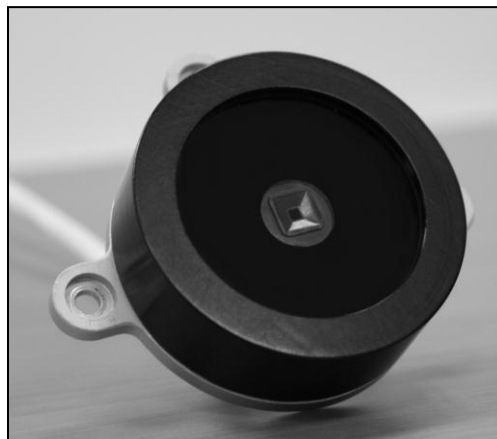


Solar MEMS Technologies S.L.

Sensor MASS-X

Magnetometer + Accelerometer + Sun Sensor

Technical Specifications



Features

- Sun-ray angle for close-loop control
- Azimuth and elevation for open-loop control
- Tilt, Roll, Hard iron compensation included
- DNI radiation measurement
- MODBUS over RS-485
- Low power consumption: 34 mA
- Wide operating voltage range: 5-12 V
- Industrial temperature range: - 40° to 85°
- Reduced size
- Low weight
- IP65 protection
- Reverse polarity protection

Applications

- Sun tracking/pointing systems
- Heliostats
- Attitude control using light sources
- Aircraft attitude control
- Satellite attitude control
- Determination of sun radiation

MASS sensor includes one accelerometer, one magnetometer, and one sun sensor to measure angle of sun-ray, DNI solar radiation and azimuth and elevation position of the device. This information is very useful to develop solar tracking controllers, with no other devices.

Its characteristics make it a suitable tool for high accurate sun-tracking and positioning systems, with low power consumption and high reliability.

MASS sensor has been designed with a unique and novel own technology based on MEMS fabrication processes to achieve high integrated sensing structures at low cost.

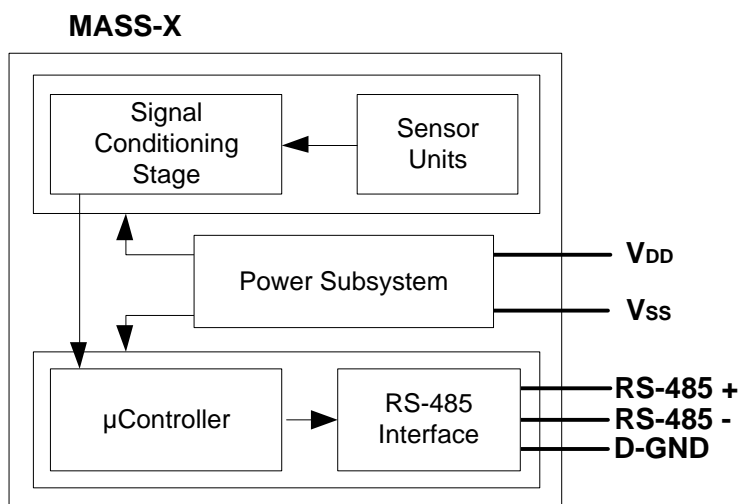


Fig 1. Block Diagram

Contents

Figures	3
Tables	3
1. Sensor MASS-X	4
2. General Specifications	4
3. Absolute maximum ratings	5
4. Recommended operating conditions	5
5. Electrical characteristics	5
6. Characteristics of the MASS	6
7. Main operations	7
7.1. MASS-X parameters	7
7.1.1. Reference Axes	7
7.1.2. Sun Sensor: angles	7
7.1.3. Sun Sensor: solar radiation DNI	8
7.1.4. Accelerometer and Magnetometer	8
7.1.5. Azimuth and Elevation angles	8
7.1.6. Temperature	8
7.1.7. Additional information	9
8. MASS-X Modbus Communication	10
8.1. Communication channel parameters	10
8.2. Master – Slave Operation	10
8.3. RS-485 bus configurations	10
8.3.1. Point to Point configuration	10
8.3.2. Bus configuration	11
8.4. Modbus operation	12
9. Electrical interface	13
10. Mechanical data	14
11. Warranty	15

Responsibility exemption:

Solar MEMS has checked the concordance of this document with the described software and hardware. However, as it is impossible to exclude deviations, Solar MEMS is not liable for full concordance. Solar MEMS reviews this document periodically. If necessary, possible corrections will be included in the next version.

