YLARA SENSORS INSTALLATION AND OUTDOOR TESTS

(LASER SAFETY SUBSYSTEMS AND CLOUD SENSOR)

YLARA Project

YLARA-LS-60-I04 (CDT Technical Report 2022 - 06)

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Change index

Version	Date	Section	Change Description
V01	02-11-2021	All	First issue
V02	23-05-2022	All	Review and approval

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Abbreviations

ADS-B	Automatic Dependent Surveillance-Broadcast
ERDF	European Regional Development Funds
FLARM	FLight alARM
GPS	Global Positioning System
IP	Ingress Protection (Code)
NMEA	National Marine Electronics Association
OGN	Open Glider Network
OTDR	Optical Time-Domain Reflectometer
OY	Yebes Observatory
RH	Relative Humidity
SLR	Satellite Laser Ranging
T	Temperature
YDALGO	Laboratory development infrastructures for space geodesy at the Yebes Observatory (Infraestructuras de desarrollo de laboratorio para geodesia espacial en el Observatorio de Yebes)
YLARA	Yebes Laser Ranging

Applicable and reference documents

Reference Documents

Most of them appear with its web link, working at the moment of writing the document.

RD01	YLARA-LS-60 2018 Radarcape - Quick Start Guide. Jetvision - 2018.
RD02	YLARA-LS- 60 2016 Radarcape - User Manual. Jetvision - 2016.
RD03	How to mount antennas outdoors - Jetvision.
RD04	YLARA-LS-60 2020 AT-1 - Installation Manual. Air Avionics - 2020.
RD05	YLARA-LS-60 2021 OMEA All Sky Camera - Installation and User Manual. Alcor Systems (v 2019 04 29).
RD06	YLARA-BS-50 2012 CloudSensor II Boltwood - User Manual. Diffraction Ltd – 2012.
RD07	Steel Wall Box 775-5340. RS PRO.
RD08	4 port USB2.0 Fibre Optic Extender. AD-net.
RD09	4 port USB2.0 Fibre Optic Extender Manual. AD-net.
RD10	Axial AC Fan Datasheet . Sunon.
RD11	SHT31-D Temperature & Humidity Sensor Manual. Adafruit.
RD12	Raspberry Pi 3 Model B+ product brief. Raspberry.
RD13	Panel mount solid state relay EZ240D5 Data sheet. Crydom.
RD14	ADS-B and FLARM receivers, OMEA-8C all sky camera, Boltwood cloud sensor: reception report, specifications and setup instructions, M. Serna Puente, B. Vaquero Jiménez, A. García Marín, CDT Technical Report 2019-7 (YLARA-LS-60-I01, 2, 3/ YLARA-BS-50-I01)
RD15	FLARM Configuration Specification FTD-014. FLARM Technology Ltd – 2021.
RD16	FLARM Data Port Interface Control Document (ICD) FTD-012. FLARM Technology Ltd – 2021.
RD17	Radarcape support Wiki – Jetvision.

1. Introduction

In the context of the Operation YDALGO (Laboratory development infrastructures for space geodesy at the Yebes Observatory) co-financed with ERDF funds, a Satellite Laser Ranging (SLR) station, YLARA (Yebes LAser RAnging), will be soon set up at the Yebes Observatory (OY).

Four of the auxiliary subsystems/modules which will be operated outdoor have just been acquired by the OY (Table 1).

YLARA Subsystem	YLARA Module	Manufacturer	Model
Laser safety: Aircraft detection	**ADS-B Receiver**	Jetvision	Radarcape
Laser safety: Aircraft detection	**Air Traffic Receiver (FLARM)**	Air Avionics	AT-1
Laser safety: Aircraft detection Operator sky awareness	**All sky camera**	ALCOR SYSTEM	OMEA 8C
Meteorological sensor	**Cloud Sensor**	Diffraction Ltd	Boltwood Cloud Sensor II

Table 1. Basic equipment to be tested.

All these subsystem's devices have been tested indoor in a preliminary way for checking they were properly working and understanding their operation.

The next step has been its installation in the OY as they will operate in YLARA: with the sensors of these modules located outside the main building.

The objectives of these tests are:

- to verify that the performance of each module conforms to its specification, especially regarding operating conditions, and design;
- to identify the ideal configuration/distribution of each of the sensors outside;
- to visualize the distribution, both internal and external, of each module and, in particular, to identify the distances at which the interior and exterior parts of each module must be as a result of restrictions on the length of the connections between the two parts; and
- to collect the data generated by these modules for further analysis and possible development of basic tools for this purpose.

The installation of these modules, although temporarily but on a stable platform similar to that planned in the operational stage at the SLR station, will allow all kinds of tests to be carried out as desired, investigate its capabilities and limitations, as well as characterize the environment of the OY in terms of air traffic.

Basically, the external installation of these equipments will include:

- the setup of these in a suitable location somewhere near the surface of the roof of the OY main building;
- the installation on the outside of their respective sensors and antennas, and their connection with the devices themselves;
- the installation of a PC (Windows) and a Raspberry Pi to interact with the equipment, both in turn connected to the local network;

This document starts describing the equipment under test as well as the proposal for the external installation of every one of them (§2). It follows the installation proposal for all the equipment under test (§3). After identifying some auxiliary equipment (heat removal subsystem and wall mounting enclosure), the description of the final configuration of the installation is done (§4). Finally, tests performed, both indoor and outdoor, have been described in §5.

2. Equipment under test

It follows a description of every of the four equipments under test (Table 1).

2.1. ADS-B Receiver (Radarcape)

It is a passive receiver of the signals emitted by aircrafts equipped with an ADS-B transponder on the 1090 MHz frequency (the most common). It incorporates a GPS receiver to set the aircraft position and the time of every event. RD01 provides a Quick Start Guide while RD02 is its User Manual.

2.1.1. Components

Table 2 lists its components (Figure 2).

Qtty	Items
1	Radarcape (S/N 1304-1826)
1	Power supply (5 V, 15 W)
1	5 m network cable
1	GPS antenna (cable length 5 m)
1	Active diapason antenna (1090 MHz)
1	Bias Tee (for power supply of the LNA over USB-jack of a computer)
1	USB cable
1	Antenna mount
1	20 m antenna cable

Table 2. ADS-B Receiver: components.

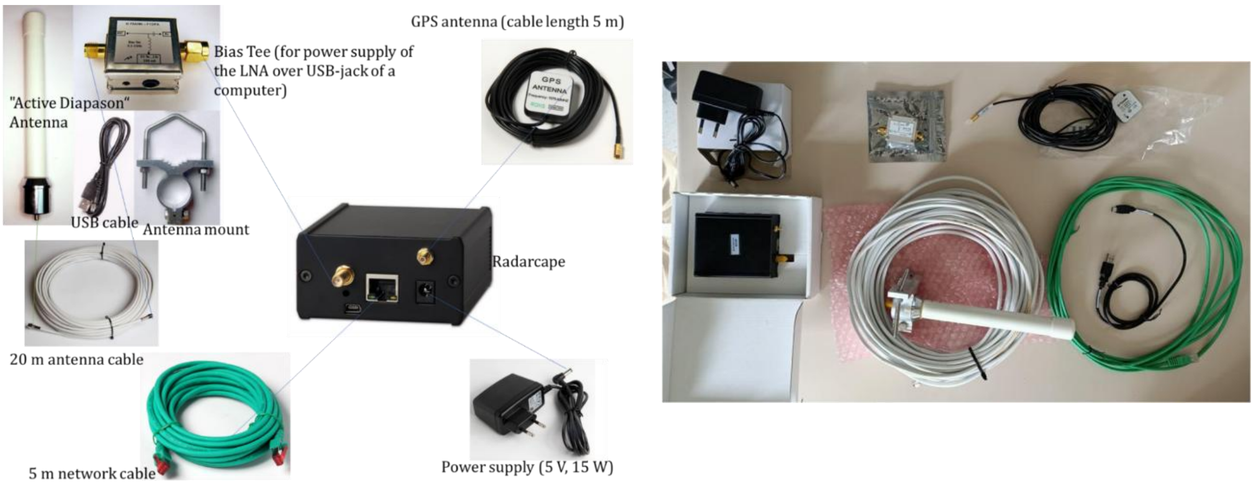


Figure 1. ADS-B Receiver: components.

A description of the Active diapason antenna (1090 MHz) can be found at §7.1.2.

2.1.2. Indoor/outdoor distribution

Figure 2 shows its typical set up. Figure 3 shows its proposed indoor/outdoor configuration.

Figure 2. ADS-B Receiver: typical configuration.

