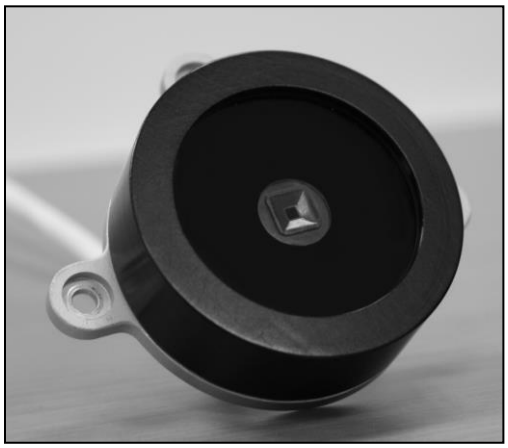
Solar MEMS Technologies S.L.

Sensor MASS-X

Magnetometer + Accelerometer + Sun Sensor

Technical Specifications



Features

Sun-ray angle for close-loop control
Azimuth and elevation for open-loop control
Auto hard iron compensation included
Magnetic declination correction 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
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.

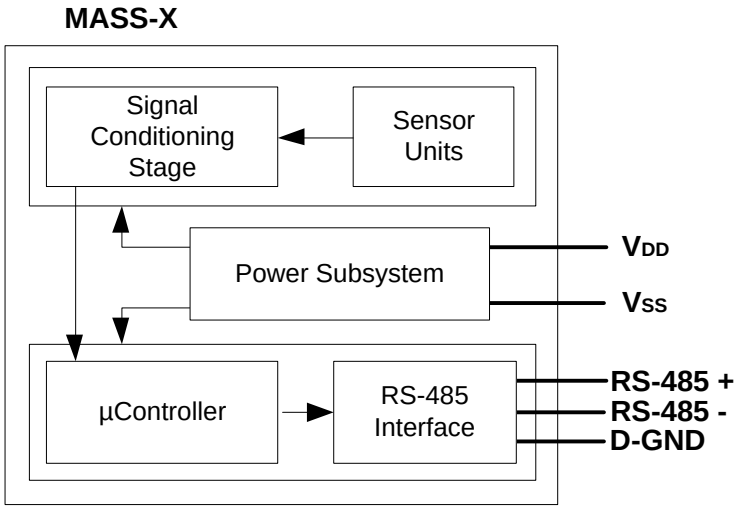


Fig 1. Block Diagram

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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

Tables

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	º	Aperture of the cone of view
Accuracy	< 10	< 10	< 10	< 10	%	% of the measured value
Precision	< 0,06	< 0,04	< 0,02	< 0,005	º	Repeatability
Azimuth						
Range	±180	±180	±180	±180	º	True north 0º East 90º West -90º
Precision	< 10	< 10	< 10	< 10	º	Sensitive to ferromagnetic materials Magnetic declination included
Elevation						
Range	±90	±90	±90	±90	º	Horizon 0º Zenith 90º
Accuracy	< 1	< 1	< 1	< 1	º	
Precision	< 0,2	< 0,2	< 0,2	< 0,2	º	
Others						
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

Table 1. General Specifications

3. Absolute maximum ratings

Symbol	Parameter	Minimum value	Maximum value	Unit
V_{DD}	Supply voltage	0	16	V
T_{OP}	Operating temperature	-40	85	ºC
V_{RS485}	RS-485 input voltage	-10	10	V

Table 2. Absolute maximum ratings

4. Recommended operating conditions

Symbol	Parameter	Minimum value	Maximum value	Unit
V_{DD}	Supply voltage	5	12	V
V_r	Supply voltage ripple	0	100	mVpp
T_{OP}	Operating temperature	-40	85	ºC
V_{RS485}	RS-485 input voltage	-10	10	V