Solar MEMS is not liable for the correct operation of the system if the user does not follow the instructions of this document or use replacement parts that are not covered by this guarantee.

Figures

Fig 1. Block Diagram	1
Fig 2. Sun Sensor response MASS-5: axis x	6
Fig 3. Sun Sensor response MASS-5: axis y	6
Fig 4. MASS-X reference system	7
Fig 5. Reference for sun sensor measurements	7
Fig 6. Reference system of accelerometer and magnetometer measurements	8
Fig 7. Communication timeouts	10
Fig 8. Recommended point to point configuration	10
Fig 9. Optional bus configuration for more than one MASS-X	11
Fig 10. Optional bus configuration for more than one MASS-X	11
Fig 11. Recommended wiring diagram	13
Fig 12. MASS-X dimensions	14

Tables

Table 1. General Specifications	4
Table 2. Absolute maximum ratings	5
Table 3. Recommended operation conditions	5
Table 4. Electrical characteristics	5
Table 5. Characteristics of the sensor	6
Table 6. Additional information	9
Table 7. UART link parameters	10
Table 8. MASS-X modbus registers	12
Table 9. Electrical interface	13

1. Sensor MASS-X

MASS-X measures the position of the device, the incidence angle of a sun ray, and the DNI solar radiation. It includes the following sensor units:

- Sun Sensor model MASS-X from Solar MEMS Technologies.
- 3-axes accelerometer.
- 3-axes magnetometer.

Different models of the MASS-X are offered, differing in the field of view (FOV) of the sensor. The accuracy of the sensor is inversely proportional to this field of view.

2. General Specifications

Parameter	MASS-60	MASS-25	MASS-15	MASS-5	Unit	Comments
Sun Sensor						
Sensor type	2 axis	2 axis	2 axis	2 axis	-	Orthogonal
Field of view (FOV)	120	50	30	10	°	Aperture of the cone of view
Accuracy	< 10	< 10	< 10	< 10	%	% of the measured value
Precision	< 0,06	< 0,04	< 0,02	< 0.005	°	Repeatability
Accelerometer						
Sensor type	3 axis	3 axis	3 axis	3 axis	-	
Sensitivity	0,01	0,01	0,01	0,01	g	
Magnetometer						
Sensor type	3 axis	3 axis	3 axis	3 axis	-	EMI sensitive
Sensitivity	0,1	0,1	0,1	0,1	uT	It includes Hard-iron compensation
Azimuth measurement						
Range	±180	±180	±180	±180	°	North-magnetic 0° East 90°
Precision	< 0,5	< 0,5	< 0,5	< 0,5	°	EMI sensitive It includes Tilt and Roll compensation
Elevation measurement						
Range	±90	±90	±90	±90	°	Horizon 0° Zenith 90°
Accuracy	< 1	< 1	< 1	< 1	°	It includes Roll compensation
Precision	< 0,2	< 0,2	< 0,2	< 0,2	°	
Average consumption	34	34	34	34	mA	
Dimensions						
Diameter	80	80	80	80	mm	
Height	27	27	27	27	mm	
Weight	100	100	100	100	g	
Level of protection	IP65	IP65	IP65	IP65		CEI 60529 Standard
Pressure	Tested at 0,05 mbar and 25°C					

Table 1. General Specifications

3. Absolute maximum ratings

Symbol	Parameter	Minimum value	Maximum value	Unit
VDD	Supply voltage	0	16	V
TOP	Operating temperature	-40	85	°C
VRS485	RS-485 input voltage	-10	10	V

Table 2. Absolute maximum ratings

4. Recommended operating conditions

Symbol	Parameter	Minimum value	Maximum value	Unit
VDD	Supply voltage	5	12	V
Vr	Supply voltage ripple	0	100	mVpp
TOP	Operating temperature	-40	85	°C
VRS485	RS-485 input voltage	-10	10	V

Table 3. Recommended operation conditions

5. Electrical characteristics

Symbol	Parameter	Min	Typical	Max	Unit
VDD	Supply voltage	5	5	12	V
IDD	Feed current	-	34	-	mA
RS-485					
VIH	Voltage <i>input high</i>	2			V
VIL	Voltage <i>input low</i>			0.8	V
VOH	Voltage <i>output high</i>	3.5			V
VOL	Voltage <i>output low</i>			0.4	V

Table 4. Electrical characteristics

Reverse polarity protection.
120Ω RS-485 termination resistors included (see figs. 10 to 12):
Please, refer to the manufacturer for any other particular configuration.