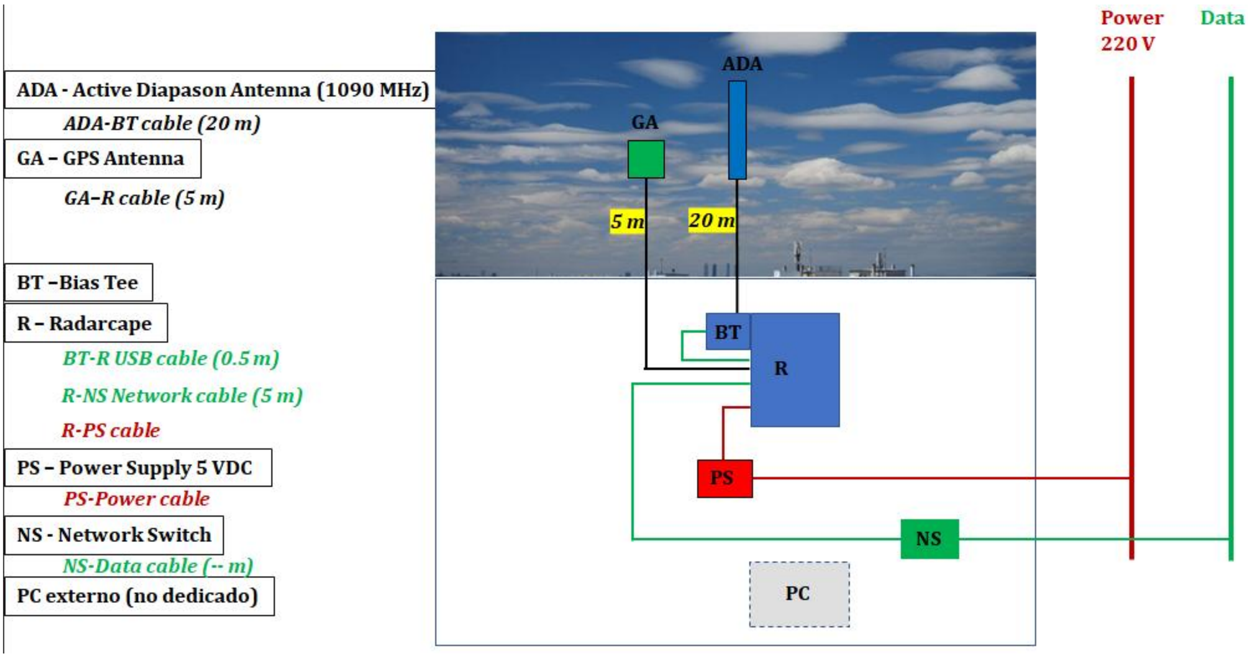
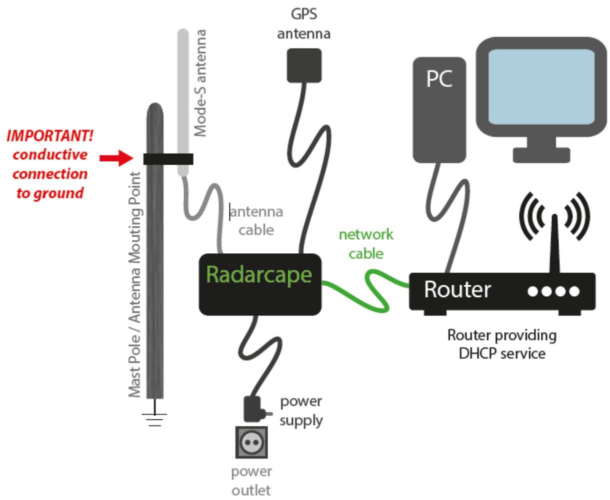


Figure 3. ADS-B Receiver: test configuration.

2.1.3. Installation considerations

GPS antenna	Place the GPS antenna to a location with at least half of sky view, e.g. a window sill (§RD01).
Antenna Diapason	Place the antenna as free and as high as possible.  Figure 4. ADS-B Receiver: antenna location. Static electricity around the antenna can damage your Radarcape or Internet router if there is no ground connection! Do NOT mount the antenna on isolated ground (e.g. wooden stick) or without any connection to ground! THE ANTENNA MUST BE GROUNDED! See appendix (§7.1.1) for more information.

2.2. Air Traffic Receiver (FLARM) (AT-1)

It is an aircraft anti-collision system based on a proprietary FLARM protocol (868 MHz) which, additionally, has the ability to receive ADS-B signals (1090 MHz) emitted by an aircraft. Due to its main purpose, this device emits FLARM signals, although this emission mode will not be used in YLARA. For these receptions it has two FLARM antennas, external and internal, and an external ADS-B. In addition, it has an internal GPS antenna to set its own position and the time of each event.

Note: in the manufacturer documentation external is refereed as "building" and internal as "cockpit", both terms related with the original field of application of this system: aircraft anti-collision system.

2.2.1. Components

Table 3 lists its components (Figure 2).

Qtty	Items
1	AT-1 FLARM device (P/N: AT-1-(00000/on device – 00118/on packing list)
1	Power supply with cable (set up at Yebes Observatory)
1	Data cable with USB/serial converter
1	USB cable
1	GPS cockpit antenna
1	ADS-B building antenna 1090 MHz (P/N: B596, Nf connector) + mast clamps (x2)
1	ADS building antenna cable, 3 m + 2 m = 5 m
1	FLARM building antenna 868 MHz (P/N: B578, Nf connector) + mast clamps (x2)
1	GAV-868 antenna cable, 3 m + 2 m = 5 m
1	ADS-B & FLARM antennas ("cockpit antennas") (not needed)

Table 3. Air Traffic Receiver (FLARM) components.

Figure 5. Air Traffic Receiver (FLARM): components.

A description of the ADB-S building antenna and the GPS receiver can be found at §7.2.2.

2.2.2. Indoor/outdoor distribution

Figure 6 shows its proposed indoor/outdoor configuration. ADS-B (FLARM) cockpit antenna, crossed out in Figure 6, has not been installed by now, this being redundant when installing the external antenna designed for its location in buildings.

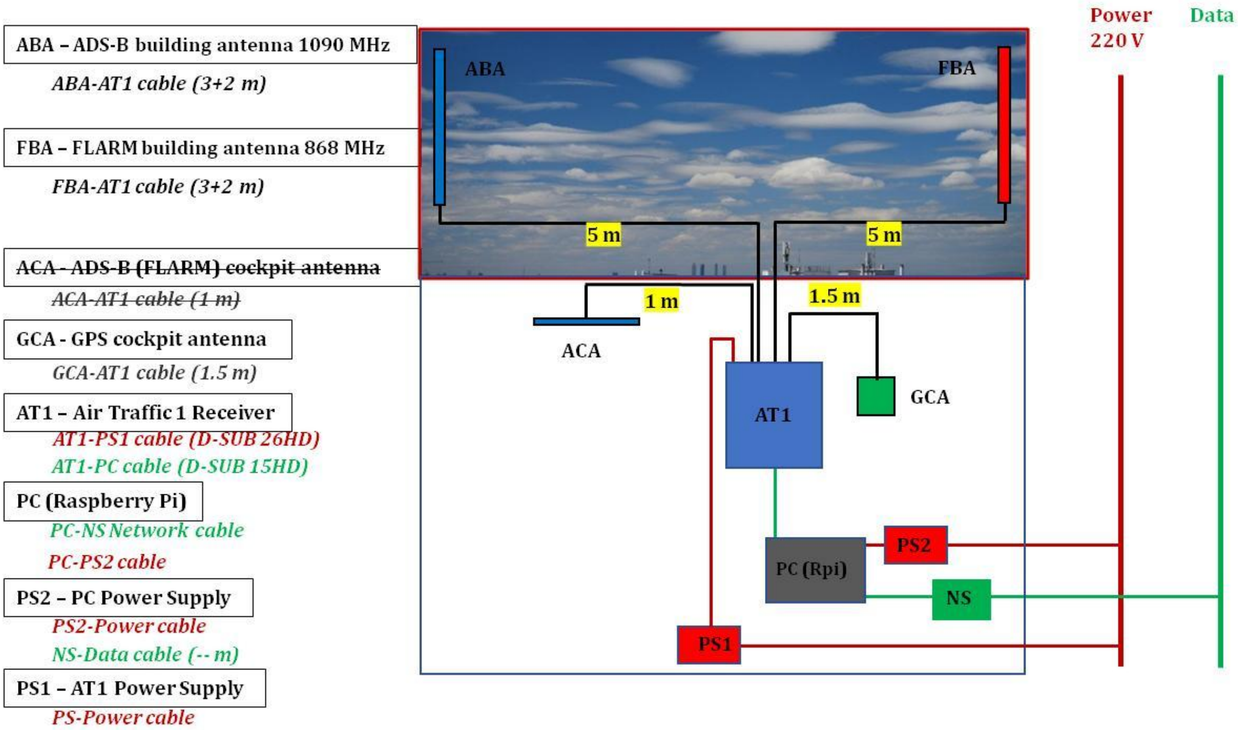
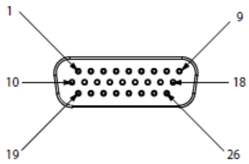


Figure 6. Air Traffic Receiver (FLARM): test configuration.

2.2.3. Installation considerations

These aspects are detailed in the Installation Manual (RD04, some of them can be found in §7.2.1). The main details are collected here.

Power connector	The power connector (Connector 1: AT-1-PS1 cable (D-SUB 26HD)) must be properly grounded:  Figure 7. Air Traffic Receiver (FLARM): Connector 1 pin map

Pin Name	Pin number	I/O
Aircraft Power (VIN)	1.1	In
RS-232 Port 1 receive data (RXD1)	1.2	In
RS-232 Port 2 receive data (RXD2)	1.3	In
RS-232 Port 3 receive data (RXD3)	1.4	In
Aircraft Ground (GND)	1.5	–
Analog Input (AIN)	1.6	In
Relay Output (ROUT)	1.7	Out
Relay Input (RIN)	1.8	In
Aircraft Ground (GND)	1.9	–
Aircraft Power (VIN)	1.10	In
RS-232 Port 1 transmit data (TXD1)	1.11	Out
RS-232 Port 2 transmit data (RXD2)	1.12	Out
RS-232 Port 3 transmit data (TXD3)	1.13	Out
Power Output 3.3V (3v3out)	1.14	Out
Audio Output (AUD)	1.15	Out
Discrete Input 1 (DIN1)	1.16	In
Discrete Input 2 (DIN2)	1.17	In
Discrete Input 3 (DIN3)	1.18	In
Data Bus Low Signal (CANLO)	1.19	In/Out
Data Bus High Signal (CANHI)	1.20	In/Out
Data Bus Termination 120R (CANTERM)	1.21	–
Enable (EN)	1.22	In
Aircraft Ground (GND)	1.23	–
ARINC429 Out A (A429A)	1.24	Out
ARINC429 Out B (A429B)	1.25	Out
Aircraft Ground (GND)	1.26	–

Table 4. Air Traffic Receiver (FLARM): Connector 1 pin map.