Table 3. Recommended operation conditions

5. Electrical characteristics

Symbol	Parameter	Min	Typical	Max	Unit
V_{DD}	Supply voltage	5	5	12	V
I_{DD}	Feed current	-	34	-	mA
RS-485					
V_{IH}	Voltage *input high*	2			V
V_{IL}	Voltage *input low*			0.8	V
V_{OH}	Voltage *output high*	3.5			V
V_{OL}	Voltage *output low*			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 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	º	Aperture of the cone of view
Accuracy	< 10	< 10	< 10	< 10	%	% of the measurement value
Precision	< 0,06	< 0,04	< 0,02	< 0,005	º	Repeatability
Angle resolution	0,01	0,001	0,001	0,001	º	
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	-	Sensitive to ferromagnetic materials
Sensitivity	0,1	0,1	0,1	0,1	uT	Hard-iron compensation included
Azimuth						
Range	±180	±180	±180	±180	º	True north 0º East 90º West -90º
Precision	< 10	< 10	< 10	< 10	º	Sensitive to ferromagnetic materials Magnetic declination included
Elevation						
Range	±90	±90	±90	±90	º	Horizon 0º Zenith 90º
Accuracy	< 1	< 1	< 1	< 1	º	
Precision	< 0,2	< 0,2	< 0,2	< 0,2	º	
Temperature						
Accuracy	2	2	2	2	ºC	
Resolution	1	1	1	1	ºC	
Tª 25ºC, V_{DD} 5V, Radiation 900 W/m^2						
Expected lifetime: 10 years +						

Table 5. Characteristics of the sensor

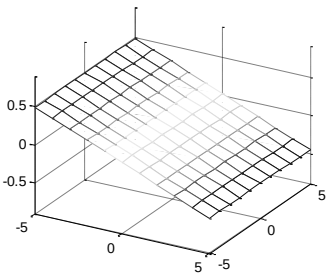


Fig 2. Sun Sensor response MASS-5: axis x

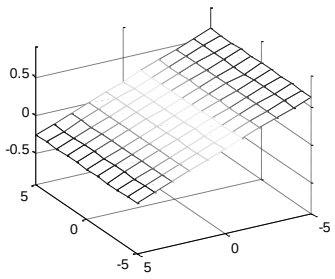


Fig 3. Sun Sensor response MASS-5: axis y

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

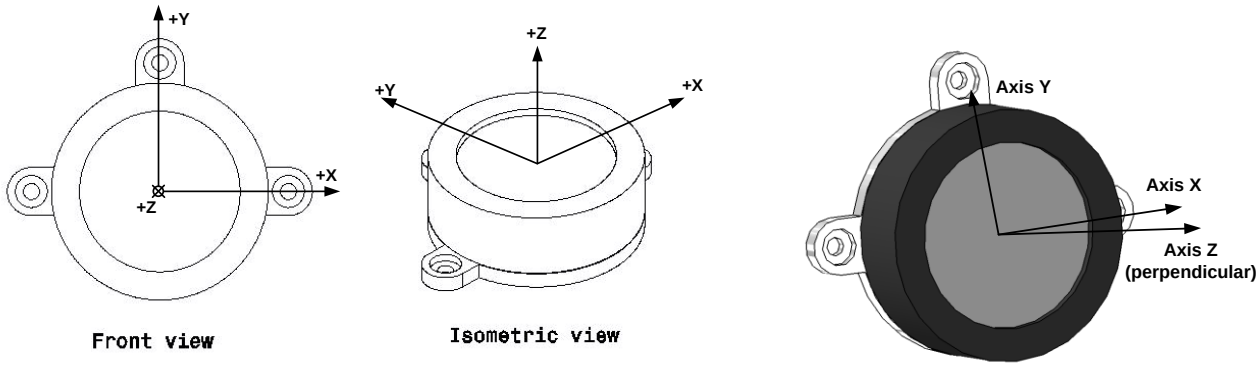


Fig 4. MASS-X reference system

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.

