OIAC3

CANopen inclination sensors

User Reference Manual

Rev. H

10-02-2020

Date	Revision	Notes
08-02-2012	0	Preliminary
27-02-2012	A	Preliminary; Numeric Filter Chapter Integration
08-05-2012	B	System start-up time
06-02-2013	C	Single axis mode reset condition
21-01-2014	D	Cross Axis; Save All Frame; Data Order
05-02-2015	E	Updated firmware 2.x.y, measure revision
30-09-2015	F	Updated paragraph 3.4
01-03-2016	G	New commercial codes
11-02-2020	H	Minor bugs corrections, different versions added

Table 1 – User manual revisions

INDEX

A general knowledge of CAN bus based systems and CANopen protocol is suggested for a proper understanding of this manual. All the numbers reported in the present manual are expressed in decimal format. Hexadecimal values are reported with a final “h” symbol in order to indicate the different format.

This document is subject to change without notice. No claims can be made from the details, illustration and descriptions in this document.

1. Technical information

1.1. Main Features and applications

- **1D inclination sensor with measurement range 0-360deg**
- **2D inclination sensor with measurement range up to ±60deg**
- **High Resolution: up to 0.001 deg**
- **Very fast sampling rate: up to 550 S/s**
- **2nd order analog filter with 20Hz cut frequency**
- **Anti-Vibration flexible programmable filter**
- **Wide (7-40V) power supply range**
- **CANopen interface**
  - **CiA DS-301, device profile 410**
  - **Programmable baud rate from 10kbps to 1Mbps**
  - **One TPDO object**
    - **RTR frame based transmission**
    - **Cyclic transmission**
    - **Event-controlled transmission**
    - **Synchronized transmission**
  - **SYNC Consumer**
  - **EMCY Producer**
  - **Failure monitoring via Heartbeat or Nodeguarding/Lifeguarding**
- **Very Easy Programming via CAN frames without additional tools**
- **IP67 protection class and industrial temperature range**
- **Factory Calibrated**
- **Several options on request:**
  - **reduced temperature drift**
  - **connector style**

- **Applications:**
  - **Construction equipment**
  - **Aerial work platforms**
  - **Solar farms**
  - **Agricultural and forestry machines**
  - **Drilling and piling equipment**

1.2. Mechanical dimensions, pin description and wiring scheme

All the dimensions below are reported in millimetres.

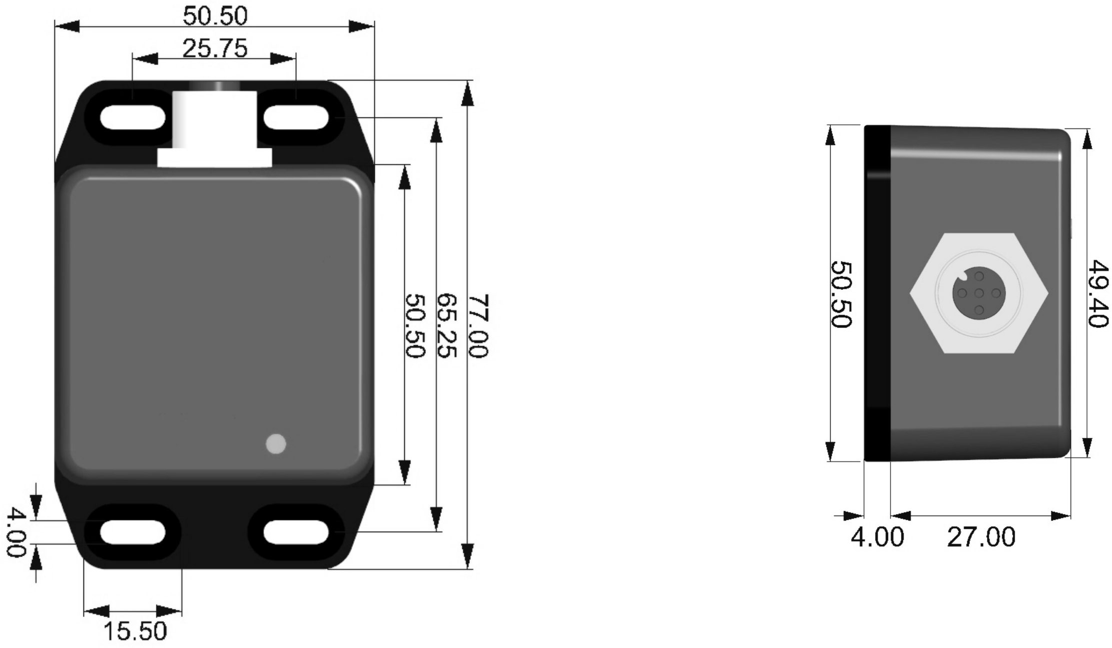


Figure 1 - OIAC3 mechanical dimensions

OIAC3 sensor is available as standard version with M12 male/plug connector, but it is also available with AT04-4P Amphenol connector or with cable.

Figure 2 – OIAC3 standard M12 5 poles connector and Amphenol ATM04-4P

M12 connector	ATM connector	Cable color	Name	Function
1	-	Cable shield if	**SHIELD**	Optional CAN shield (N.C.)
2	4	White	**VCC**	Power Supply
3	1	Blue	**GND**	Power Ground
4	2	Brown	**Data AH**	CAN_H bus line (dominant high)
5	3	Green	**Data BL**	CAN_L bus line (dominant low)

Table 2 – Pin description

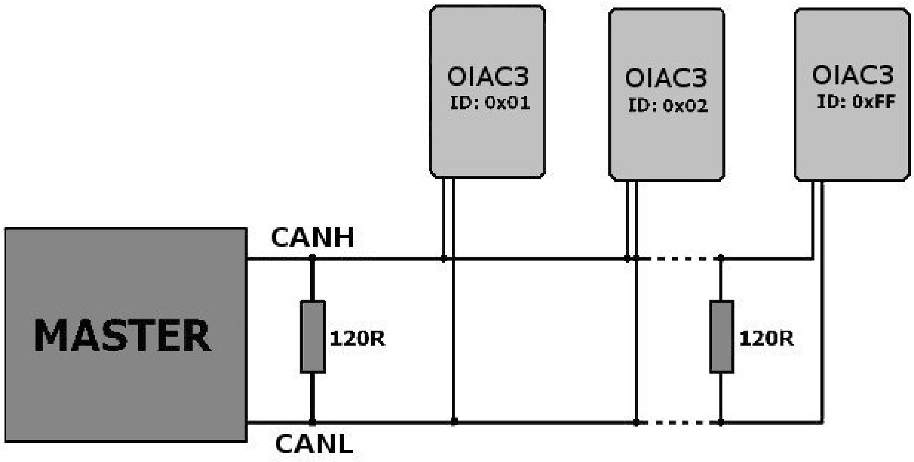


Figure 3 - OIAC3 wiring scheme

OIAC3 has no internal bus line terminator resistor: the user must connect a 120Ω-terminator at the beginning and at the end of the CAN bus.