Antennas: general considerations	FLARM antennas. - FLARM signals are transmitted with very low power so a good placement and installation of the antenna is critical for the performance of the equipment. 1090 MHz FLARM antennas (ADS-B) and GPS antenna. - They must be installed following certain position requirements because if this is not optical, their range and coverage are limited.
Antennas: cable installation	Avoid tight curves, tighten them and/or rub them.
Indoor antennas	ADS-B indoor antenna (not used): see RD04, §4.4.3. GPS indoor antenna: see RD04, §4.4.4.
ADS-B outdoor antenna (1090 MHz)	RD04 (§4.4.3) mentions them: although it refers to another geometry of antennas (shark fin) the principles apply (§2.2.4). Installation requirements for optimal performance: - Install the 1090 MHz antennas vertically - Make sure the antenna cable runs away from the antenna by 90° in the first 15 cm or use angled antenna connectors (outdoor antennas) - Do not coil the antenna cable - There should be no conductive parts (metal, carbon fibre) near it - Install the antenna in a place where it has a clear view and is not obstructed by nearby structures See the comments to the installation of the diapason antenna of the previous paragraph and appendix (§7.1.1).
FLARM outdoor antenna (868 MHz)	RD04 (§4.4.2) mentions them, but refers to another antenna geometry (shark fin). In essence, it should apply everything.

2.2.4. Points to consider

Various aspects of the purchased material (performance, mounting configuration, etc.) are described in their respective documentation within the context of aircraft navigation aids and being mounted on them. Some points related to the performance improvement or its correct use in our application needed to be clarified later with Air Avionics[1].

- An internal GPS antenna with 1.5 m cable has been received. This antenna is designed for use inside the aircraft, ideally in the cockpit and attached to the window (§7.2.1 and RD04 §4.4.4), to have the entire sky accessible without obstruction. If mounted inside a building, indoors or on a window, performance loss issues may arise as these indoor antennas are not suitable for extended outdoor use. If this happens, it should be installed outside, preferably on the roof, so that it can be oriented to the zenith. This would mean using a longer cable up to a maximum of 6m. Outdoor antennas, which can be used outdoors permanently, are available with significantly longer cables.
- The cables to both outdoor antennas are a bit short (5 m). By using good low loss cable, like ECOFLEX 10 or similar, the maximum allowed cable length could be extended till 15 m – 20 m.
- Regarding the minimum distance that both external antennas (ADS-B and FLARM building antennas) should be kept, there are no limitations: maybe 30 cm would be good.

  Comment: Although it is not contemplated, in principle, to use the ADS-B antenna with the AT-1, the query has been made because it applies to the situation of the ADS-B antenna of the ADS-B receiver (Radarcape): it is convenient, therefore, separate both external antennas. It is understood that with the safety distance possible mechanical shielding between both antennas is avoided rather than interference (both are used in receiver mode).
- The installation manual (RD04 and §7.2.1) does not contain a specific procedure for the installation of the external antennas. The installation procedure for external pole-type antennas contains guidelines that generally also apply to building antennas.

2.3. All Sky Camera (OMEA 8C)

Its purpose is to carry out surveillance of the entire sky, night or day, continuously and in real time through the acquisition and analysis of the images obtained. Its ultimate functionality will include providing station personnel with real-time information about the Observatory environment and potentially becoming part of the air safety system with some degree of automation.

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[1] support@air-avionics.com

2.3.1. Components

Table 5 lists its components (Figure 8).

Qtty	Items
1	All sky camera - OMEA 8C (S/N: 127404)
1	Optional stand + gimbal table (OY manufactured)
1	24V/2.5A power supply
1	Connector #1 External Temperature / Humidity sensor
1	Connector #2 Power connector and RS232 link (15 m)
1	Connector #3 USB Link (20 m)
1	RS232 to USB converter

Table 5. All Sky Camera: components.

Figure 8. All Sky Camera: components.

2.3.2. Indoor/outdoor distribution

Figure 9 shows its proposed indoor/outdoor configuration. The camera has been mounted in a gimbal platform to make easy its alignment with the celestial sphere. External Temperature and Relative Humidity probe has been mounted in an auxiliary arm to keep it looking to the floor as required.

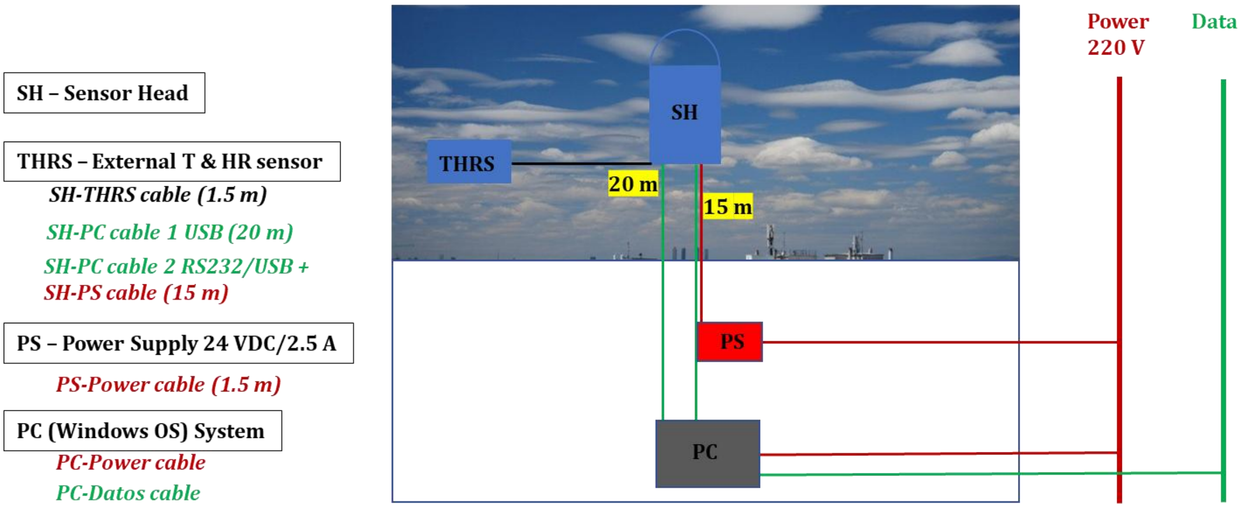
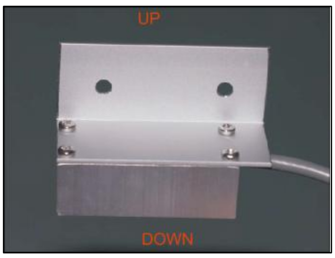


Figure 9. All Sky Camera: test configuration.

2.3.3. Distribution and installation considerations

These aspects are detailed in the Installation Manual (RD05). The main details are collected here.

Tightness level	The camera is waterproof enough (heavy rains) to be able to work outdoors. Its interior has an IP67 sealing: - IP: Ingress Protection - Dust protection level: «6»; dust does not enter under any circumstances - Level of protection against liquids (usually water): «7». The object must withstand (without any filtration) complete immersion at 1 meter for 30 minutes
External T and RH sensor probe position	It must be oriented with the sensor facing the ground to prevent water from entering it. For it: - An arm has been manufactured to secure this position - It is advisable to mount the camera at a certain distance from the ground so that drops do not splash on it in heavy rain: at least half a meter  Figure 10. All Sky Camera: external sensors.
Location	Care must be taken that its location does not include obstacles to the camera's field of view (local horizon line below the horizontal plane of the camera or at no more than 10°).
Grounding	The user manual, in its troubleshooting section (RD05, §7.1), mentions that if the internal heater of the head does not activate when it should, it could be due to a problem with the camera ground. It proposes two ways to implement it correctly: - option # 1: the camera earth connected

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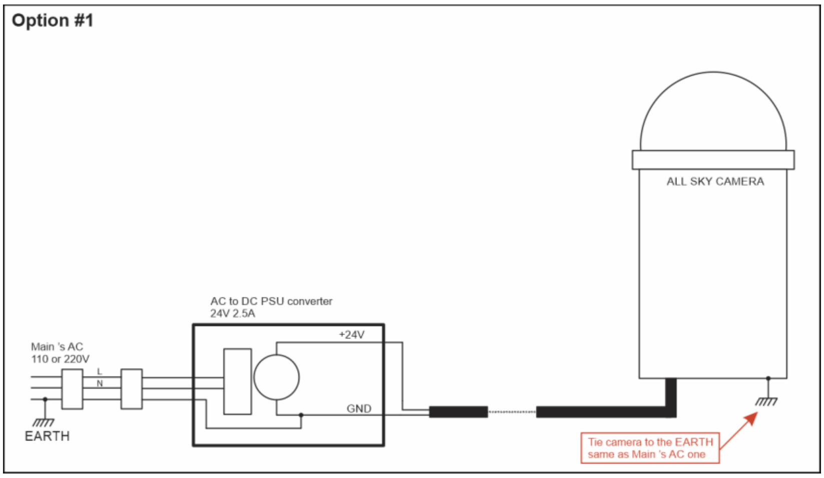
<tr>
<td></td>
<td>


Figure 11. All Sky Camera: grounding configuration #1.