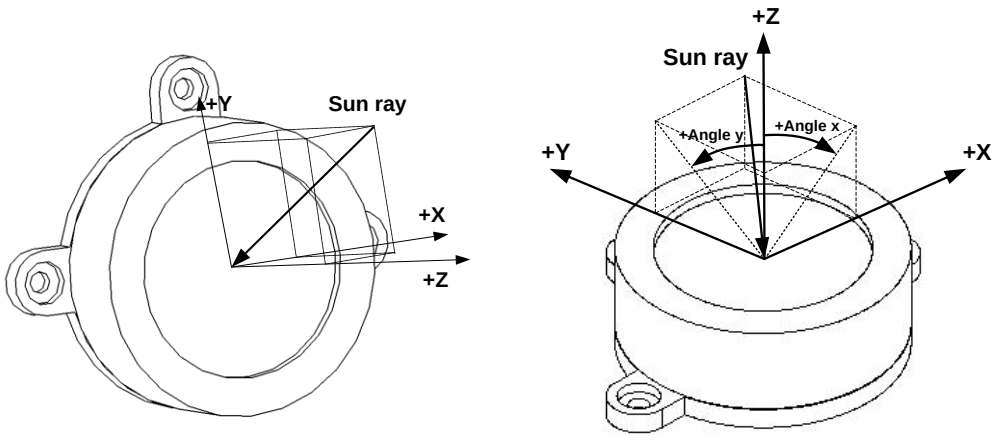


Fig 5. Reference for sun sensor measurements

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 cut-off 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 measure with 0.01 g resolution.
Vectors (X,Y,Z) of the magnetometer measure with 0.1 uT resolution.
Both measurements are according to the sensor reference XYZ axes.
The magnetometer measurement includes a compensation of hard-iron effects.
The following picture shows the sensor reference system:

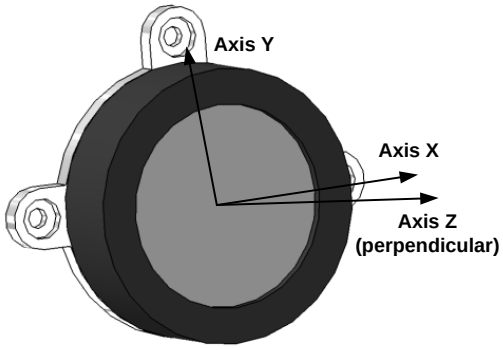


Fig 6. Reference system of accelerometer and magnetometer measurements

7.1.5. Azimuth and Elevation angles

Both measurements are taken using the magnetometer and the accelerometer measurements:

- Azimuth is the angle between the true north 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 ºC (Celsius).

7.1.7. Additional information (register 10)

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 0º Radiation not enough: less than 300 W/m^2
0x33	Sun is out of FOV	Angles values set to 0º
0x01	Sun is out of FOV	Angles values set to 0º Sun is to X positive reference
0x02	Sun is out of FOV	Angles values set to 0º Sun is to X negative reference
0x10	Sun is out of FOV	Angles values set to 0º Sun is to Y positive reference
0x20	Sun is out of FOV	Angles values set to 0º Sun is to Y negative reference
0x11	Sun is out of FOV	Angles values set to 0º Sun is to X positive and Y positive reference
0x12	Sun is out of FOV	Angles values set to 0º Sun is to X negative and Y positive reference
0x21	Sun is out of FOV	Angles values set to 0º Sun is to X positive and Y negative reference
0x22	Sun is out of FOV	Angles values set to 0º Sun is to X negative and Y negative reference

Table 6. Additional information

7.2. Magnetometer compensation for azimuth calculation

Azimuth angle is calculated applying several corrections to the magnetometer measurements:

- Magnetic declination.
- Hard iron effects, related to fixed magnetic fields around and inside the sensor.

7.2.1. Magnetic declination calculation and application

Magnetic declination is calculated based on a stored grid of the World Magnetic Model (WMC, date 2024, https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#igrfgrid). This value is calculated using the geo-location of the MASS sensor: latitude and longitude (registers 8 and 9).

It is necessary to configure these registers (latitude and longitude) to get an accurate magnetic declination, which value could vary a lot, and to get an expected magnetic field in the current location according to the WMC.

Once these parameters are written, the values are stored in EEPROM, no matter if you turn it OFF, and magnetic declination is calculated and applied automatically.

7.2.2. Hard iron compensation

Hard iron effect is the impact on the magnetic field measurement due to any fixed and permanent magnetic field surrounding the magnetometer device. Additionally, any zero-field offset in the magnetometer is detected and corrected in the Hard iron compensation.

Hard iron compensation is estimated automatically and validated based on the measured and the expected values of the magnetic field:

- Expected magnetic field: an expected total intensity of the Earth Magnetic Field is estimated based on the World Magnetic Model (WMC, date 2024).
- Measured magnetic field: total intensity of the magnetic field measured by the magnetometer is compensated (hard iron) and calculated automatically.

When measured and expected values are close, hard iron compensation is achieved:

- High fitting/compensation: measured and expected values are closer than 5 uT.
- Med fitting/compensation: measured and expected values are closer than 10 uT.
- Low fitting/compensation: measured and expected values are closer than 20 uT.