1.3. Axes definition

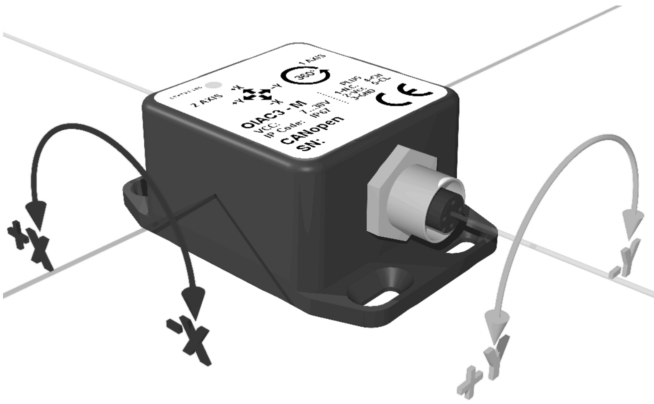


Figure 4 – Dual-axis mode up to +/-60deg

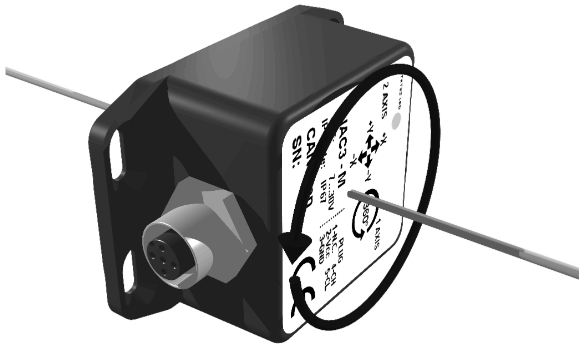
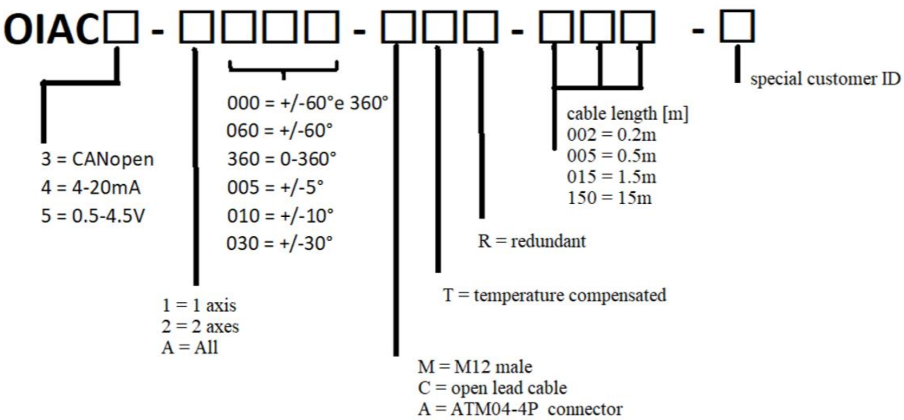


Figure 5 – Single-axis mode 0-360deg

Zero degrees on single-axis mode are obtained by keeping the connector on the left, as shown in fig. 5.

1.4. Ordering information



2. Introduction to CANopen

CANopen is the internationally standardized (EN 50325-4) CAN-based higher-layer protocol for embedded control systems. The set of CANopen specifications comprises the application layer and communication profile as well as application, device and interface profiles. OIAC3 has been CANopen certified by CiA GmbH.

2.1. CANopen certification

Certificate # **CiA201502-301V42/30-0190**

Vendor ID **00 00 03 C4**

Manufacturer Optoelettronica Italia S.r.l.

Device OIAC3

Product code: Object 1018h/02h	0041 4333h	Revision number: Object 1018h/03h	0000 0041h
Hardware version: Object 1009h	-	Software version: Object 100Ah	V.2.0.0

EDS P10.013.265.A EDS 1 axis.eds;

File version:	1	File revision:	1
EDS version:	4.0		

Nuremberg, 02.02.2015

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2.2. CiA 301 v.4.2.0 and Cia 410 specifications

OIAC3 is compliant with CiA v.4.2.0, that specifies the CANopen application layer and communication profile. This specification includes the data types, encoding rules and dictionary objects as well as the CANopen communication services network management (services and protocols). It also specifies the CANopen communication profile, e.g. the physical layer, the predefined communication object identifier connection set, and the content of the Emergency, Timestamp, and Sync communication objects.
OIAC3 is thus fully compliant with the specification given by the CiA 410 device profile for single and double-axis inclination sensors with 16-bit resolution.

2.3. COB identifiers and communication objects

CANopen communications occur via CAN-frames. A CAN-frame or Communication Object is a command sent to/ from the device. Its 11-bit identifier (called COB-ID) is divided in a 4-bit function code and 7-bit Node ID. At any hardware or software reset, COB IDs and the Node ID are loaded from the device objects dictionary (paragraph 3.1).

Message	Direction [2]	COB - ID	Object description
NMT	RX	00h	NMT services: operational, pre-operational, stop, reset
SYNC	RX	80h	Sync object
EMCY	TX	80h + Node ID	Emergency object
TPDO1	TX	180h + Node ID	Pitch, Roll and Internal Temperature
SDO (Client → Server)	RX	600h + Node ID	Access to object dictionary
SDO (Server → Client)	TX	580h + Node ID	Reply to SDO request
Boot Up \ Heartbeat	TX	700h + Node ID	Boot Up Heartbeat: sent periodically if configured

Table 3 - COB identifiers

The Node ID default value (also indicated as NID) is 0Ah.

2.4. Boot-up message

As OIAC3 is switched on, the boot-up procedure is initialized. OIAC3 sends a *boot-up message* with the following frame structure, according to CANopen DS301 v4.x:

COB-ID	Byte 0
700h + NID	00h

Table 4 –Boot-up message structure

[2] *Direction is considered from the point of view of OIAC3*

2.5. Network management objects (NMT)

As the initialization is completed, the device enters the Pre-operational state. The maximum time for a sensor initialization is 300ms. A malfunction may be caused if any data frame is sent before the end of the initialization: in this case an hardware reset of the sensor is necessary.
In order to start getting data, OIAC3 must be set in Operational state. The figure below shows the NMT state machine of a generic CANopen device.

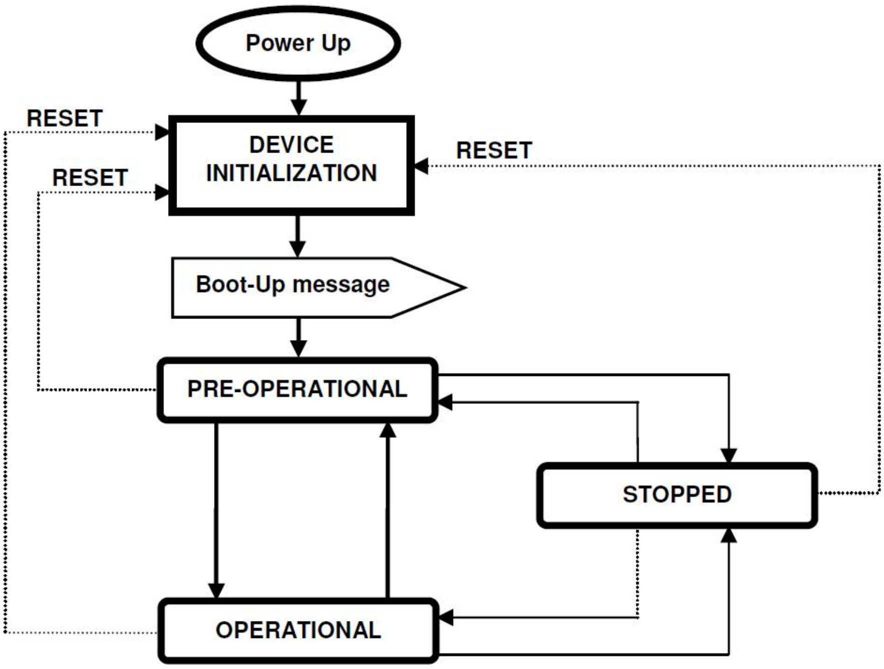

Figure 6 – NMT state machine

NMT commands are used to change the machine state (e.g. to start and stop devices), detect remote device boot-ups and error conditions. The NMT frame structure used for NMT commands is reported below:

COB ID	Byte0	Byte1
0000h	COMMAND CODE	00h (broadcast) or Node – ID (specific node)

Table 5 – NMT frame structure

Byte 0 must be replaced by one of the following command codes:

COMMAND CODE	Description
01h	Start remote node → Enter the node OPERATIONAL state
02h	Stop remote node → Enter the node STOP state
80h	Enter node PRE – OPERATIONAL state
81h	Reset Node
82h	Reset Communications

Table 6 – Command codes

NMT command frames can be broadcast to all network nodes or sent to a specific node. The address must be written at Byte 1: 00h for the broadcast transmission, Node ID for a specific node transmission.

2.6. Transmit Process Data Object (TPDO1) frame organization

The Process Data Object protocol is used to process real-time data and send information about actual inclinations on both axes. TPDO1 frame organization is reported below. TPDO1 frames have different structures depending on the operational mode. The frame structure for dual axis mode is reported below:

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0x180 + NID	Longitudinal inclination value (LSB first)		Lateral inclination value (LSB first)		Internal temperature of the device	Not used		

Table 7 - TPDO1 frame structure for dual axis mode

Received data are in hexadecimal format and must be converted depending on the set resolution, stored at index 6000h of the objects dictionary (reported in paragraph 3.1).