6. Characteristics of the MASS

Parameter	MASS-60	MASS-25	MASS-15	MASS-5	Unit	Comments
Sun Sensor						
Sensor type	2 axes	2 axes	2 axes	2 axes	-	Orthogonal
Field of view (FOV)	120	50	30	10	°	Aperture of the cone of view
Accuracy	< 10	< 10	< 10	< 10	%	% of the measurement value
Precision	< 0,06	< 0,04	< 0,02	< 0.005	°	Repeatability
Angle resolution	0.01	0.001	0.001	0.001	°	
Radiation accuracy	< 10	< 10	< 10	< 10	%	As accurate as close to normal vector
Radiation resolution	1	1	1	1	W/m ²	
Max. radiation	1200	1200	1200	1200	W/m ²	
Sampling frequency	50	50	50	50	Hz	
Bandwidth	0,4	0,4	0,4	0,4	Hz	
Accelerometer						
Sensor type	3 axis	3 axis	3 axis	3 axis	-	
Sensitivity	0,01	0,01	0,01	0,01	g	
Magnetometer						
Sensor type	3 axis	3 axis	3 axis	3 axis	-	EMI sensitive
Sensitivity	0,1	0,1	0,1	0,1	uT	Includes Hard-iron compensation
Azimuth measurement						
Range	±180	±180	±180	±180	°	North magnetic 0° East 90°
Precision	< 0,5	< 0,5	< 0,5	< 0,5	°	EMI sensitive It includes Tilt and Roll compensation
Elevation measurement						
Range	±90	±90	±90	±90	°	Horizon 0° Zenith 90°
Accuracy	< 1	< 1	< 1	< 1	°	It includes Roll compensation
Precision	< 0,2	< 0,2	< 0,2	< 0,2	°	
Temperature						
Accuracy	2	2	2	2	°C	
Resolution	1	1	1	1	°C	
T ^a 25°C, V _{DD} 5V, Radiation 900 W/m ²						
Expected life time: 10 years +						

Table 5. Characteristics of the sensor

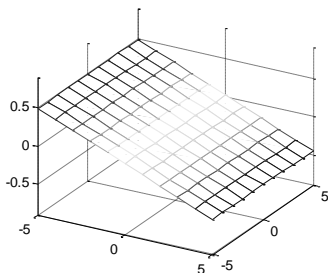


Fig 2. Sun Sensor response MASS-5: axis x

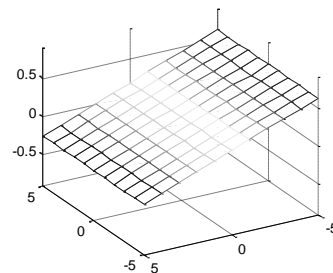


Fig 3. Sun Sensor response MASS-5: axis y

7. Main operations

MASS-X sensor measures angles respect to its normal vector. This information is provided through a RS485 UART channel (master-slave configuration).