7.2.3. Magnetometer calibration and hard iron compensation

To get a good compensation, magnetometer must measure the magnetic field in all directions as possible (full sphere). A way to achieve that is performing a lemniscate with the MASS in front of you while you are turning around.

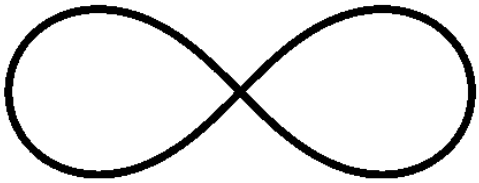


Fig 7. Lemniscate

While you do this, MASS sensor will be calibrating and compensating hard iron effect automatically and storing internally that compensation. If it loses calibration because new unexpected magnetic fields appear

around by any reason, MASS sensor will try to calibrate again and again while it points to new directions, until getting a good fitting again. Please, check register 17 (azimuth additional info) to know the status of the compensation:

- If it is “no-calibrated”, MASS sensor has lost calibration and needs recalibration. You could continue working with it and pointing to new directions until getting a good fitting again, or you could get it and repeat first calibration (lemniscate + turning around) to achieve good fitting again.
- If it is low fitting, MASS delivers azimuth but with low accuracy.
- If it is med or high fitting, MASS sensor delivers a good azimuth.

7.2.4. Soft iron effects

Soft-iron effects are not compensated: these are due to induced magnetic field to ferromagnetic materials around the sensor. Those materials must be avoided, and MASS should be separated from them to avoid unexpected deviations on azimuth measurement. This effect depends on the size and shape of ferromagnetic materials and surrounding magnetic fields. The impact is complex to estimate.

Recommendation: test the MASS on your application. If you are not able to get a good (med/high) fitting between measured and expected magnetic field, then separate it from any ferromagnetic material: iron, steel, and others.

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 *Please, refer to the manufacturer for any other configuration.*
Data Bits	8	Bits	
Stop Bits	1 (default) 2	Bit	Bit rate is modifiable by MODBUS *Please, refer to the manufacturer for any other configuration.*
Parity	No (default) Even Odd	-	Bit rate is modifiable by MODBUS *Please, refer to the manufacturer for any other configuration.*

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.

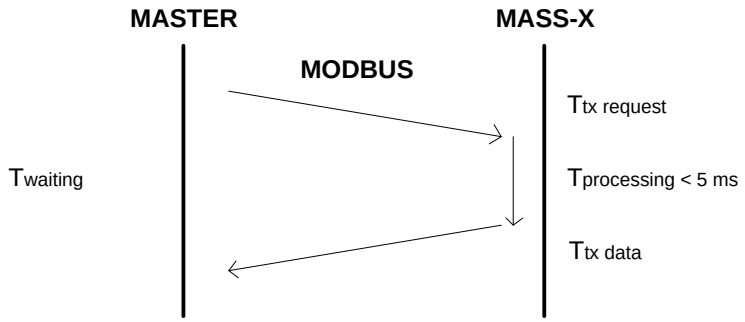


Fig 8. Communication timeouts.

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.

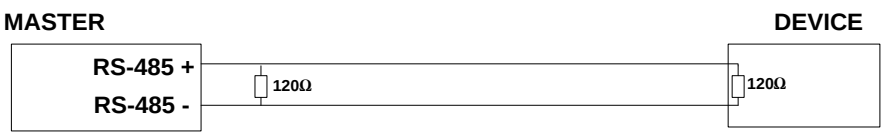


Fig 9. Recommended point to point configuration

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.