- option # 2: the power supply floating option

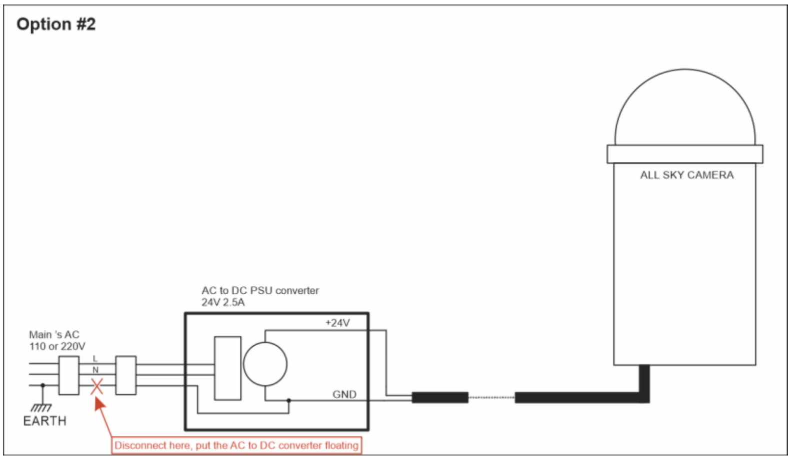


Figure 12. All Sky Camera: grounding configuration #2.

To implement the most suitable one before installation.
</td>
</tr>
</table>

2.3.4. Points to consider

As confirmed by ALCOR Systems[2], the power cable + RS232 (15 m) could be extended by using an available 30 m reliable USB extension that could be zoomed out to 45 m.

[2] Sales Alcor System [sales@alcor-system.com]

2.4. Cloud Sensor (Boltwood Cloud Sensor II)

The Boltwood Cloud Sensor II (RD06**,** User's manual):

- Measures the **amount of cloud cover** by comparing the temperature of the sky to the ambient ground level temperature. The sky temperature is determined by measuring the amount of radiation in the 8 to 14 micron infrared band. A large difference indicates clear skies, whereas a small difference indicates dense, low-level clouds. This allows the sensor to continuously monitor the **clarity** of the skies, and to trigger appropriate alerts.
- Detects **rain and snow** (it includes a **moisture sensor)**. To prevent false alarms due to frost or dew, a heater keeps the sensor slightly above ambient temperature. When rain or snow falls, the sensor is automatically heated to 70 °C. This clears the sensor quickly when the precipitation ends, and ensures that the sky-measuring thermopile has a clear view.
- Measures **wind speed**, using a specially-designed anemometer with no moving parts. The sensor will warn you when winds speeds are too high.
- Detects **daylight** and can be set to automatically close the roof to prevent any possibility of sunlight entering the telescope.
- Measures **humidity.**

The Cloud Sensor provides a continuous readout of temperature, humidity, and dew point, and detects how clear the sky is, humidity (snow and rain) and daylight, and measures ambient temperature, wind speed and humidity

2.4.1. Components

Table 6 lists its components (Figure 13).

Qtty	Items
1	Cloud sensor head (S/N 5018)
1	Cloud sensor mounting bracket (mounted)
1	Adaptor Box
1	30 m cable to sensor head
1	USB cable to PC
1	Power Supply

Table 6. Cloud Sensor: components.

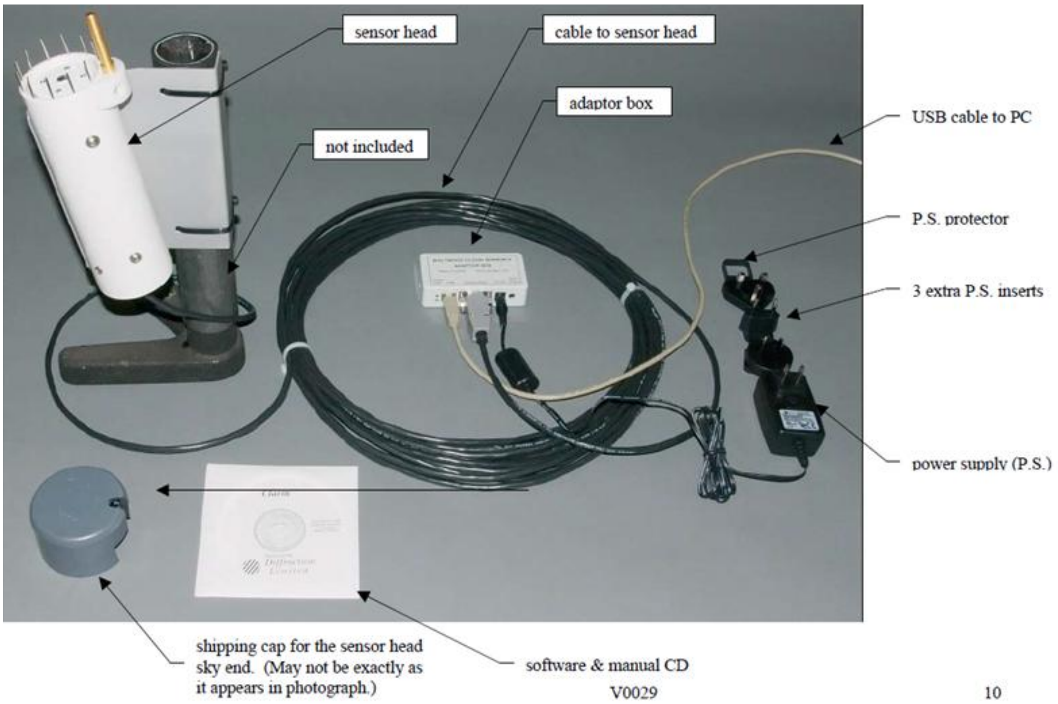


Figure 13. Cloud Sensor: components. Possible (top) / acquired (bottom).

2.4.2. Indoor/outdoor distribution

Figure 14 shows its proposed indoor/outdoor configuration.

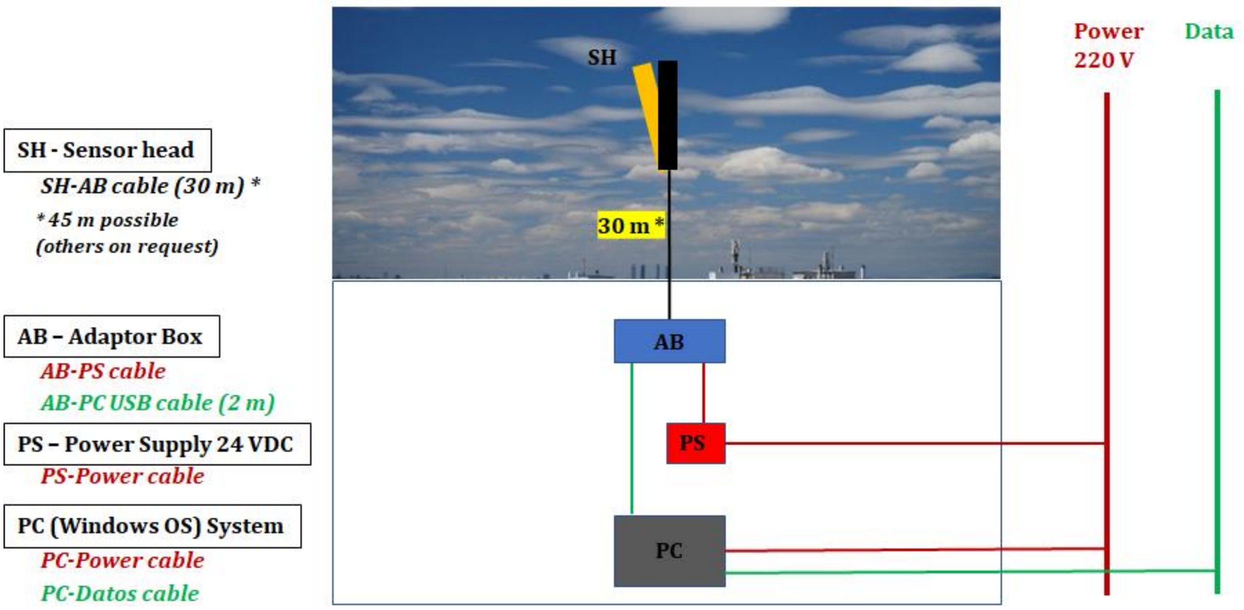


Figure 14. Cloud Sensor: test configuration.

2.4.3. Distribution and installation considerations

<table>
<tr><td>Installation place</td><td>Outdoors in a location that provides a clear view of the sky. Its field of view is in the shape of a cone with an included angle of approximately 80° (it is assumed ± 40°) with some sensitivity up to 120° (± 60°). Any substantial obstruction in that field of view will reduce the sensitivity and accuracy of the sensor head. Avoid obstructing it.

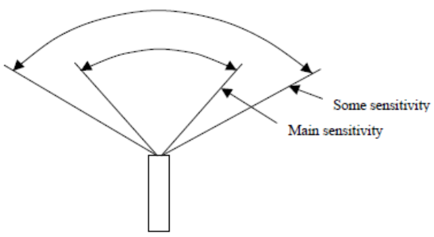
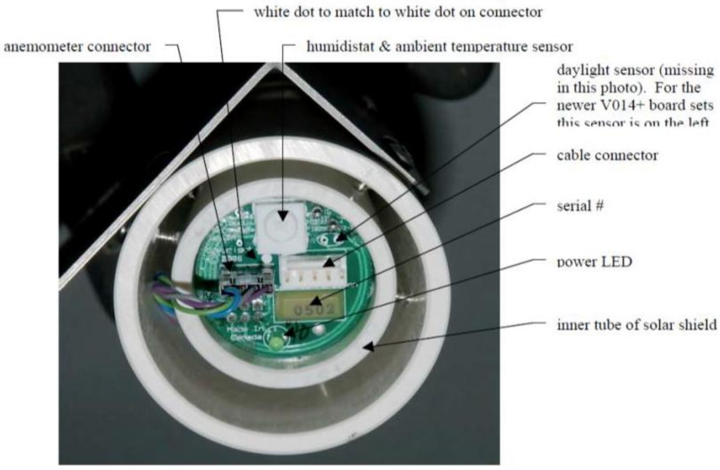