7.1. MASS-X parameters

7.1.1. Reference Axes

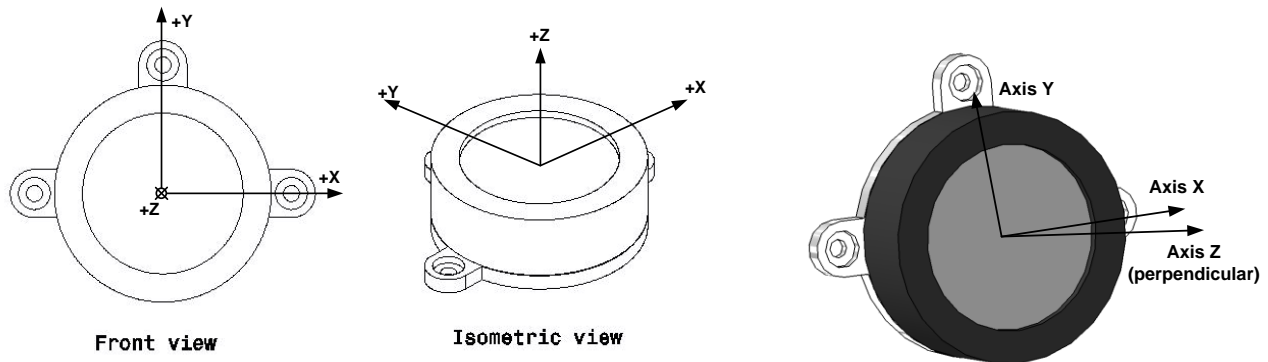


Fig 4. MASS-X reference system

Z axis is perpendicular to the sensor base plane.

7.1.2. Sun Sensor: angles

The *angle x* and *angle y* of the sun sensor specify the angular position of the incident sun ray inside the field of view of the MASS-X sensor. The accuracy of the sensor increases close to zero degrees (perpendicular). Both angles are provided in degrees.

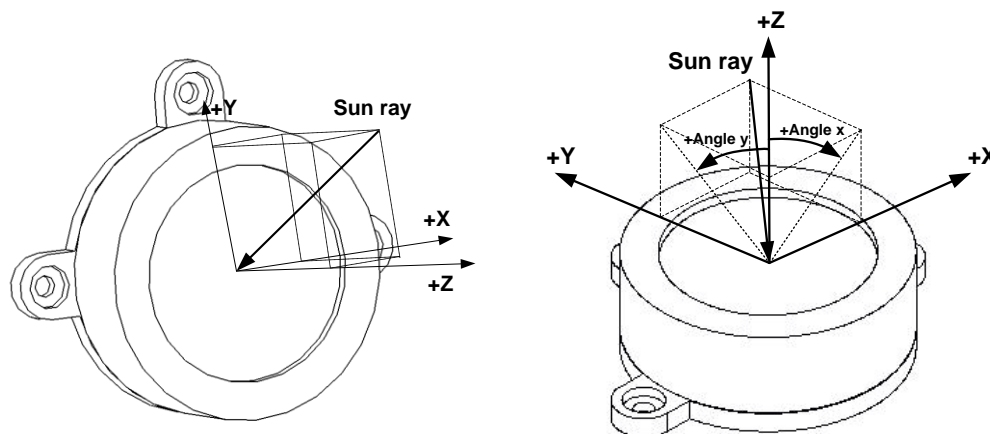


Fig 5. Reference for sun sensor measurements

The MASS-X does an internal filtering processing to the angle measurements with the following features: third-order Butterworth filter with sampling frequency of 50 Hz and cutoff frequency of 0.4 Hz.

7.1.3. Sun Sensor: solar radiation DNI

Radiation is an estimation value of the atmospheric solar radiation, according to the measurements inside FOV. In sunny day conditions, this radiation is equivalent to the direct solar radiation. Radiation is provided in W/m^2 .

The user can utilize this information, in addition to the sensor data, to estimate the atmospheric conditions at the time of measurement, i.e. clouds, fog, dust, etc.

7.1.4. Accelerometer and Magnetometer

Vectors (X,Y,Z) of the accelerometer and the magnetometer are normalized to $1g$ and $1\mu T$ respectively. The first one measures the gravity + acceleration vector and the second one measures the north magnetic vector, according to the sensor reference.

The magnetometer measurement includes a compensation of hard-iron effects.
The following picture shows the sensor reference system:

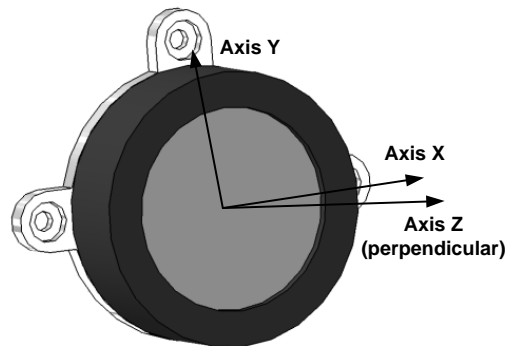


Fig 6. Reference system of accelerometer and magnetometer measurements

7.1.5. Azimuth and Elevation angles

Both measurements are taken using the magnetometer and the accelerometer measurements, compensating Hard Iron effects, and Tilt and Roll rotations.