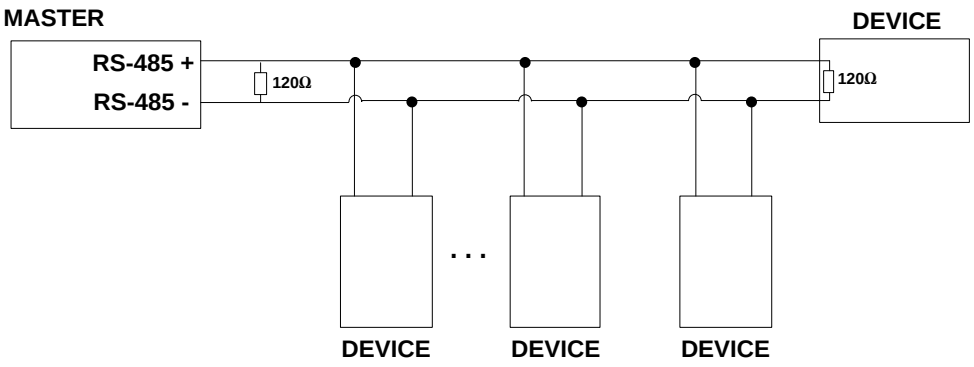


Fig 10. Optional bus configuration for more than one MASS-X

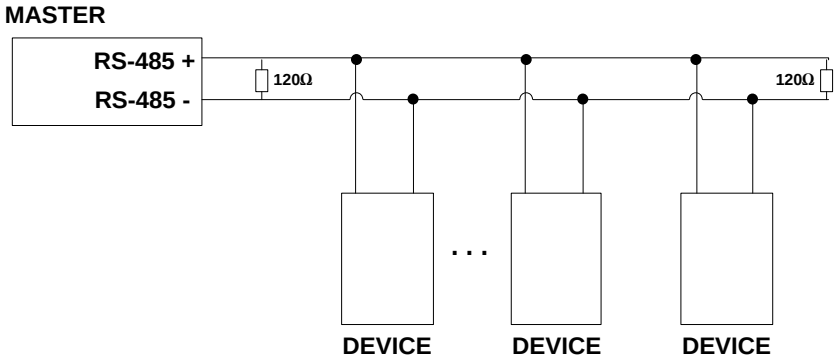


Fig 11. Optional bus configuration for more than one MASS-X

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	-	º	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	Latitude	R/W	0		Signed decimal, scale of 0.01º
9	Longitude	R/W	0		Signed decimal, scale of 0.01º
10	Additional information	R	-	-	Values according to table 6
11	DNI Radiation	R	-	W/m^2	Signed decimal
12	Temperature	R	-	ºC	Signed decimal, scale of 0.1ºC.
13	Sun Sensor Angle X	R	-	º	Signed decimal, scale according to field of view: 60: scale of 0.01º 5,15,25: scale of 0.001º With third-order Butterworth filter.
14	Sun Sensor Angle Y	R	-	º	
15	Azimuth position	R	-	º	Signed decimal, scale of 0.1º
16	Elevation position	R	-	º	Signed decimal, scale of 0.1º
17	Azimuth additional info	R	-	-	MSbyte: If 1 = Auto hard iron calculation activated If 0 = Auto hard iron calculation deactivated LSbyte: If 0 = hard iron not compensated If 1 = hard iron low compensation If 2 = hard iron med compensation If 3 = hard iron high compensation
18	Measured magnetic field	R	-	uT	Signed decimal, scale of 0.1 uT
19	Expected magnetic field	R	-	uT	Signed decimal, scale of 0.1 uT
20-48	Reserved parameters	R	-	-	-