Figure 15. Cloud Sensor: sky angular coverage.</td></tr>
<tr><td>Sensor verticality</td><td>It must be installed at 10° from the vertical (the support that includes it guarantees it) so that the possible humidity that forms on the upper face can slip and do not fog the optical window of the sensor. If the wind direction at the installation site prevails in a certain direction, it is advisable to mount the sensor facing that direction so that it helps more to evaporate the water.</td></tr>
</table>

	 Figure 16. Cloud Sensor: relative orientation relative to the vertical.
Head sealing level	The sensor head incorporates sensors and a connection in its lower part. This connection does not seem very robust to be outside (humidity) and should be reviewed. The same for the printed circuit.  Figure 17. Cloud Sensor: Ground End of the Sensor Head.
No head shielding	The field of view should not be screened as the day / night detector needs to receive light from the ground.
Accessibility	The sensor needs maintenance (cleaning) so its location should not limit / prevent its access, but it should be far enough away so that it cannot be touched since the rain or humidity sensor and the wind probe can reach the 70°.
Location	The sensor head bracket is designed to mount to a metal or wood vertical tube or pole. One possible location would be the edge of the roof using a piece of aluminium. An even better location would be to have it surrounded by greenery and mounted on a pole (this prevents the T sensor from being affected by the T on the roof or driveway at the end of a hot sunny day).
Ray protection	**The Cloud Sensor II has lightning protection on both the sensor head and the "adapter box".** This protects against close lightning, but not very close or direct lightning. It is recommended: - add an optical isolation device on the USB I/F between the "adapter" and the PC; - place a suitably grounded pole close to and higher than the sensor head; - use a thick ground wire to connect a ground rod either to the aluminium support plate of the head sensor or to the metal post on which the head sensor is mounted;

	- in the area where the cable enters the building, give it a few turns to help prevent a direct lightning strike from entering the building through the cable.
ESD protection	The same devices that protect against lightning protect against ESD. These devices route any lightning or ESD surges to the USB cable shield and from it to the PC chassis, which must be grounded. If proprietary lightning protection devices are added to the cable, ensure that the 4800 BPS data on pins 1 and 2 of both connectors (red/green pair on the cable) is not significantly distorted by the protection devices. If the firmware ever needs to be updated, 38.400 BPS must be passed if the function available in the Settings window is used. If changes have been made to the supplied ceiling wire configuration, this data rate might high. In that case see RD06 (§16.2) and use “Start Bootloader & Download”.

3. Installation: proposal

3.1. Indoor / outdoor distribution

After analyzing the architecture of each of the subsystems, the first outdoor/indoor installation scheme of the subsystems is proposed.

- **Analysis of the outdoor side**
  - Figure 18 shows the arrangement of the sensors outdoor with respect to their respective indoor components. In yellow the lengths of the connections are shown, with the upper figure indicating the length in the current configuration and the lower figures indicating the possible extensions of the same already confirmed by the manufacturers.
  - Based on this, the limiting element, with the material currently received, are the two antennas of the Air Traffic Receiver (AT-1) that have 3+2 m long cables. After consulting with the manufacturer, both sensors could be separated by up to 15-20 m with the purchase of the recommended extensions / cables.

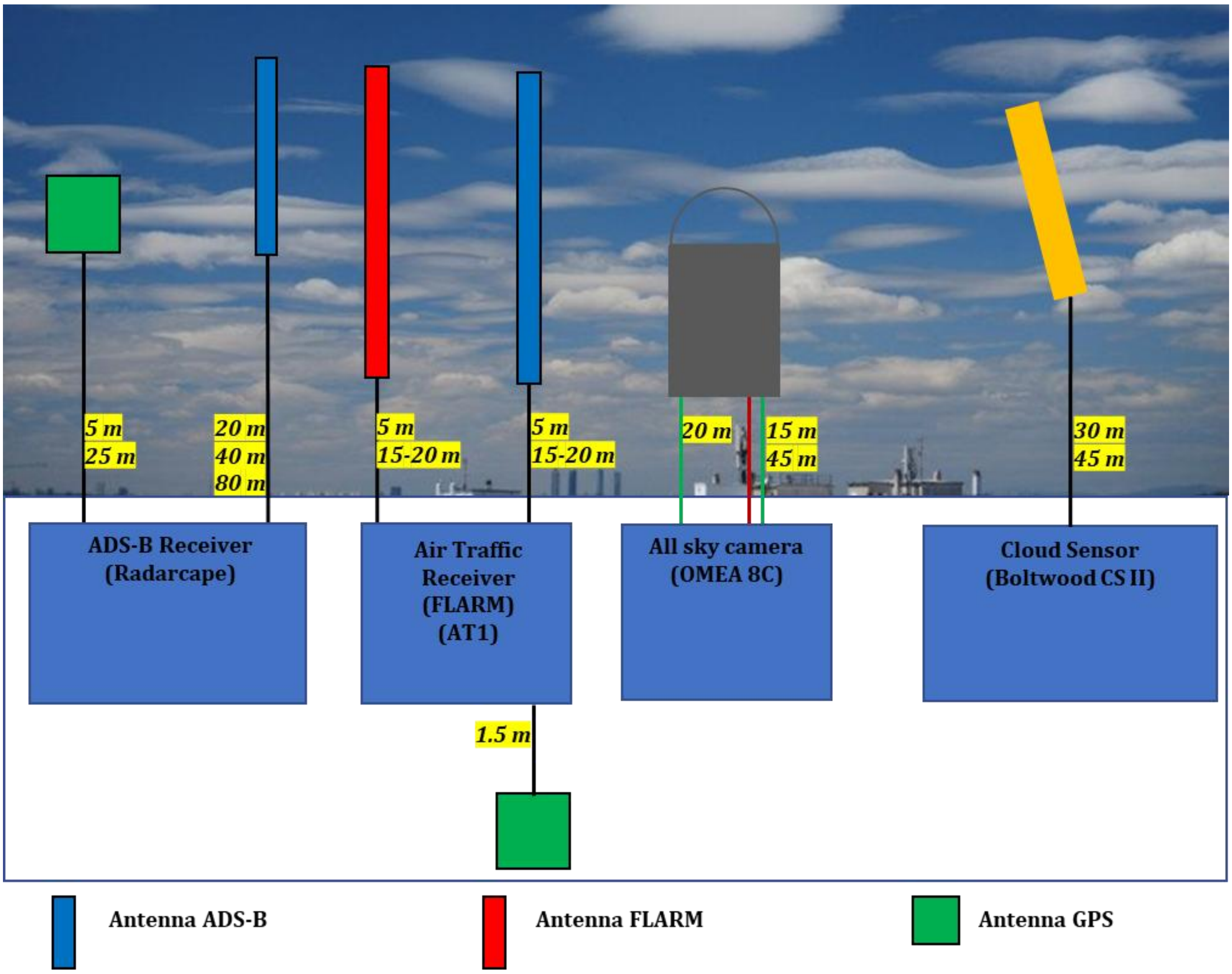


Figure 18. Outdoor installation: final configuration proposal.

  - The ideal would be to have lengths of the order of 15-20 m for all the subsystems, as long as this does not diminish the performance of each one of them.
  - The equipment must be grounded in the manner indicated for each one of them.

- In the case of equipment with Temperature sensors, heat accumulation areas (vents, air conditioning, ...) must be avoided.

- **Analysis of the indoor side**

  - With regard to the connections to the network, no problems have been detected: if a cable falls short, concentrators (hubs) or switches (switches) could be used to facilitate their access to the network.
  - It is assumed the installation of a switch to connect the relevant equipment (ADS-B, PC, and Raspberry-pi).
  - With regard to the power outlet, no problems have been identified either.
  - The Air Traffic Receiver (AT-1) GPS antenna is short for outdoor installation. It will be necessary to establish whether its operation in the proposed internal location is satisfactory (in any case, it is being analyzed whether it can be extended).
  - During the analysis, some aspects to be taken into account in its final installation at the station were also pointed out, which also affect its installation during the first tests.

3.2. Electrical power requirements

Table 7 shows the contributions of each subsystem.

Subsystem Model	Supply	Other
ADS-B Receiver Radarcape	AC power supply: 110 V AC o 230 V AC Alternatively (RD02): DC Power supply: 5 V DC / 1 A	Power Consumption: - 5 V DC external power supply (15 W) - Standard 5.5 mm / 2.1 mm DC connector (plus inside, minus outside) - Electrical current with GPS (including antenna) typical 720 mA
Air Traffic Receiver AT-1	**Electrical** Voltage (nom.) 13.8 V DC Voltage (operational) 9 to 32 V DC Low voltage shutdown 8 V DC Current (nom.) 0.15 A	See §7.3.1
All sky camera OMEA 8C	Converter: - Input: 100 - 240 V AC - Output: 24 V DC / 2.5 A	Manufacturer/Model: RS PRO/RS 188-781
Cloud Sensor Boltwood Cloud Sensor II	Converter: - Input: 110 - 240 V AC - Output: 24 V DC / 0.75 A	See §7.3.2

Table 7. Electrical power budget contributions.

3.3. Antennas to be used

With respect to the FLARM antenna of the FLARM receiver there is no open point.

With respect to the rest:

- ADS-B antennas.

  - Each of the two receivers has an external ADS-B antenna. In principle, only that of the ADS-B receiver is necessary. However, for the verification of the FLARM receiver, in the absence of signals of this type, it is necessary to mount the ADS-B antenna. Sharing an antenna between both receivers has been considered, although eventually each receiver will be used with its antenna.

- GPS antennas.

  - While the ADS-B has a GPS antenna ready to work outdoors, the FLARM receiver is only ready to work indoors, with a 1.5 m long cable extendable to 6 m (to be purchased if necessary) . If the reception of said antenna when mounted inside a building was poor, it would be necessary to acquire one prepared for the exterior with its corresponding longer cables.

3.4. Installation proposal

Based on the above information, the installation described in Figure 19 is proposed as a starting point: components in green and orange boxes will be located outdoors inside a wall mounting enclosure.