Azimuth is the angle between the north magnetic vector and the Z direction of the sensor, positive to East and negative to West.

Elevation is the angle between the horizon and the Z direction of the sensor, positive to Zenith and negative to Ground.

7.1.6. Temperature

This parameter is an estimation of the internal MASS-X sun sensor temperature. Thermal data is provided in $^{\circ}C$ (Celsius).

7.1.7. Additional information

This information is a data packet for validating the measurements: indicates if the sun sensor receives enough radiation, or if it detects the Sun out of its field of view (FOV).

The data packet is one byte with the following meaning according to its value:

Value (hexadecimal)	Information	Comments
0x00	No information	
0xFF	Zero radiation	Angles values set to 0° Radiation not enough: less than 300 W/m ²
0x33	Sun is out of FOV	Angles values set to 0°
0x01	Sun is out of FOV	Angles values set to 0° Sun is to X positive reference
0x02	Sun is out of FOV	Angles values set to 0° Sun is to X negative reference
0x10	Sun is out of FOV	Angles values set to 0° Sun is to Y positive reference
0x20	Sun is out of FOV	Angles values set to 0° Sun is to Y negative reference
0x11	Sun is out of FOV	Angles values set to 0° Sun is to X positive and Y positive reference
0x12	Sun is out of FOV	Angles values set to 0° Sun is to X negative and Y positive reference
0x21	Sun is out of FOV	Angles values set to 0° Sun is to X positive and Y negative reference
0x22	Sun is out of FOV	Angles values set to 0° Sun is to X negative and Y negative reference

Table 6. Additional information

8. MASS-X Modbus Communication

MASS-X communication protocol is based on UART over MODBUS (RS-485) master/slave configuration. MASS-X always acts as slave. Up to 247 sensors can be connected to the same communication bus.

8.1. Communication channel parameters

Parameter	Options	Unit	Comments
Bit rate	115200 38400 19200 (default) 9600	bps	Bit rate is modifiable by MODBUS <i>Please, refer to the manufacturer for any other particular configuration.</i>
Data Bits	8	Bits	
Stop Bits	1 (default) 2	Bit	Bit rate is modifiable by MODBUS <i>Please, refer to the manufacturer for any other particular configuration.</i>
Parity	No (default) Even Odd	-	Bit rate is modifiable by MODBUS <i>Please, refer to the manufacturer for any other particular configuration.</i>

Table 7. UART link parameters

8.2. Master – Slave Operation

The master/slave operation allows the master of the system to request information to the MASS-X. Recommended maximum sampling frequency is 10 Hz.

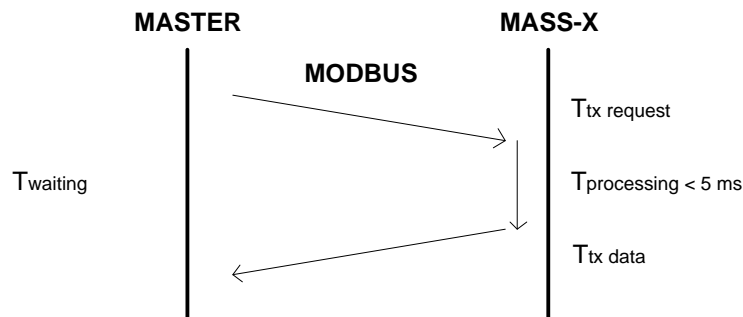


Fig 7. Communication timeouts.

8.3. RS-485 bus configurations

8.3.1. Point to Point configuration

MASS-X sun sensors include one 120 ohm terminator resistor for point to point configuration.

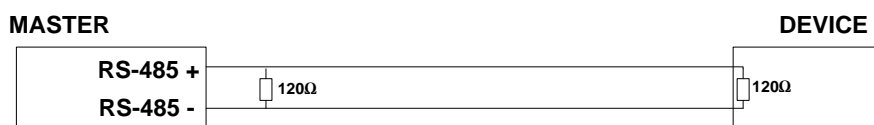


Fig 8. Recommended point to point configuration

8.3.2. Bus configuration

According to TIA/EIA-485 standard, the termination resistors are modifiable and depend on the bus configuration.

Please refer to the manufacturer for MASS-X sun sensors without terminator resistor, or any other value for this element.