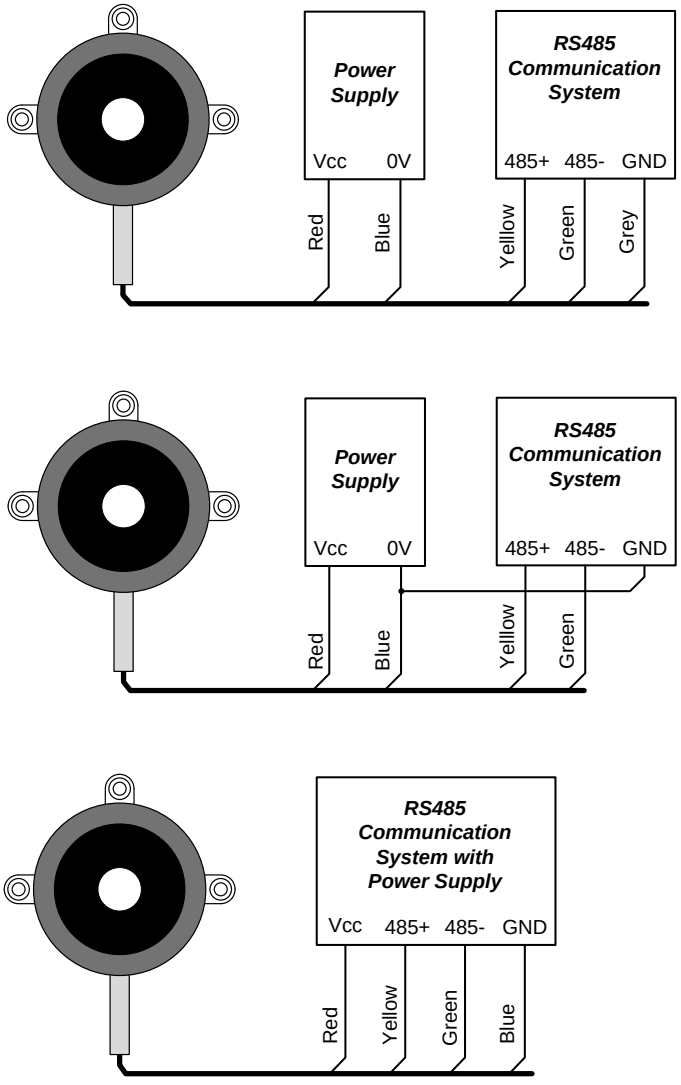
Tabla 8. MASS-X modbus registers

Please, refer to the manufacturer for a particular configuration.

9. Electrical interface

Colour	Terminal	Type	Comments
Red	V_{DD}	Power	Power Supply
Blue	V_{SS}	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 12. Recommended wiring diagram

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

10. Mechanical data

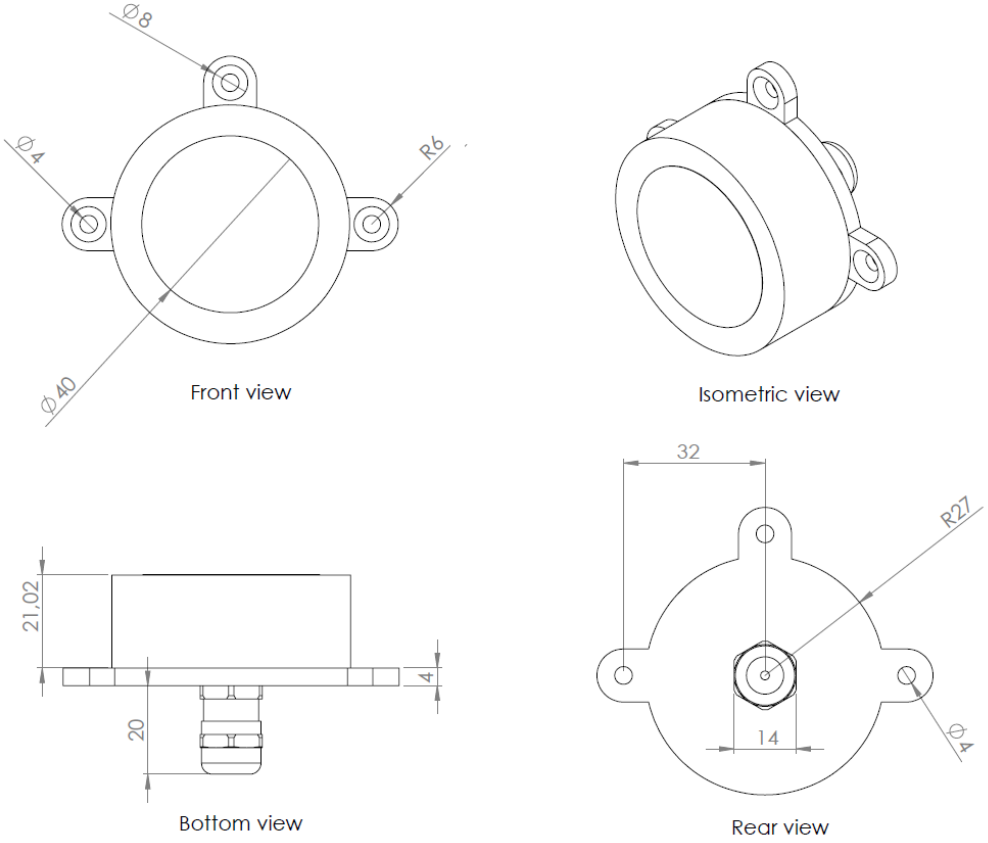


Fig 13. MASS-X dimensions

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.
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