The final configuration, including power and data components, is described in the next paragraph.

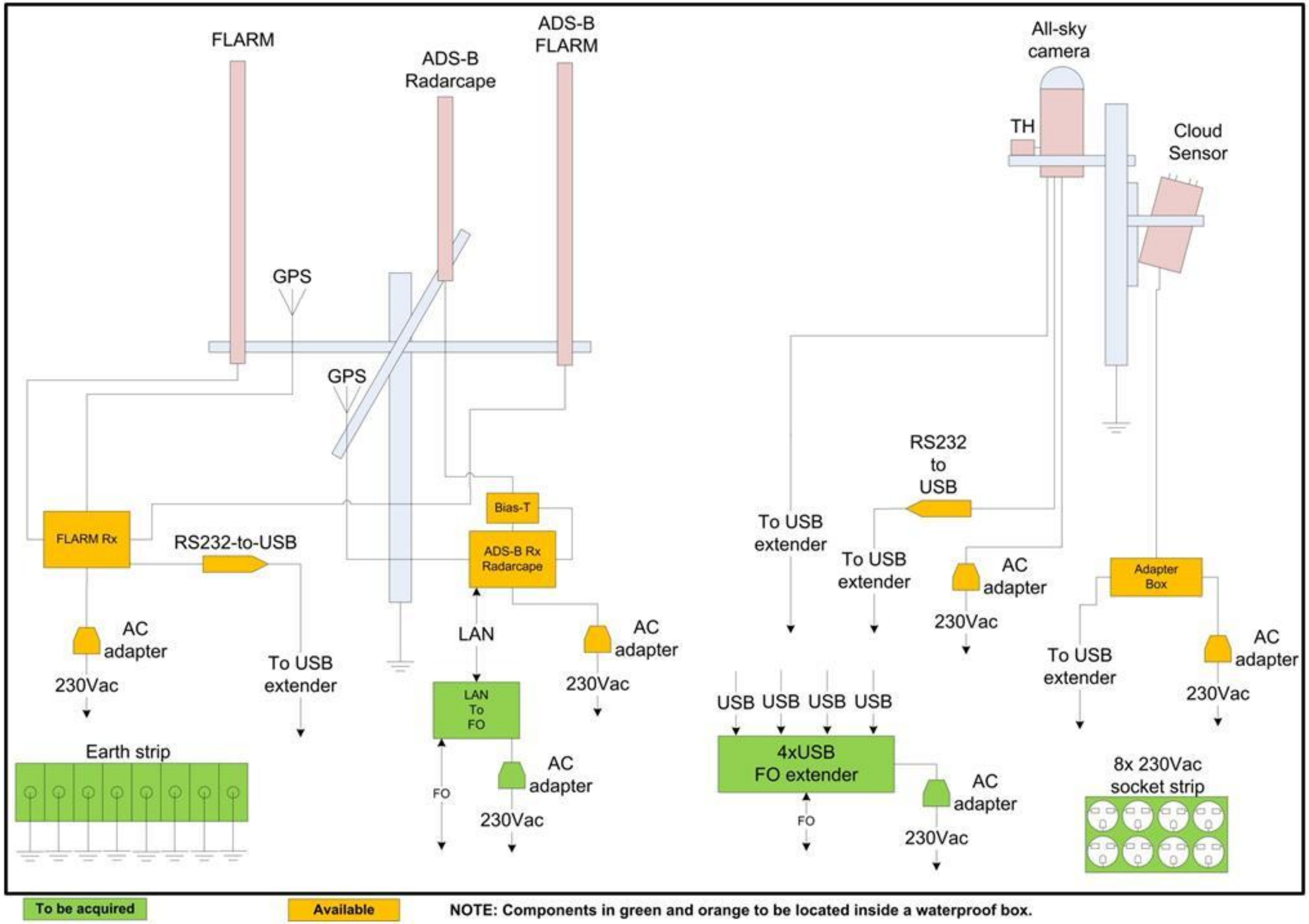


Figure 19. Installation proposal.

4. Installation: final configuration

4.1. Introduction

This section describes the final configuration of the installation for testing the different system sensors described above. The described elements are:

- Wall mounting enclosure
- Data link components
- Heat removal subsystem

The final configuration of the installation is also included.

4.2. Wall mounting enclosure

In the outdoor side of the installation, part of the equipment has to be enclosed in a wall enclosure against intrusion, dust, and water for protecting it of the environment, mainly, the water.

Manufacturer	RS PRO
Model	775-5340
Description	**IP66 Metal Wall Box with Din Rail** CRNG Multi-Purpose Steel Wall Box Enclosure with Cable Gland Plate. External dimensions: 600 mm x 600 mm x 210 mm IP Rating: IP66  Figure 20. Wall mounting enclosure.

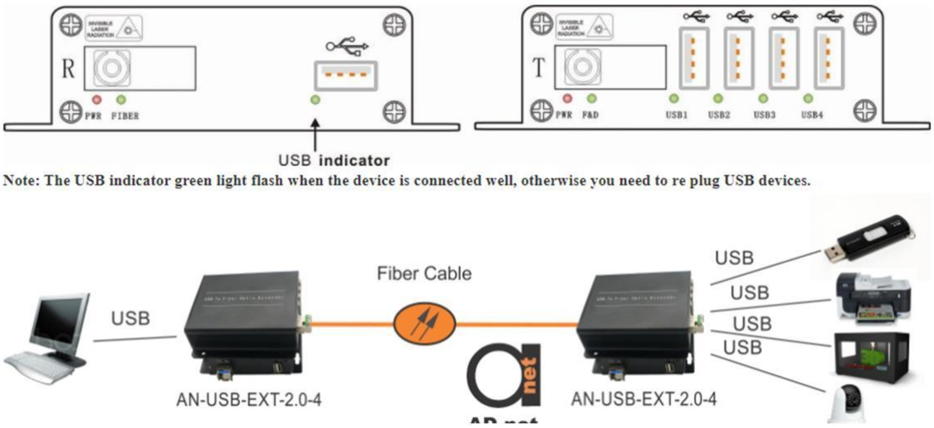
More information in RD07.

4.3. Data link subsystem

The sensors under tests shall be linked to a computer both for controlling them and acquiring their output data. It follows a description of all the components needed for that (see Figure 32).

4.3.1. 4 port USB2.0 Fibre Optic Extender

USB to Fibre optic ports connection kit with 4 connectors.

Manufacturer	AD-NET (Taiwan)
Model	AN-USB-EXT-2.0-4
Description	**4 PORT USB 2.0 To Fibre Optic Extender.** Supports USB 2.0, USB 1.1 & USB 1.0 (not compatible to USB 3.0 or USB 3.1) Max distance 250 m, for single mode single Fibre or OM3 multi mode single Fibres, ST connector – One pair (Transmitter + Receiver).  Figure 21. 4 port USB2.0 Fibre Optic Extender.

More information in RD08 and RD09.

4.3.2. ST DX MM 10/100 2 km Media Converter

LAN to Fibre Optics to LAN converter.

Manufacturer	LightMax (Spain)
Description	**LM-CM110STM02** ST DX MM 10/100 2 km Media Converter Fast Ethernet converter that converts a copper medium (RJ45) to an optical medium (Fibre optic). Transmission speed: 10/100 Mbps in copper and 1300 nm for optical fibre; maximum distance 2 km; OM3 multimode fibre optic.  Figure 22. Media Converter.

4.3.3. Fibre optical cable

The final installation needed three fibres about 35 m long. (40 m recommendable).

Manufacturer	LightMax (España)
Description	**LMODUOM3X6** Optical Cable · Ind/Out · MM OM3 · Dielectric Armoured Unitube · 6 Fibres · Tube 6 Fibres · LSZH · Class Eca · Color Code France Telecom  Figure 23. Fibre optical cable.

4.3.4. Fibre optic patch cords

Manufacturer	LightMax (España)
Description	**LMPISTPM3SX020ZH09LT001AQ** Pigtail · ST/PC · MM OM3 · Simplex · 2.0m · LSZH · 900um · Loose Tube · One Piece · Aqua New par t number 2020 · **LMPISTPM3SX020ZH09LT001AQ**  Figure 24. Fibre optic patch cords.

These patch cords were fused to any of the three fibres in the optical cable. Fusing quality was measured by means of an OTDR measurement device (MT9083A, Anritsu).

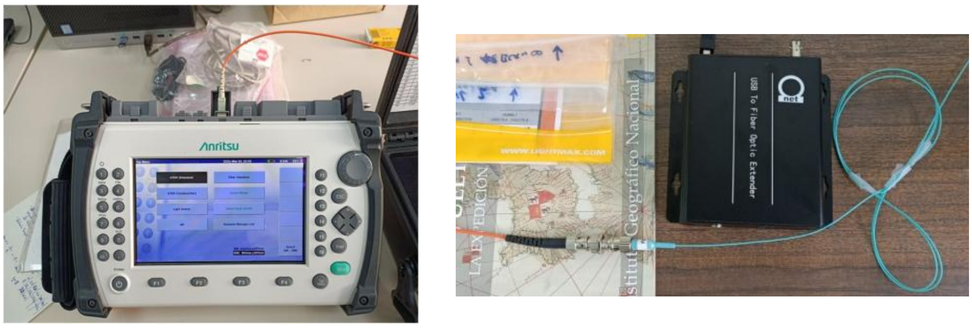


Figure 25. OTDR measurements of the fibre optic patch cords fusion.

4.3.5. Control PC

The whole system is controlled by means of a Windows running PC located in a control room 40 m far from the external installation.

4.4. Heat removal subsystem

The heat generated by the different modules and power supplies inside the enclosure increases its internal temperature. In order to prevent reaching any potentially dangerous temperature for the items inside, this heat shall be dissipated as much as possible.