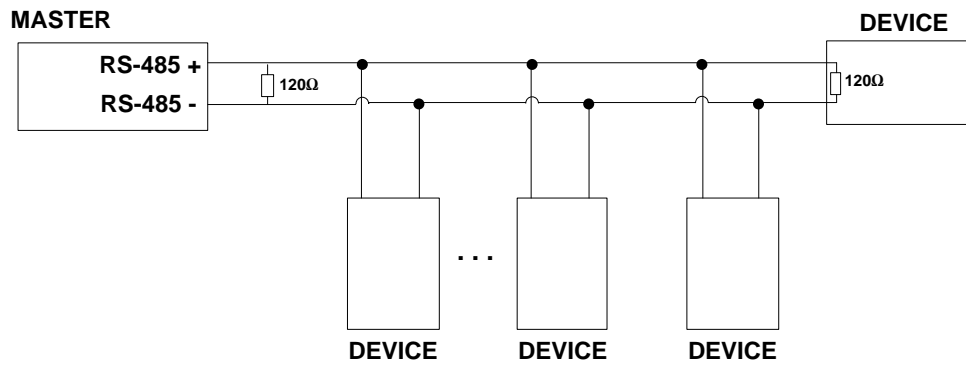


Fig 9. Optional bus configuration for more than one MASS-X

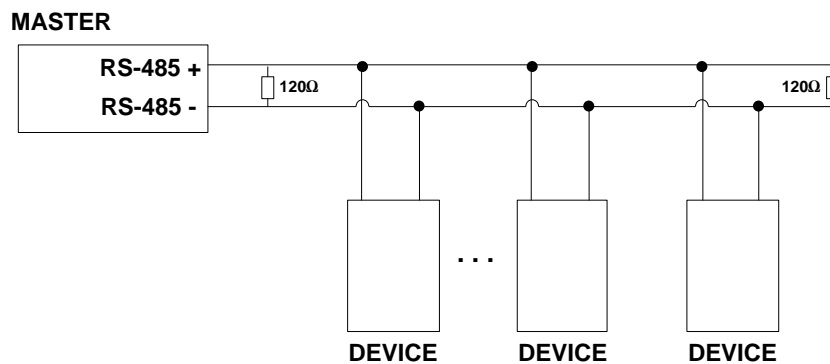


Fig 10. Optional bus configuration for more than one MASS-X

8.4. Modbus operation

The MASS-X sun sensor communicates by means of Modbus RTU framing:

- **Address:** MASS-X detects unicast address. Every MASS-X has address (=identifier) 1 by default.
- **Function code:** MASS-X detects only “Read Register/s” (0x03) code and “Write Single Register” (0x06) code.
- **Exceptions:** MASS-X runs the following exceptions: 01, 02, 03 and 04.
- **CRC16:** according to Modbus standard.
- **Registers:** each register has two bytes.

The MASS-X sun sensor has the following stack of registers:

Order	Name	Allowed operation	Default value	Units	Comments
1	Identifier (address)	Read/Write	1	-	Signed decimal: from 1 to 247
2	Field of view	R	-	°	Signed decimal: 5,15,25 or 60
3	MASS-X model	R	-	-	ASCII code: A=0x41
4	Reference code	R	-	-	Signed decimal
5	Bit rate	R/W	19200	Bps	Values: 1=9600; 2=19200; 3=38400; 4=115200.
6	Parity	R/W	3	-	Values: 1=even; 2=odd; 3=none
7	Stop bits	R/W	1	Bits	Values: 1=1bit; 2=2bits
8	Additional information	R	-	-	Values according to table 6
9	DNI Radiation	R	-	W/m ²	Signed decimal
10	Temperature	R	-	°C	Signed decimal, scale of 0.1°C.
11	Sun Sensor Filtered Angle X	R	-	°	Signed decimal, scale according to field of view: 60: scale of 0.01° 5,15,25: scale of 0.001° With third-order Butterworth filter.
12	Sun Sensor Filtered Angle Y	R	-	°	
13	Sun Sensor Angle X	R	-	°	Signed decimal, scale according to field of view: 60: scale of 0.01° 5,15,25: scale of 0.001°
14	Sun Sensor Angle Y	R	-	°	
15	Azimuth position	R	-	°	Signed decimal, scale of 0.1°
16	Elevation position	R	-	°	Signed decimal, scale of 0.1°
17	Magnetometer Vector (X)	R	-	uT	Signed decimal, scale of 0.1 uT
18	Magnetometer Vector (Y)	R	-	uT	Signed decimal, scale of 0.1 uT
19	Magnetometer Vector (Z)	R	-	uT	Signed decimal, scale of 0.1 uT
20	Accelerometer Vector (X)	R	-	g	Signed decimal, scale 0.001 g
21	Accelerometer Vector (Y)	R	-	g	Signed decimal, scale 0.001 g
22	Accelerometer Vector (Z)	R	-	g	Signed decimal, scale 0.001 g