Measured inclination values are also stored into the objects dictionary according to CiA DSP-410: the longitudinal value (X axis) at index 6010h, the lateral value (Y axis) at index 6020h. The registers store the last measured angle values in a 2'complement fixed-point 16-bit-number. Together with inclination values, the device internal temperature (stored at address 5000h sub-index 00h) is transmitted as a 2's complement 8-bit number.

<u>Example:</u>

X-axis value at index 6010h is "F3B1h". For the 2's complement conversion, the number is equal to -3151d. The resolution stored at address 6000h and expressed in thousandths of degrees is 0Ah = 10d, that means resolution is of 0,01 degrees. The final actual angle is then calculated as -3151/100 = -31,51 degrees.

The frame structure for single axis mode is similar, but with only one field for the inclination value.

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
0x180 + NID	Inclination value (LSB first)		Internal temperature of the device	Not used				

Table 8 - TPDO1 frame structure for single axis mode

According to CiA DSP-410, the inclination value is mapped at index 6010h, that is the field used for X-axis in the dual axis mode. This register stores the last measured angle value in a 2's complement fixed-point 16-bit-number. Together with the inclination value, the device internal temperature is also transmitted as a 2's complement 8-bit number

3. How to configure OIAC3

3.1. Objects dictionary

The objects dictionary is the "identity card" of the device. It contains all the settings related to the device and communication procedures. The following paragraph shows its structure, where registers are organized in indexes, sub-indexes, descriptions, data type, access, default value and range.

Index	Sub Index	Parameter description	Data Type	Ac-cess	Default value	Range	Store
1000h	0	Device type (device profile 410, two axes)	UNS32	RO	2019Ah	2019Ah 1019Ah	
1001h	0	Error register	UNS8	RO	0		
1002h	0	Manufacturer error reg	UNS32	RO	0		
1003h	Pre defined error field						
	0	Number of errors	UNS32	RW	0		
	1	New error code [i]	UNS32	RO			
	2	Error code [i-1]	UNS32	RO			
	3	Error code [i-2]	UNS32	RO			
	4	Error code [i-3]	UNS32	RO			
	5	Oldest Error code [i-4]	UNS32	RO			
1005h	0	Sync COB-ID [4]	UNS32	RW	80h	1...2047	YES
100Ah	0	Manufacturer firmware version [5]	VSTR	const.	{device dep.}		
100Ch	0	Guard time [multiple of 1ms]	UNS16	RW	0	0...65535	YES
100Dh	0	Life time factor	UNS8	RW	0	0...255	YES
1010h	Save parameters						
	0	Largest supported sub-index	UNS32	RO	1		
	1	Save ALL parameters (value = 73617665h)	UNS32	RW	1		
1011h	Restore all parameters						
	0	Largest supported sub-index	UNS32	RO	1		
	1	Reload ALL DEFAULT parameters ("load" = 6C6F6164h)	UNS32	RW	1		
1014h	0	COB-ID Emergency object	UNS32	RO	80h+NID		
1015h	0	Inhibit time between two EMCY object trans-mission [multiple of 100us]	UNS16	RW	0	0...65535	YES
1017h	0	Producer Heartbeat interval time [multiple of 1ms, 0 = disabled]	UNS16	RW	0	0...65535	YES
1018h	Identity Object						
	0	Largest supported sub-index	UNS8	RO	4		
	1	Vendor ID	UNS32	RO	3C4h		
	2	Product code	UNS32	RO	414333h → "AC3"		
	3	Revision number	UNS32	RO	41H → "A"		
	4	Serial number	UNS32	RO	{device dep.}		
1200h	Server SDO1 parameters						
	0	Largest supported sub-index	UNS8	RO	2		
	1	COB-ID Client > Server	UNS32	RO	600h + NID		
	2	COB-ID Server > Client	UNS32	RO	580h + NID		

[4] *Follow the saving procedure at paragraph 3.2.3 to validate modifications*
[5] *Refer to segmented transfer CiA 301, paragraph 7.2.4.3*

1800h	Transmit PDO1 communication parameters						
	0	Largest supported sub-index	UNS8	RO	5		
	1	COB ID	UNS32	RO	180h + NID		
	2	Transmission type [synchronous, manufacturer specific]	UNS8	RW	FEh	0...240 or 253 or 254	YES
	3	Inhibit time between two TPDO object [multiple of 100us]	UNS16	RW	0	0...65535	YES
	4	Reserved	UNS8	RW	0		
	5	Event timer for cyclical transmission [multiple of 1ms, 0 = disabled]	UNS16	RW	0	0...65535	YES
1A00h	Transmit PDO1 mapping parameters (fixed mapping)						
	0	Largest supported sub-index	UNS8	RO	3		
	1	Inclination value X-axis parameters	UNS16	RO	60100010h		
	2	Inclination value Y-axis parameters [6]	UNS16	RO	60200010h		
	3	Device internal temperature [°C]	UNS16	RO	50000008h		
2000h	0	Node ID [7]	UNS8	RW	0Ah	1...127	YES
2001h	0	Baud Rate [kBit\s] [7]	UNS16	RW	500	10...1000	YES
3000h	0	Filtered samples [7]	UNS16	RW	1000	1...1000	YES
3001h	TPDO1 transmission on inclination change						
	0	Largest supported sub-index	UNS8	RO	3		
	1	Enable/Disable (1/0) TX on inclination change	UNS8	RW	0	1 or 0	YES
	2	Minimum inclination change for X axis	UNS16	RW	100	{res. dep.}	YES
	3	Minimum inclination change for Y axis [6]	UNS16	RW	100	{res. dep.}	YES
3002h	0	Single axis data format (0:[0;360]°; 1:±180°) [8]	UNS8	RW	0	1 or 0	YES
4000h	Pitch and Roll Value Range [6]						
	0	Largest supported sub-index	UNS8	RO	3		
	1	X range	UNS16	RW	30000	{res. dep.}	YES
	2	Yrange	UNS16	RW	30000	{res. dep.}	YES
	3	Enable/Disable (1/0) User Range	UNS8	RW	0	1 or 0	YES
4001h	0	Sensor operational mode 2 Axes/1 Axis [7] [9]	UNS8	RW	0	00h or AAh	YES
5000h	0	Device Internal temperature [°C] (2's compl.)	INT8	RO			
5001h	Surveillance of the device's internal temperature						
	0	Largest supported sub-index	UNS8	RO	3		
	1	Enable/Disable (1/0) temperature surveillance	UNS8	RW	0	1 or 0	YES
	2	Lower temperature limit [°C] (2's complement)	INT8	RW	-30	-55...+120	YES
	3	Upper temperature limit [°C] (2's complement)	INT8	RW	75	-55...+120	YES
5555h	Reserved for calibration and debug values						
5544h	Reserved for calibration and debug values						
6000h	0	Resolution [multiple of 0.001°]	UNS16	RO	1	1,10,100,1000	YES
6010h	0	Measured X axis value (2's complement)	INT16	RO		{type dep.}	
6011h	0	Inversion of X axis range	UNS8	RW	0	1 or 0	YES
6012h	0	X axis preset value (2's complement)	INT16	RW	0	{para. 3.12}	
6013h	0	X axis offset value (2's complement)	INT16	RW	0	{para. 3.12}	YES
6020h	0	Measured Y axis value (2's complement) [6]	INT16	RO		{type dep.}	
6021h	0	Inversion of Y axis range [6]	UNS8	RW	0	1 or 0	YES
6022h	0	Y axis preset value (2's complement) [6]	INT16	RW	0	{para. 3.13}	
6023h	0	Y axis offset value (2's complement) [6]	INT16	RW	0	{para. 3.13}	YES

[6] *Unavailable for OIAC3-1360 and single mode of measurement on OIAC3-A000*
[7] *Follow the saving procedure reported at paragraph 3.2.3 to validate modifications*
[8] *Unavailable for OIAC3-2060*
[9] *Unavailable for OIAC3-1360 and OIAC3-2060*

3.2. SDO commands

SDO commands (Service Data Objects) let the user read or modify the objects' dictionary registers. COB-IDs used for SDO commands are stored at index 1200h of the objects dictionary. OIAC3 firmware version 2.x.y supports the segmented data transfer, as explained by Cia 301 specification.
Due to its asynchronous functioning, SDO commands being too frequently used could affect the inclination measure.

