempts to operate on registers 96, 97, 98, 99 and 100, and there is no register with address 100.
03	ILLEGAL DATA VALUE	A value contained in the query data field is not an allowable value for server. This indicates a fault in the structure of the remainder of a complex request, such as that the implied length is incorrect. It specifically does NOT mean that a data item submitted for storage in a register has a value outside the expectation of the application program, since the MODBUS protocol is unaware of the significance of any particular value of any particular register.
04	SERVER DEVICE FAILURE	An unrecoverable error occurred while the server was attempting to perform the requested action.
05	ACKNOWLEDGE	Specialized use in conjunction with programming commands. The server has accepted the request and is processing it, but a long duration of time will be required to do so. This response is returned to prevent a timeout error from occurring in the client. The client can next issue a Poll Program Complete message to determine if processing is completed.
06	SERVER DEVICE BUSY	Specialized use in conjunction with programming commands. The server is engaged in processing a long–duration program command. The client should retransmit the message later when the server is free.
08	MEMORY PARITY ERROR	Specialized use in conjunction with function codes 20 and 21 and reference type 6, to indicate that the extended file area failed to pass a consistency check. The server attempted to read record file, but detected a parity error in the memory. The client can retry the request, but service may be required

		on the server device.
0A	GATEWAY PATH UNAVAILABLE	Specialized use in conjunction with gateways, indicates that the gateway was unable to allocate an internal communication path from the input port to the output port for processing the request. Usually means that the gateway is misconfigured or overloaded.
0B	GATEWAY TARGET DEVICE FAILED TO RESPOND	Specialized use in conjunction with gateways, indicates that no response was obtained from the target device. Usually means that the device is not present on the network.

Annex A (Informative): MODBUS RESERVED FUNCTION CODES, SUBCODES AND MEI TYPES

The following function codes and subcodes shall not be part of this published Specification and these function codes and subcodes are specifically reserved. The format is function code/subcode or just function code where all the subcodes (0-255) are reserved: 8/19; 8/21-65535, 9, 10, 13, 14, 41, 42, 90, 91, 125, 126 and 127.

Function Code 43 and its MEI Type 14 for Device Identification and MEI Type 13 for CANopen General Reference Request and Response PDU are the currently available Encapsulated Interface Transports in this Specification.

The following function codes and MEI Types shall not be part of this published Specification and these function codes and MEI Types are specifically reserved: 43/0-12 and 43/15-255. In this Specification, a User Defined Function code having the same or similar result as the Encapsulated Interface Transport is not supported.

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Annex B (Informative): CANOPEN GENERAL REFERENCE COMMAND

Please refer to the MODBUS website or the CiA (CAN in Automation) website for a copy and terms of use that cover Function Code 43 MEI Type 13.