For doing that, a fan based heat removal subsystem has been implemented. By means of an internal probe, internal temperatures are continuously sensed. When reaching a prefixed temperature value (Thot) the fan is triggered by means of a solid-state relay. After achieving a lower prefixed temperature (Tcold) the fan is turned off by the relay. Internal hot air is expulsed through an exhaust hose located at the left side of the enclosure. It incorporates an internal grid for avoiding small animals enter to the enclosure.

It is observed that, after installing the axial fan and the exhaust hose, the tightness of the enclosure is broken although no major problems are expected with regard to the introduction of water droplets during heavy rains.

The components of this subsystem are described below.

4.4.1. Axial AC Fan

Specification	Description
Manufacturer	Sunon
Model	SF23080A
Part Number	2083HBL.GN
Distributor	RS
Distributor stock number	544-0251
Supply Voltage	230 V ac
Dimensions	80 mm x 80 mm x 38 mm
AC or DC Operation	AC
Power Consumption	18W
Maximum Current	90mA
Air Flow	40.8m^3/h

Table 8. Axial AC Fan characteristics.

More information in RD10.

4.4.2. Temperature probe

It is a **Temperature & Humidity Sensor**

Precision Barometric Pressure & Altimeter manufactured by Adafruit.

Specification	Description
Manufacturer	Adafruit
Model	Sensirion SHT31-D
Part Number	2857
Distributor	Mouser electronics
Distributor stock number	485-2857
Supply Voltage	230 V ac
Dimensions	12.7 mm x 18 mm x 2.6 mm

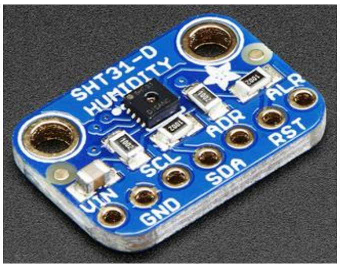


Table 9. Temperature probe characteristics.

More information in RD11.

4.4.3. Single-board computer

This is a Raspberry Pi 3 Model B+.

Processor:	Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4GHz
Memory:	1GB LPDDR2 SDRAM
Connectivity:	■ 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2, BLE ■ Gigabit Ethernet over USB 2.0 (maximum throughput 300Mbps) ■ 4 × USB 2.0 ports
Access:	Extended 40-pin GPIO header
Video & sound:	■ 1 × full size HDMI ■ MIPI DSI display port ■ MIPI CSI camera port ■ 4 pole stereo output and composite video port
Multimedia:	H.264, MPEG-4 decode (1080p30); H.264 encode (1080p30); OpenGL ES 1.1, 2.0 graphics
SD card support:	Micro SD format for loading operating system and data storage
Input power:	■ 5V/2.5A DC via micro USB connector ■ 5V DC via GPIO header ■ Power over Ethernet (PoE)–enabled (requires separate PoE HAT)
Environment:	Operating temperature, 0–50°C
Compliance:	For a full list of local and regional product approvals, please visit www.raspberrypi.org/products/raspberry-pi-3-model-b+
Production lifetime:	The Raspberry Pi 3 Model B+ will remain in production until at least January 2023.

Table 10. Single-board computer characteristics.

A 3D printed case was produced at the OY for protecting the computer.

More information in RD12.

Figure 26 shows the temperature probe connected to the single-board computer.

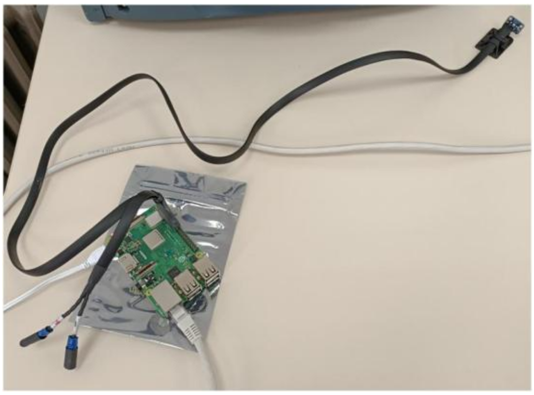


Figure 26. Temperature probe connected to the single-board computer.

4.4.4. Solid state relay

This ventilator is activated by a single channel AC output solid state relay by Crydom.

Specification	Description
Manufacturer	Crydom
Part Number	EZ240D5
Category	AC Output
Series	EZ Series
Control Voltage Range	3-15 VDC
Maximum Load Current	5 A
Operating Voltage Range	24-280 VAC
Mounting	Panel

Table 11. Solid State Relay characteristics.

More information in RD13.

4.4.5. Connectivity

The 220 V fan is connected to the mains with a solid-state relay (normally open output). The control voltage to the relay is provided by the Raspberry Pi through the GPIO pin 17 BCM, 3.3 V. The temperature sensor uses the i2c bus, and is therefore connected to the corresponding pins (3 and 5, SDA1 and SLC1). The Python libraries Rpi.GPIO and adafruit_sht31d were employed to write the temperature monitoring and fan control software.

4.5. Final installation

Figure 27. Work during the installation of the equipment abroad: fusion of the optical fibres to their terminals and verification of fusion.

The diagram of the final installation is shown in Figure 28: it includes indoor and outdoor hardware. The following figures (Figure 29 to Figure 32) individually show each of the different modules, subsystems, and elements.

The outdoor part of the installation was set up on the roof of the Observatory offices building (see Figure 33 which includes the cardinal directions).

Different views and compositions of the outdoor installation are shown from Figure 34 to Figure 37.

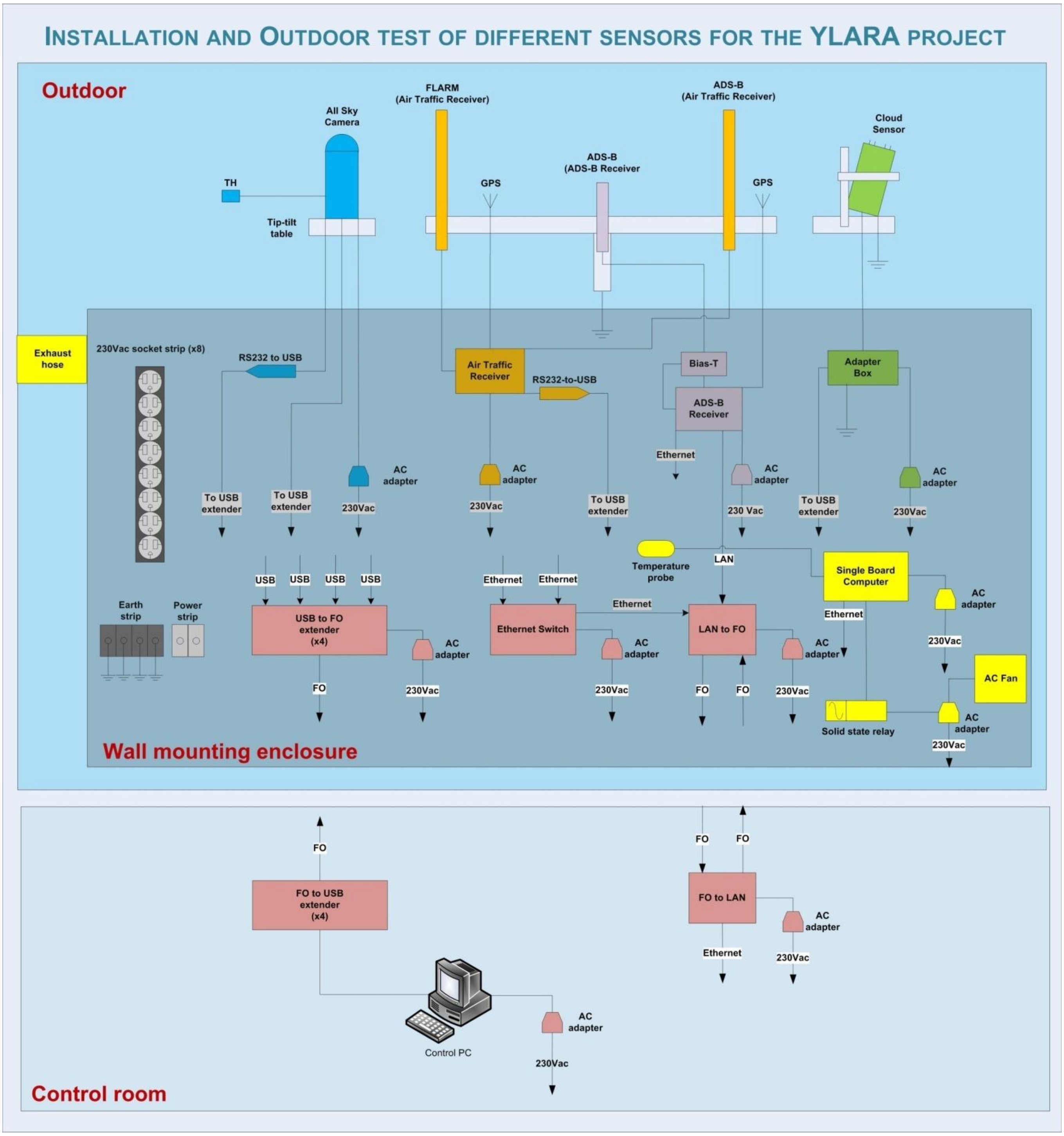


Figure 28. Final installation.