3.2.1. How to read a register

SDO request frames let the user read data from the object dictionary. The frame structure is shown in the table below.

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
600h + NID	Data length	Index LOW	Index HIGH	Sub-Index	Not used			

Table 9 – SDO request data frame

Byte 0 contains the indication of data length as shown in the table below: at request "*any size length*" = 40h must be used to avoid request errors.

Data length	Value
Any size length	40h
1	4Fh
2	4Bh
4	43h
STRING	41h

Table 10 – Values for Byte 0 (SDO request frame)

OIAC3 answers with a *response SDO frame*, whose structure shown below is the same as the request frame. Byte 0 shows the actual length of data allocated from Byte 4 to Byte 7.

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
580h + NID	Data length	Index LOW	Index HIGH	Sub-Index	Read DATA (LSB to MSB)			

Table 11 – SDO response data frame

Example:

OIAC3-A000-M is the model that can be set either for a single-axis or double-axis measure. Let us check the set operational mode. The information to be read is contained at index 4001h, sub-index 00h. Please set the data length of the request frame to the generic value (40h), COB-ID is 600h+Node-ID (table 3). Node-ID is the default value 0Ah.
The resulting frame will be the following:

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4 … Byte 7
60Ah	40h	01h	40h	00h	-

Table 12 – Example of SDO request frame

The correct SDO response data frame will be the following:

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4 … Byte 7
58Ah	4Fh	01h	40h	00h	00h

Table 13 - Example of SDO response frame

COB-ID is 580h+Node-ID. Byte 0 = "4Fh" indicates that the frame contains 1 byte of data. Byte 1, 2 and 3 report index and sub-index. Data is equal to "00h", that means the sensor is set in 2-axis operational mode.

3.2.1. How to write into a register

SDO download request frames are used to write a certain parameter into the object dictionary. Object index and sub-index must be specified at Byte 1, 2 and 3. Data to write can be 1byte, 2byte, 3byte or 4byte long. The first byte (Byte 4 at Table 14) is the least significant byte. Firmware version 2.0.0 supports the segmented data transfer, as explained by Cia 301 specification.
The frame structure is shown in the table below.

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
600 + NID	Data length	Index LOW	Index HIGH	Sub-Index	DATA TO WRITE (LSB to MSB)			

Table 14 – SDO download request data frame

Byte 0 contains the data length indication, so the user must choose one of the values reported at Table 15:

Data length	Value
Any length	22h
1 byte	2Fh
2 bytes	2Bh
4 bytes	23h

Table 15 - Values for Byte 0 (SDO download request frame)

A *SDO download response frame* is sent by OIAC3 to confirm that the request has succeeded. The structure is shown in the table below.

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
580h + NID	60h	Index LOW	Index HIGH	Sub-Index	00h	00h	00h	00h

Table 16 - SDO download response frame

Example:

Let us set OIAC3-A000-M (Node-ID = 0Ah) in 2-axis mode and limit the X range to 10 degrees.

1. Send a SDO command to modify index 4001h, s.i. 00h, and write value 00h (2-axis mode).

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	01	40	00	00	-	-	-

In case of correct request, the following answer is received:

58A	60	01	40	00	00	00	00	00

2. Now set the X-measuring range at index 4000h. First enable the user range (s.i. 03h):

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	00	40	03	01	-	-	-

In case of correct request, the following answer is received:

58A	60	00	40	03	00	00	00	00

3. Set the X-range to 10 degrees: pay attention that the value depends on the actual resolution. For a resolution of 0.01 degrees (index 6000h, s.i. 0, value = 10 = Ah), the value to write is 1000= 3E8h.

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	00	40	01	E8	3	-	-

In case of correct request, the following answer is received:

58A	60	00	40	01	00	00	00	00

4. To validate modifications, save the set parameters into the EEPROM as explained in paragraph 3.2.3 and reset the device.

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	10	10	01	73	61	76	65

3.2.2. SDO abort codes

If a SDO request or a *SDO download request frame* fails, OIAC3 answers with a *SDO abort message* reporting the error sources. The SDO abort frame structure is reported below.

COB ID	Byte0	Byte1	Byte2	Byte3	Byte4	Byte5	Byte6	Byte7
580h + NID	80h	Index LOW	Index HIGH	Sub-Index	SDO abort code (LSB to MSB)			

Table 17 - SDO abort frame

The transmitted data are one of the error codes reported in the following table.

SDO abort code	Bytes 4…7	Type of failure
0504 0001h	01h; 00h; 04h; 05h	SDO command not valid or unknown
0601 0002h	02h; 00h; 01h; 06h	Attempt to write a read-only object
0602 0000h	00h; 00h; 02h; 06h	Object does not exist in the object dictionary
0604 0043h	43h; 00h; 04h; 06h	General incompatibility reason
0607 0010h	10h; 00h; 07h; 06h	Data type does not match, length of service does not match
0609 0011h	11h; 00h; 09h; 06h	Sub-index does not exist
0609 0030h	30h; 00h; 09h; 06h	Parameter invalid value (download only)
0609 0031h	31h; 00h; 09h; 06h	Value of written parameter too high
0609 0032h	32h; 00h; 09h; 06h	Value of written parameter too low
0800 0000h	00h; 00h; 00h; 08h	General Error
0800 0020h	20h; 00h; 00h; 08h	Data cannot be transferred or stored to/in the application
0800 0024h	24h; 00h; 00h; 08h	No data available

Table 18 – SDO error codes

3.2.3. SAVE ALL procedure (1010h) and reset commands

As a register of the objects dictionary is modified, a *SAVE ALL* procedure is needed to store data into the non-volatile memory (EEPROM). The word "save" must be written into index 1010h, sub-index 01h from the least significant byte to the most (the resulting word is "73617665h"). Modifications are thus valid only after a hardware or software reset of the device.
The software resets reported in paragraph 2.5 are the following:

- Node reset (NMT command code 81h): such command resets the whole node and it is recommended for every saving procedure.
- Communication reset (NMT command code 82h): only the communication parameters are reset, so objects related to transmission and measure settings are not reset.

3.2.4. Restoring all parameters (1011h)

The default configuration of the objects dictionary can be restored by writing the word “LOAD” in ASCII format (=”6C6F6164h”) in the *Restore all parameters* object at index 1011h sub-index 01h. Node-ID (2000h), Baud rate (2001h) and Sensor operational mode (4001h) will not be affected by this command, as they must be changed manually.

3.3. Node ID (2000h) and supported Baud Rates (2001h)

Every change applied to the Node ID (index 2000h s.i. 00h) and to the Baud rate (index 2001h s.i. 00h) is effective only after the *SAVE ALL* procedure (see paragraph 3.2.3) and the node reset. After the reset, the COB IDs are recomputed according to the pre-defined connection set objects. Node ID and Baud rate default values are reported in the table below.

Default Node ID	0x0A
Default Baud Rate	500 kbit\s

Table 19 - Node ID and baud rate default values

OIAC3 is designed to support different CAN baud rates, referring to the CANopen Draft Standard 301. The supported baud rates are reported in the following table. The exact value must be written in hexadecimal format into index 2001h, sub-index 0h.

Supported Baud Rates (kbit/s)	10[10]	20	50	125	250	500	800	1000

Table 20 - Supported baud rates

NODE ID and Baud rate are not restored by the *Restore all parameters* command set at index 1011h, and they have to be changed manually.

3.4. Sensor operational mode (4001h) and device type (1000h)

OIAC3-A000 version can be configured for 1 or 2 axis operational mode by modifying the register at index 4001h sub-index 00h. OIAC3-1360 and OIAC3-2060 have fixed operational mode, respectively 1 and 2 axis mode.

OIAC3-A000 and OIAC3-1360 are at zero degrees as the connector is kept on the left (Table 21).

			
0/360 deg	**90 deg**	**180 deg**	**270 deg**

Table 21 – OIAC3 positions for single axis measurements

In dual-axis mode (OIAC3-A000 and OIAC3-2060), please follow the arrows indicated on the top of the device: by lowering the inclinometer along a specific arrow, the measured value increases following the signs indicated on the label. The example below reports the procedure to switch from 2 to 1 axis mode.