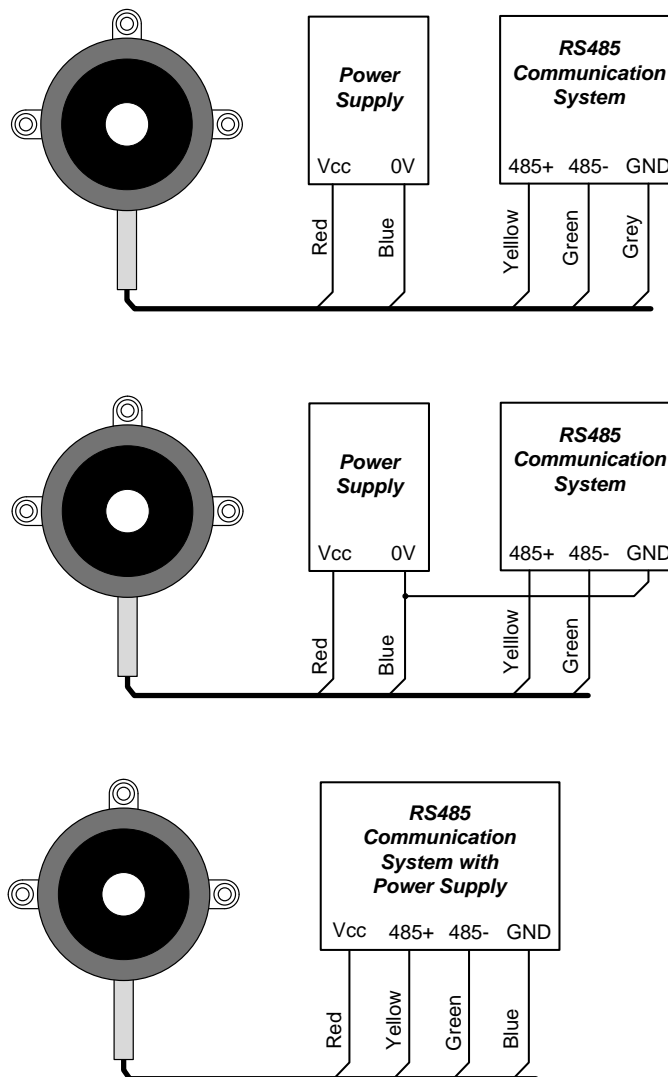
Tabla 8. MASS-X modbus registers

Please, refer to the manufacturer for a particular configuration.

9. Electrical interface

Colour	Terminal	Type	Comments
Red	VDD	Power	Power Supply
Blue	VSS	Power	Ground
Yellow	RS-485 +	I/O	Terminal + RS-485
Green	RS-485 -	I/O	Terminal - RS-485
Grey	D-GND	Communications	Digital Ground
White	-	-	Do Not connect
Brown	-	-	Do Not connect
Pink	-	-	Do Not connect
Shield	-	-	See fig. 13

Table 9. Electrical interface



In any configuration we recommend connecting the shield to the blue wire

Fig 11. Recommended wiring diagram

The housing of the sun sensor MASS-X is isolated electrically.