[10] *Check that your CAN bus supports a baud rate = 10kbps before setting it on the OIAC3.*

Example:

1. Write the value “AAh” into index 4001h sub-index 00h.
2. Send a “SAVE ALL” SDO command
3. Reset the device.

Only after resetting the OIAC3, the device type object value (address 1000h s.i. 00h) changes from 2019Ah (2 axes with max resolution of 16 bit) to 1019Ah (1 axis with max resolution of 16 bit) according to CiA device profile for inclinometers (CiA410).

When set for single axis mode, all the objects related to the Y-axis are disabled and cannot be accessed for reading or writing procedures, otherwise a *SDO abort command* is received (0602 0000h).

The command 4001h is deactivated for OIAC3-1360 and OIAC3-2060 versions.

3.5. TPDO1 transmission type (1800h)

OIAC3 implements different types of transmission, which can be set at index 1800h, sub-index 02h. Values from 0d to 240d (0h to F0h) are used for synchronous transmissions, 253d for the RTR transmission, and 254d for asynchronous types.

3.5.1. Synchronous transmissions and SYNC frames

The synchronous transmission occurs through SYNC frames, that are sent by the master with the frame structure reported in Table 22.

COB ID
Sync COB-ID object

Table 22 - SYNC frame structure

The default value of the Sync COB-ID object is “80h” and it is stored at index 1005h, s.i. 0h of the objects dictionary. When more than one sensor are connected to the CAN bus, each sensor must have a different Sync COB-ID to correctly synchronize the communication. Available values for Sync COB-ID objects are in the range [1;2047]d: low values are suggested in order to assign a higher priority to the message on the bus. If different devices have the same Sync COB-ID object, the SDO abort code 0609 0030h will be received. After any modification, the SAVE ALL procedure is required for validation.

Besides the COB-ID definition, the transmission must be programmed at index 1800h, sub-index 02h. The stored value (from 1 to 240d) is the number of SYNC frames that are received by OIAC3 before answering with the TPDO1 frame.

Example:

Consider that one of the OIAC3 connected to the bus have a Sync COB-ID object = “2Bh” and the transmission type is set to “5h”. This means that the master must send the frame “2Bh” 5 times, in order to get the TPDO1 frame from the specific OIAC3.

The transmission type can be set to 0d for an *acyclic synchronous transmission*. This configuration makes the OIAC3 send the TPDO1 frame only after an event occurrence (e.g. event timer, transmission on inclination change, etc.) and the SYNC frame.

Example:

Consider the following time line: T0: Event T1: SYNC frame T2: TPDO1 transmission →

T0, T1 and T2 are progressive instants. Only after an event occurrence and the reception of a SYNC frame, the TPDO1 frame will be transmitted.

3.5.2. RTR: Remote Transmit Request

RTR is a request that the NMT master performs directly to a specific CANbus node. OIAC3 implements RTRs for TPDO1 transmissions and Lifeguarding/Nodeguarding (see paragraph 5.2).
Upon reception of a RTRand, if it is in operational mode the OIAC3 answers with the object requested by the RTR COB-ID. In case of a TPDO1 request, the COB-ID that is sent by the master is the following:

COB ID
180+Node ID

Table 23 – RTR frame structure for a TPDO1 transmission

RTR can be sent at any time by the master: OIAC3 will answer even if other transmission types are set. In order to make the OIAC3 answer only to RTRs, index 1800h, sub-index 2 must be set to 253d.
RTRs are the less recommended type of transmission in a CAN network.

3.5.3. Asynchronous transmissions

Asynchronous transmissions are triggered by an event occurrence, i.e. an inclination change or an event timer. This type of transmission is set by writing 254h (=FEh) into index 1800h, s.i. 02h.

3.5.3.1. Transmission on inclination change (3001h)

The transmission on inclination change is enabled by setting the value at index 3001h, s.i. 01h to “01h”. TPDO1 is transmitted as the inclination changes of at least the value stored into registers 3001h s.i. 02h for X axis and s.i. 03h for Y axis, depending on the resolution indicated at index 6000h, s.i. 00h. TPDO1 transmission on inclination change occurs only if the node is in operational state. In order to prevent CAN bus flooding, the inhibit timer is suggested to be activated and the event timer deactivated.

Example:
If resolution is set to 1 degree (value =1000d =3E8h) and the minimum inclination value at index 3001h, s.i. 02h is set to “07h”, TPDO1s are transmitted every time the inclination on X axis changes by more than 7 degrees.

Transmission on inclination change is also active for single axis [0-360deg] mode. In this case only the sub-index value for X-axis is active, while the respective for the Y-axis is disabled. The maximum available resolution for the single axis mode is hundredths of degree. As the resolution is modified, the transmission is deactivated in order to prevent bus overflows, and must be reactivated at the end of the resolution setting.

Example:
Resolution is set to 1 degree. Minimum inclination change for X axis is set to “0Ah”. So TPDO1s are transmitted only at changes greater than 10 degrees. Let us modify the resolution to 0.001 degrees. If the TPDO1 hadn’t been automatically deactivated, transmissions at changes of 0.01 degrees would have happened, leading to the CAN bus overflow. To prevent CAN bus overflows, the setting of inhibit timer is suggested (see paragraph 3.5.4).

3.5.3.2. Transmission on event timer

A TPDO1 can be temporally forced by an event timer and transmitted whether the measured inclination changes or not. The value stored at address 1800h sub-index 05h represents the period between two TPDO1 transmissions, values are in the range [1;65535] ms, with the fixed resolution of 1ms. Default time is 0ms, which means that the timer is deactivated and TPDO1 is transmitted only at inclination changes. A minimum value of 50ms is suggested in order to get correct data (please note that OIAC3 has an internal hardware low-pass filter with cut-frequency = 20Hz).

3.5.4. Inhibit timer

In order to prevent CAN bus flooding due to continuous frequent transmissions, an inhibit timer can be set. The inhibit timer is configured at index 1800h, s.i. 03h of the objects dictionary. Available values are multiple of 100us in the range [0 ; 65535]. The value indicates the period during which no TPDO1 will be transmitted. The default value is “0”.
The inhibit timer setting can be done only if TPDO1 transmission is deactivated, by writing “8000 0180h + Node ID” (CiA 301 specifies that Bit31 of the COB-ID must be set to “1”) into index 1800h, s.i. 01h. As the inhibit timer is set, the TPDO1 transmission can be re-activated.
If transmission on inclination change is used, an inhibit timer greater than 0ms is suggested in order to prevent CAN bus saturations.

3.6. Transmit PDO1 mapping parameters (1A00h)

Registers at index 1A00h store the mapping parameters of the TPDO1s.
The default value at sub-index 1, referred to the TPDO1 of X-axis, is “60100010h”:

- The first part refers to the register index where the last measured value on X-axis is stored (6010h);
- The second part is the value resolution stored at index 6000h, s.i. 00h.

The mapping parameters for Y-axis are stored into sub-index 02h and have the same structure of sub-index 01h.

3.7. Programmable digital filter – 3000h

When the environment is vibrating, noise reduction is necessary in order to get stable measure and correct data. OIAC3 features two filters that reduce the environmental noise effects: the first is an active 2^{nd} order analog filter, with a cut-off frequency of 20Hz (fixed by hardware layout), the second is a software filter, that implements a moving average on acquired data.
The average is programmable by the user, who can set the number of averaged samples at index 3000h, sub-index 00h. The default value (03E8h) corresponds to the maximum number (1000 samples). If set to 01h, the filter is deactivated. The value is valid both for one axis and two axis mode. The *SAVE ALL* procedure is necessary to validate modifications.

The optimal number of samples to be averaged depends on the application and is a trade-off between measure stability and sensor response time: the higher the number of averaged samples, the lower the response time, but the measure is more stable.

The filter frequency response is strictly related to the number of averaged samples and the sample rate, which is fixed to 550 samples per second. Sample rate is guaranteed in normal run conditions, when transmission commands (TPDO1) and SAVE ALL commands are not too frequent.

The formula of filter frequency response is reported below.

$$H[f] = \frac{\sin(\pi \times f \times M)}{M \times \sin(\pi \times f)}$$

Figure 7 - Filter frequency response

The plot of the filter frequency response is a sync graph in the normalized frequency domain (see figure below).

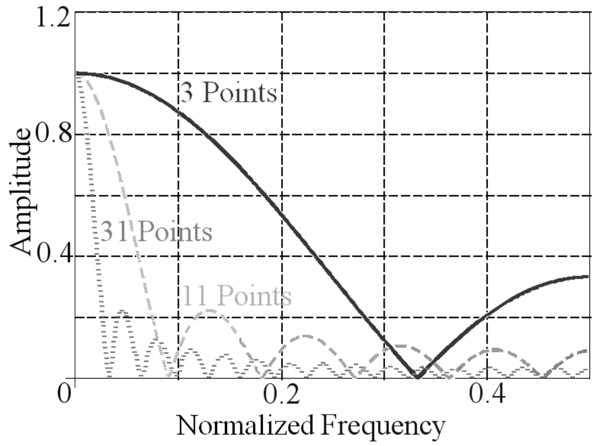

Figure 8 - Software filter response in frequency domain

The normalized frequency domain runs from 0 to 0.5 rad/sample. For a normalized frequency of 0 rad/sample, the frequency response H[f] is equal to 1. To convert a specific vibration/noise frequency (expressed in Hz) into a normalized frequency, the formula reported below is used:

$$f_{NORM} = \frac{f\left[\frac{cycles}{\sec}\right]}{S_R\left[\frac{Samples}{\sec}\right]} = \left[\frac{cycles}{Samples}\right] = \left[\frac{radians}{Samples}\right]$$

$f\left[\frac{cycles}{\sec}\right]$	→	Noise frequency expressed in Hz
$S_R\left[\frac{Samples}{\sec}\right]$	→	Sampling rate (constant at 550 samples/s for OIAC3)
$f_{NORM}\left[\frac{cycles}{samples}\right]$	→	Normalized frequency

The filter frequency response can be plotted for different numbers of filtered samples.

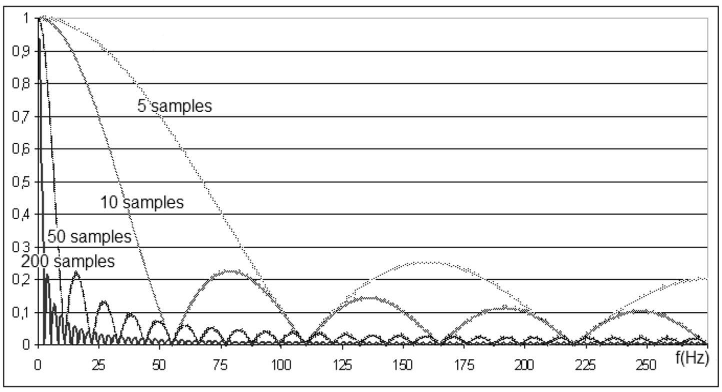

Figure 9 - Filter frequency response with different numbers of filtered samples

In Figure 9, the Y-axis indicates the response gain, while the X-axis the frequency in Hz. Different noise frequencies can be cut by correctly choosing a specific number of samples. The number of filtered samples must be set as a trade-off between response stability and response time. The higher the filter, the shorter the time to wait for a correct measure. The graph below reports the response time, calculated as 5τ, versus the number of filtered samples.

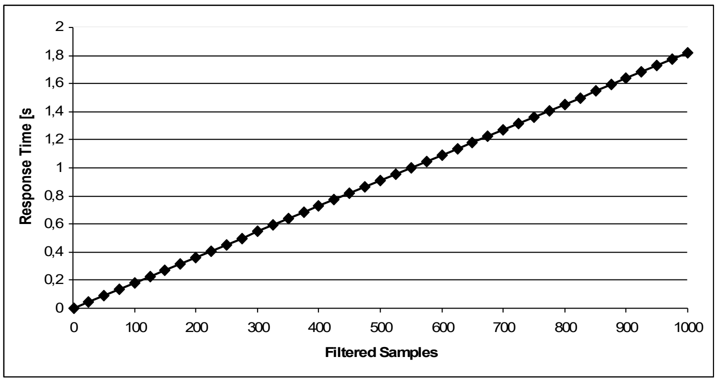

Figure 10 - Response time vs filtered samples

The response time (or damping time) is the ratio between the number of averaged samples and the sampling time. The sampling time is the inverse ratio of the sampling rate.

$\#samples = \frac{Td}{Ts}$, where Td is the damping time and Ts is the sampling time (fixed at 1.82ms)

In relation to the graph reported in Figure 10, if a damping time of 1 second is required, the number of average samples to be set is: 1000/1.82 = 549 samples. The graph below shows the step response in the time domain.

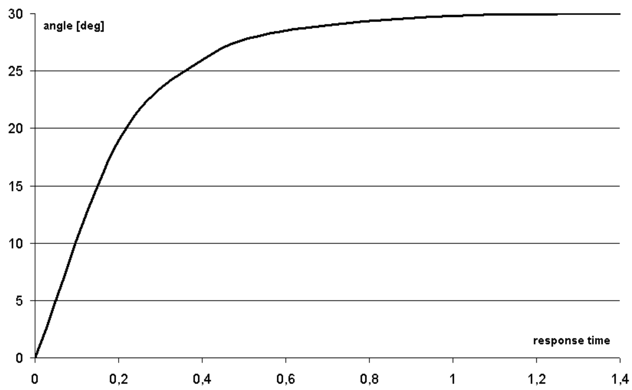

Figure 11 - Step response in time domain with 550 samples filter

Example:

The following example shows a simple procedure to set the filter properly, depending on the final application.

1. Selection of the maximum number of filtered samples. Supposing that 50ms is the maximum acceptable response time, the maximum number of samples is equal to 50ms/1.82ms = 27 samples. The filter must be set to less than 27 samples.
2. Now let us suppose that the main noise frequency due to vibration is 50Hz. At this frequency the characteristic H[f] is null for multiples of 11 samples. Following the condition found at point 1, quantities of 11 or 22 samples are suggested: the user can choose for a better response time (with 11 samples) or a better band-pass filter (22 samples).
3. Some practical tests and a comparison to check the theoretical calculations are recommended.

3.8. Single axis data format – 3002h

The feature is valid only for OIAC3-A000 and OIAC3-1360 models, as it allows the user to set the single axis data format. If set to “0”, data transmitted via TPDO1 and stored into index 6010h are in the range 0…360deg. If set to “1”, the range goes from -180deg to +180deg.

Example:

Let us consider the OIAC3-1360 with a 0.01deg resolution. The register at index 3002h is set to "0" and the value transmitted by the TPDO1 is 80E0h = 32992, that means 329,92 deg; in relation to the range 0…360deg, it means a negative inclination of about 30deg. Set the index 3002h to value "1" and save all data. After the reset the value transmitted by the TPDO1 is F440h = -3008d that means -30,08 deg.

3.9. Pitch and Roll Value Range in dual axis mode – 4000h

The feature is valid only for dual-mode of measurement on OIAC3-A000 and model OIAC3-2060. Registers at index 4000h allow the user to fix the operative ranges for X and Y axes. The values stored into sub-indexes 01h and 02h are unsigned and their resolution is stored at index 6000h. The feature works only for the dual-axis operational mode and can be enabled at sub-index 03h (write the value 01h). When one of the two set thresholds are exceeded, an *EMCY frame* relative to the axis affected by the error is sent. If disabled, X and Y range values are kept equal to the absolute operative range of ±60deg.

User-defined ranges are considered symmetric to the sensor relative zero that is obtained by adding the offset value to the absolute zero. The ranges summed to the relative zero (initial offset) must be lower than the sensor absolute operative range (±60deg): if the measured angle value is greater than +60deg or smaller than -60deg, it is automatically clipped (see example below).

Example:

- Set offset for X axis (object 6013h) = -45deg
- Set offset for Y axis (object 6023h) = +15deg
- Set range for X axis = ±30deg
- Set range for Y axis = ±15deg

In this case the X-axis relative zero is equal to the +45deg absolute angle. In order to avoid *EMCY frames*, the inclination on X axis must be in the range:

X MAX = [60deg - 45deg] = +15deg (+60deg absolute angle)

X MIN = - 30deg (+15deg absolute angle)

The maximum measurable value on X-axis is +15deg instead of +30deg because of the actual sensor absolute operative range.