10. Mechanical data

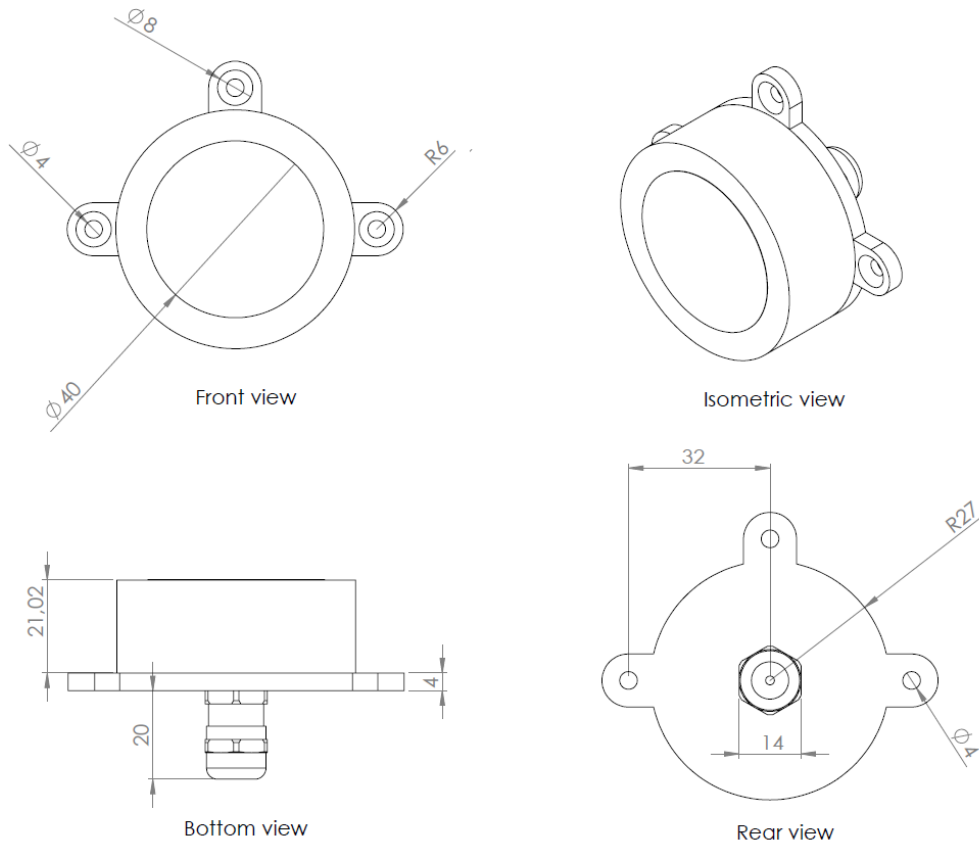


Fig 12. MASS-X dimensions

The box of the MASS-X sensor is composed of a top and bottom housing, both made of Aluminum 6082: it has good corrosion resistance. The top housing has a protective coating of anodizing and it is black lacquered, and the bottom housing has a protective coating of matt anodizing.

11. Warranty

Solar MEMS Technologies S.L. warrants the MASS-X sun sensor to the original consumer purchaser any product that is determined to be defective for the following terms will be repaired, or replaced.

The warranty is one year from date of purchase.

The product in question must be sent to Solar MEMS Technologies S.L. (address is shown below) within the warranty period and the original consumer purchaser must comply with the following conditions, to be eligible for repair or replacement under this warranty:

- The product must not have been modified or altered in any way by an unauthorized source.
- The product must have been installed in accordance with the installation instructions and the technical specifications.

This limited warranty does not cover:

- Damage due to improper installation;
- Accidental or intentional damages;
- Misuse, abuse, corrosion, or neglect;
- Product impaired by severe conditions, such as excessive wind, ice, storms, lightning strikes or other natural occurrences;
- Damage due to improper packaging on return shipment.

Any and all labor charges for troubleshooting, removal or replacement of the product are not covered by this warranty and will not be honored by Solar MEMS Technologies S.L.

Return shipping to Solar MEMS Technologies S.L. must be pre-paid by the original consumer purchaser. Solar MEMS Technologies S.L. will pay the normal return shipping charges to original consumer purchaser within the European Union countries only.

Address of Solar MEMS Technologies S.L.

Solar MEMS Technologies S.L.
Parque Científico Tecnológico Cartuja 93.
Tecnoincubadora Marie Curie.
C/ Leonardo da Vinci 18, Planta 1, Módulo 2.
C.P. 41092, Seville, Spain.
E-mail: smt@solar-mems.com
Phone: (+34) 954 460 113

Solar MEMS has a system of quality and environment according to the ISO 9001 and ISO 14001 standards, provided by the certification company Applus CTC.