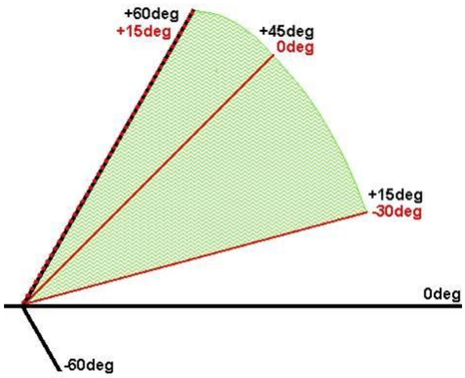

Figure 12 – Graph that describes example 9: values in red refer to X axis, values in black to Y axis

The Y-axis relative zero is equal to the -15deg absolute Y angle. In order to avoid *EMCY frames*, the inclination on Y axis must be in the range:

Y MAX = +15deg (0deg absolute angle)

Y MIN = - 15deg (-30deg absolute angle)

X-axis range is asymmetric to the measured zero while Y-axis range is symmetric, as it is included in the absolute range of ±60deg. Pitch and roll ranges depend on the resolution set at index 6000h: if greater than 0.001deg, ranges can be specified from +/-5deg up to +/-60deg. If the resolution is set to 0.001deg, ranges can only be specified up to +/-30deg.

The mentioned feature can even be exploited in order to use the OIAC3 as an "*ON/OFF*" device: if the event timer is deactivated (index 1800h, s.i. 05h, value=0h) and the device is set in operational mode, the CAN master will only receive EMCY frames at any thresholds exceeding.

3.10. Internal temperature (5000h) and surveillance (5001h)

The device internal temperature is transmitted by the TPDO1 as information on node operational condition. It is also stored at dictionary index 5000h sub-index 00h.

A surveillance of the device internal temperature can be enabled at index 5001h sub-index 01h (value = 01h to enable, value = 00h to disable). The lower and upper temperature thresholds are written into the sub-indexes 02h and 03h in 2's complement 8-bit numbers. Resolution is units of Celsius degrees. As the internal temperature goes out of the set range, an *EMCY frame* is transmitted and the three error registers are thus updated. The control on the internal temperature is done every second. Note that the two thresholds can go from -55°C to +120°C but the maximum operating range of the sensor is between -40°C and +85°C. Default values are -30°C and 75°C.

3.11. Resolution Object (6000h)

The resolution is set at index 6000h sub-index 00h and is expressed in thousandths of degree. Available values are:

Resolution		Object 6000h sub-index 00h value	
Entire degree	[1deg]	1000d	03E8h
Tenths of degree	[1deg / 10]	100d	0064h
Cents of degree	[1deg / 100]	10d	000Ah
Thousandths of degree	[1deg / 1000]	1d	0001h

Table 24 - Available resolutions

Angle data are 16-bit numbers in 2's complement format that limit the measurable range to ±30 degrees as the resolution of thousandths of degree is selected. The whole angle range of ±60 degrees is instead measurable with the other three configurations. Default resolution is thousandths of degree.

3.12. Measured X axis value, angle inversion, X axis preset and offset values (6010h – 6011h – 6012h – 6013h)

3.12.1. Dual-axis mode

The measured value for X-axis angle is written at index 6010h sub-index 00h. Value format is a 2's complement 16-bit number and depends on the stored resolution. Value sign can be inverted by writing 01h into the object 6011h sub-index 00h.

The object at address 6013h, sub-index 00h represents the **offset** value for X axis: it is a 2's complement 16-bit number that is added to the absolute measured angle to get the relative angle stored as *Measured X value*:

$$\text{Measured X angle}_{\ 6010h} = X_{\text{ACQUIRED ABSOLUTE ANGLE}} + \text{X Offset}_{\ 6013h}$$

The offset can be directly set through a SDO command. It is also automatically modified when the preset value is set. The **preset** value is meant as the measured angle to be obtained at a specific inclination. Value format is a 2's complement 16-bit number stored at index 6012h s.i. 00h (for X axis). The preset value is subtracted to the absolute measured angle and the result stored as offset value into index 6013h.

Example:

Let us consider the inclination of +13deg on X-axis. In order to set the zero at +7deg, it is necessary to indicate to the sensor the new inclination to read. So a preset value of +6deg must be set.

The preset value can even be used as **auto-zero command**: if the value is set to 00h, the measured X-axis value becomes 00h and the offset is updated with the difference between the preset value (00h) and the actual inclination.

It is strongly recommended to clear the offset value stored at address 6013h before setting a preset value, otherwise problems on the offset computation may occur.

3.12.2. Single-axis mode

In single-axis mode the inclinometer stores the data into the registers relative to the X-axis at indexes 6010h, 6012h and 6013h, as explained in the paragraph above.

The inversion object at index 6011h behaves depending on the data format set at index 3002h. If the measure range is [-

180;180] deg, the inversion mode behaves as explained in the previous paragraph. Otherwise, if the range is [0;360] deg, the sign inversion inverts the sense of rotation with respect to the X axis, as shown in Table 25.

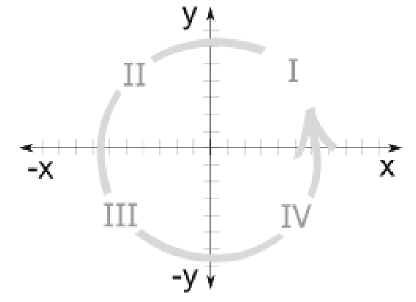	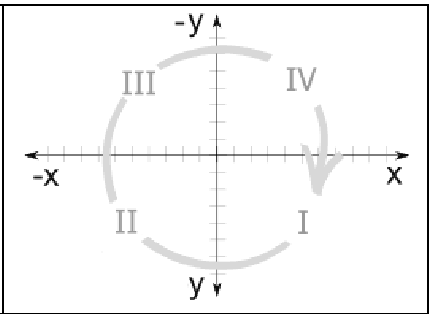
Angle inversion disabled	**Angle inversion enabled**

Table 25 - Single axis mode inversion

Example:
Let us suppose that we read an inclination of 35deg. The value at index 3002h is 00h (so the range is [0;360]deg). Enable the inversion of X axis by writing 01h into index 6011h, s.i. 00h. The new read inclination is now 325deg.

3.13. Measured Y axis value, angle inversion, Y axis preset and offset values (6020h – 6021h – 6022h – 6023h)

The measured value for Y-axis angle is written at index 6020h sub-index 00h. Value format is a 2's complement 16-bit number and depends on the stored resolution. Value sign can be inverted by writing 01h into the object 6021h sub-index 00h.
The object at address 6023h, sub-index 00h represents the **offset** value for Y axis: it is a 2's complement 16-bit number that is added to the absolute measured angle to get the relative angle stored as *Measured Y value*:

$$\text{Measured Y angle}_{6020h} = Y_{\text{ACQUIRED ABSOLUTE ANGLE}} + \text{Y Offset}_{6023h}$$

The offset can be directly set through a SDO command. It is also automatically modified when the preset value is set. The **preset** value is meant as the measured angle to be obtained at a specific inclination. Value format is a 2's complement 16-bit number stored at index 6022h s.i. 00h (for Y axis). The preset value is subtracted to the absolute measured angle and the result stored as offset value into index 6023h.

The preset value can even be used as **auto-zero command**: if the value is set to 00h, the measured Y-axis value becomes 00h and the offset is updated with the difference between the preset value (00h) and the actual inclination.
It is strongly recommended to clear the offset value stored at address 6023h before setting a preset value, otherwise problems on the offset computation may occur.

The mentioned registers are disabled for the single axis mode of measurement.

4. Errors

CANopen manages error conditions through the transmission of Emergency frames and the update of specific registers in the objects dictionary.

4.1. Error register (1001h)

As an error occurs, the error register at index 1001h (1-byte long) is updated. Each bit in the register is associated with a specific error, concerning working conditions, communications or internal status. The register is accessible only for reading: depending on the error source, one of the bits of the error register is set to "1".

The bit scheme below shows the error register format:

ERROR REGISTER FIELD STRUCTURE							
Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Hardware Error	Not Used	Profile Specific Error	Communication Error	Temperature Error	Not Used		At least one active error

Table 26 - Error register format

The 8 bits are activated at the following conditions:

- Bit0: everytime an error condition occurs.
- Bit3: as the temperature exceeds one of the thresholds stored at registers 5001h.
- Bit4: as a communication error occurs and the Communication Error Field is modified (see the paragraph below).
- Bit5: as it exceeds either the user-defined range stored at register 4000h or the absolute sensor range.
- Bit7: as an hardware error occurs either on the EEPROM CRC32 control or on the sensor self-test procedures performed at any device reset.

4.2. Manufacturer error register (1002h)

The manufacturer error register shows the recent state of all detectable errors. It reports information about the communication and the device functioning. Each bit refers to a specific error that is active if set to "1". The last 16 bits are also sent in the manufacturer specific part of the EMCY object shown at paragraph 4.4. The manufacturer error register structure is shown in the table below:

MANUFACTURER ERROR REGISTER FIELD STRUCTURE																
Bit31…Bit16	Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
Not Used	**Communication Error Field**								**Device Error Field**							

Communication Error Field							
Bit15	Bit14	Bit13	Bit12	Bit11	Bit10	Bit9	Bit8
Guarding Error	Not Used				Receive queue overrun	CAN BUS-OFF state reached	CAN WARNING limit reached

Device Error Field							
Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
HW error (sensor self test)	Not used		CRC32 memory error	Temperature error	Sensor Error Y - Axis	Sensor Error X - Axis	Not used

Table 27 – Structure of the manufacturer error register

Example:

If the sensor position exceeds the longitudinal or lateral inclination threshold stored in the object dictionary at index

4000h (see paragraph 3.9), Bit1 or Bit2 is set to 1 depending on the affected axis.

4.3. Pre-Defined error field (1003h)

The pre-defined error field at index 1003h stores the last 5 occurred error conditions. Sub-index 00h counts the number of occurred errors, which are chronologically stored into the consecutive objects: the latest at sub-index 01h, the oldest at sub-index 05h. As a new error condition occurs and the register is full, the oldest error condition is deleted and the new error enters at sub-index 01h. The pre-defined error field has the structure reported in the table below.

PRE-DEFINED ERROR FIELD STRUCTURE		
Bit31…Bit16 Additional Information Field		Bit15…Bit0
Communication Error Field	Device Error Field	Error Code (see Table 29)

Table 28 - Pre-defined error field structure

The 16 most significant bits are the Communication and Device Error fields of the manufacturer error register. The 16 least significant bits represent an error code with the following descriptions:

Error Code	Error description
0000h	Error reset or no more error present
1030h	Generic error
4200h	Device temperature error
5000h	Self-test error or CRC memory error
5010h	Sensor error on X axis
5020h	Sensor error on Y axis
8110h	Receive\Transmit buffer overflow
8120h	CAN warning limit reached
8130h	Node guard event occurred
8140h	Recover from Bus-off

Table 29 - Pre-defined error codes

4.4. Emergency frames (EMCY)

As any kind of error occurs, an emergency message (*EMCY frame*) is triggered and sent with high priority to the bus. When the emergency situation is recovered, an *Error reset* message is sent by the device.
As shown in Table 30, EMCY frames are structured with the COB-ID = 80h (specified at index 1014h) + Node ID, followed by the Emergency object that contains all the information related to the occurred error. The frame organization is shown in the table below.

	Emergency Object							
COB-ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
80h+NID	Emergency error code		Error register	Manufacturer specific error field				
				Communication error	Device error	00h	00h	00h

Table 30 - Emergency object frame structure

Register at index 1015h allows the user to set an inhibit time between two consecutive EMCY frames. In the set period, the client will not receive any EMCY frame. Bus overflow is thus limited when the device works close to error conditions. The 16-bit value is expressed in multiple of 100us.

Example.

Let us set the device (Node-ID = 0Ah) in 2-axis mode and limit the X range to 10 degrees. Then let us check the EMCY transmitted as the inclination of 10 degrees is exceeded, and the subsequent *Error reset* message as the inclination returns to less than 10 degrees.

1. Send a SDO command to modify index 4001h, s.i. 00h, and write value 00h (2-axis mode).

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	01	40	00	00	-	-	-

In case of correct request, the following answer is received:

58A	60	01	40	00	00	00	00	00

Now set the X-measuring range at index 4000h.

2. Enable the user range (s.i. 03h):

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	00	40	03	01	-	-	-

In case of correct request, the following answer is received:

58A	60	00	40	03	00	00	00	00

3. Set X-range to 10 degrees: pay attention that the value depends on the actual resolution. For a resolution of 0.01 degrees (index 6000h, s.i. 0, value = 10 = Ah), the correct value is 1000= 3E8h.

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	00	40	01	E8	3	-	-

In case of correct request, the following answer is received:

58A	60	00	40	01	00	00	00	00

4. Save the set parameters into the EEPROM as explained at paragraph 3.2.3 and reset the device.

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
60A	22	10	10	01	73	61	76	65

5. Set the device in operational state.

COB ID	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
00	01	0A	-	-	-	-	-	-

6. Finally turn the OIAC3 over 10 degrees on the X-axis. The Emergency frame you will get is the following:

8A	10	50	21	00	02	00	00	00

What does the message mean?

- "8A" is the COB-ID for an EMCY frame
- "10" is the low part of the error code, while "50" is the high part. The resulting error code is "5010h" as indicated in Table 29.
- "21" is the Error register value, where Bit5 and Bit0 are active, meaning that there has been an error and it is a Profile specific error.
- "00" is the Communication error of the Manufacturer error register. It means that no errors occured on the communication.
- "02" is the Device error of the Manufacturer error register. Bit1 is active, meaning that the error occurred on X-axis.

Now let us recover from the emergency situation and turn the inclinometer less than 10 degrees. An *Error reset* message will be received: the frame is an EMCY with updated error register values.

5. Failure monitoring: Heartbeat and Nodeguarding / Lifeguarding

As OIAC3 is configured for asynchronous transmissions, e.g. on inclination change, the transmission is not recurring, so the node could not be periodically controlled. The CANopen network uses two different protocols to monitor the nodes state: the *heartbeat* and the *nodeguard/lifeguard protocol*. One of these two protocols excludes the other: if both active, the *heartbeat* wins and *nodeguarding* is deactivated.

5.1. Heartbeat

The *heartbeat* is a failure monitoring mechanism that is managed by the CAN slave (OIAC3). If active, the node sends periodically a heartbeat message, which contains information relative to the state of the inclination sensor. The transmission of the *heartbeat frame* can be enabled by writing a value greater than zero into index 1017h, sub-index 00h. The value represents the interval between two heartbeat transmissions and is expressed in milliseconds. Values smaller than 50ms are automatically set to 50ms. The default value is zero, so no heartbeat transmission is set. The *heartbeat* message presents the following frame structure:

COB ID	Byte 0	Corresponding OIAC3 state
700h + NID	00h	Boot up
	04h	Stop condition
	05h	Run condition
	7Fh	Pre-operational condition

Table 31 - Heartbeat frame structure

5.2. Nodeguarding and Lifeguarding

The *Nodeguarding* is the monitoring of one or several nodes interfaced to the CANopen network through cyclic RTR frames. As the CAN master sends a *RTR message frame* to the node to be monitored, the requested node answers providing its state and a toggle bit. The toggle bit is toggled after every nodeguarding request. If the status/toggle bit does not match with the status/toggle bit expected, or no response is provided to the master, a slave error is assumed.

This mechanism can be even used to detect master failures. In this case two parameters are used: the guard time and the life time factor. The guard time parameter specifies the interval between two state requests from the master and is defined at index 100Ch of the object dictionary. The life time factor is specified at index 100Dh and defines the time multiplier after which the connection with the master is assumed interrupted. This time is defined as the *node lifetime*:

NODE LIFETIME = GuardTime x LifeTimeFactor

If the node does not receive any guarding request from the master within the lifetime, a master failure is assumed and the device sends an *EMCY frame*. The node returns to the pre-operational state.

5.3. Status LED

The two-color LED complies with CiA DR-303-3 specifications. Green LED is used as run LED indicator and red LED is used as error LED. The tables below describe all LED configurations.

RUN LED	LED state	LED state description
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	OFF	The device is switched off
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	Single flash	The device is in Stop mode
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	Blinking	The device is in Pre-operational mode
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	ON	The device is in Operational mode

Table 32 - Run LED configurations

ERROR LED	LED state	LED state description
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	OFF	The device is in working conditions
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	Single flash	CAN warning limit reached
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	Double flash	Loss of Guarding-master detected
¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤ ¤	ON	The device is in state Bus-Off

Table 33 - Error LED configurations