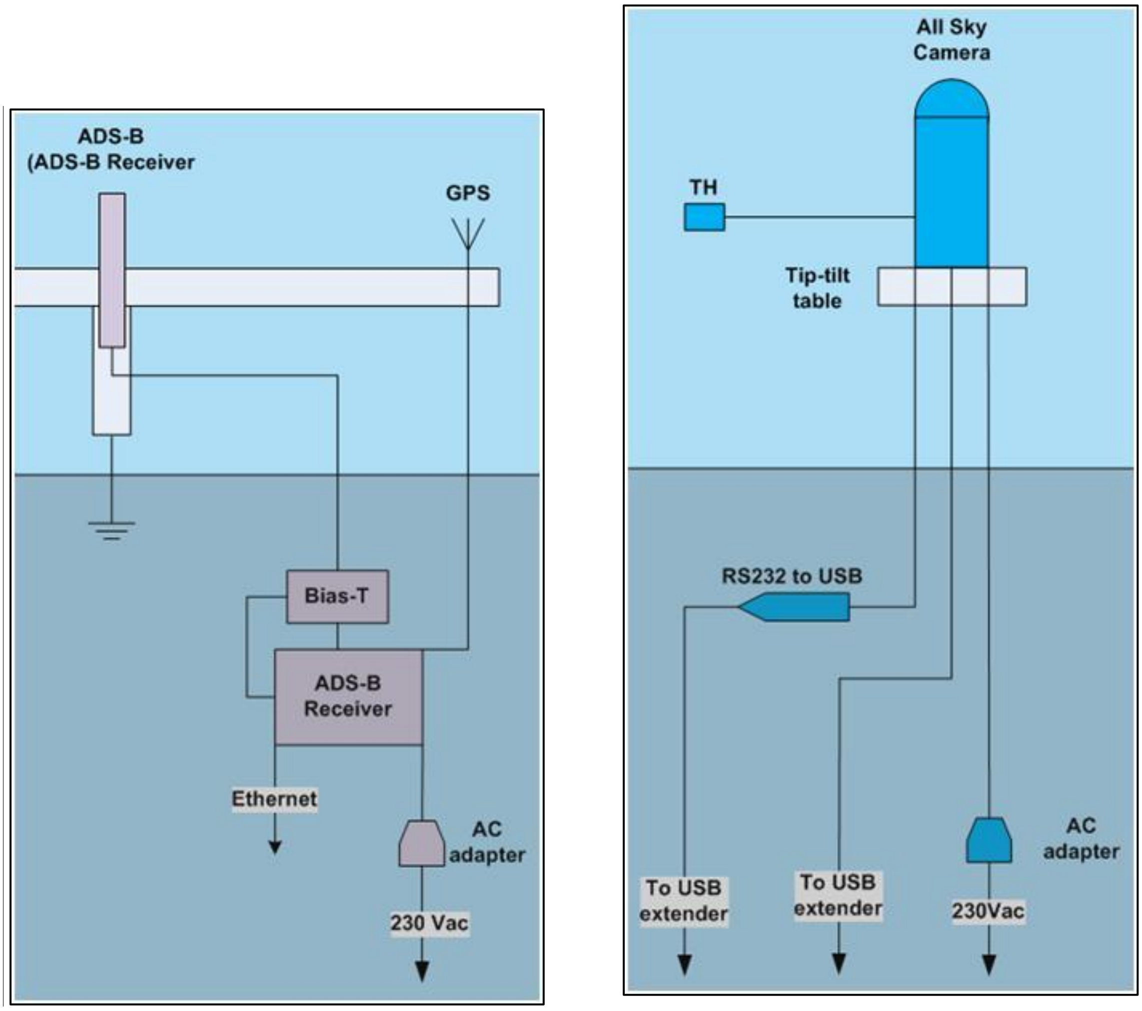


Figure 29. Final installation: (left) ADS-B Receiver (Radarcape) and (right) All sky camera (Omea-8C) modules.

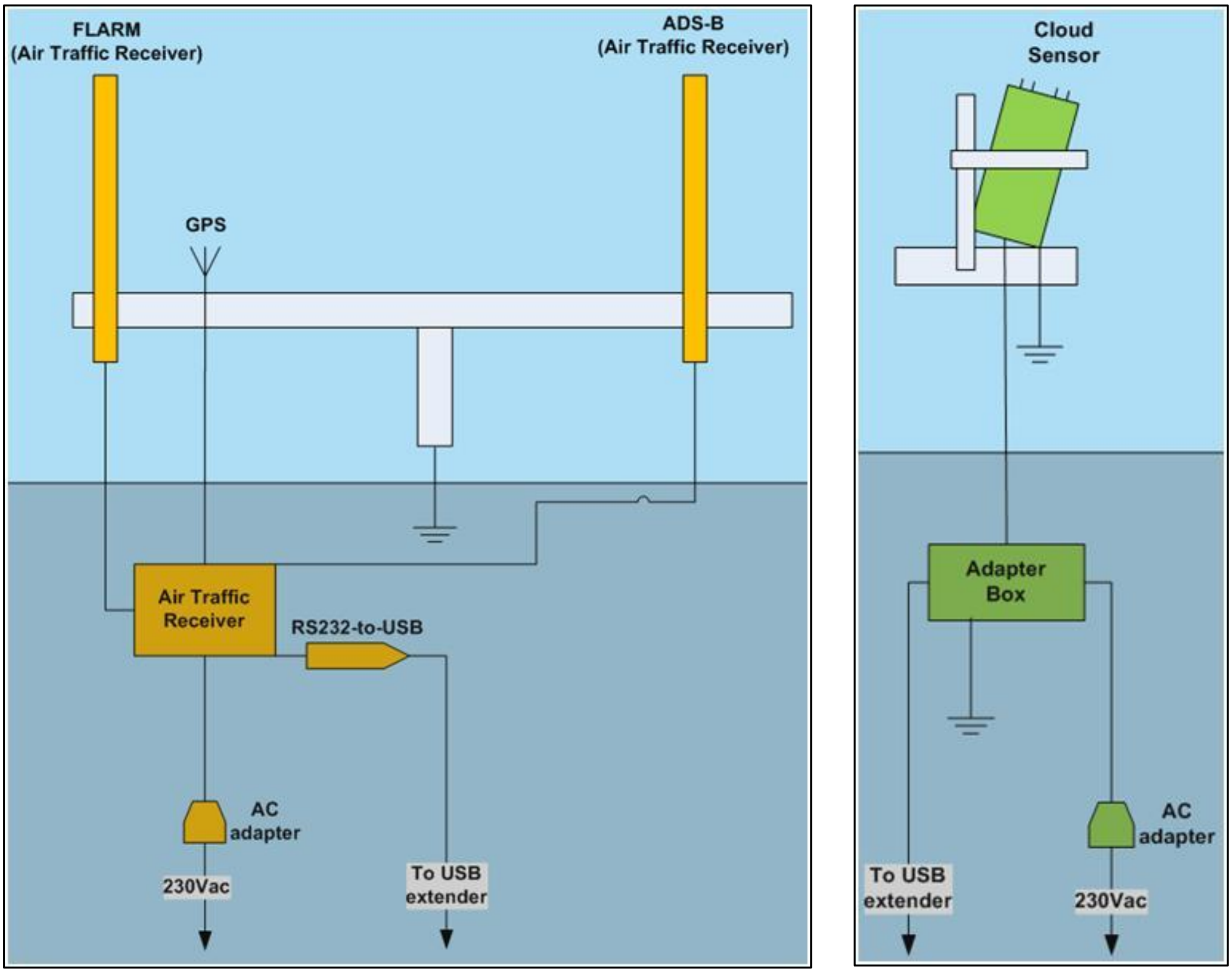


Figure 30. Final installation: (left) Air Traffic Receiver (FLARM) (AT-1) and (right) Cloud Sensor (Boltwood Cloud Sensor II) modules.

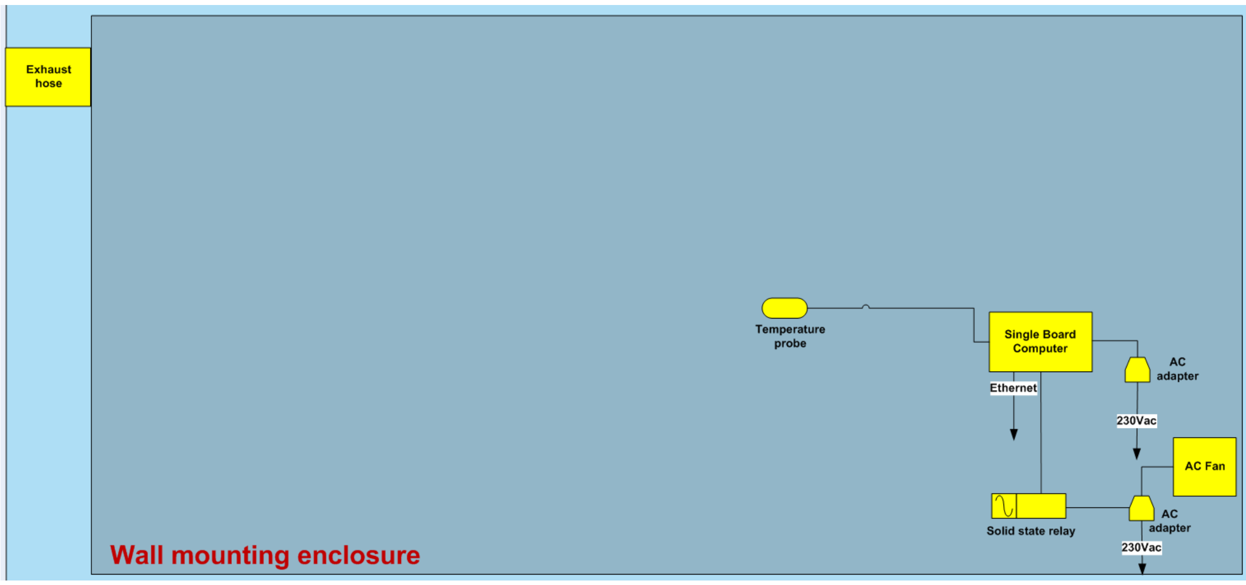


Figure 31. Final installation: Heat removal subsystem.

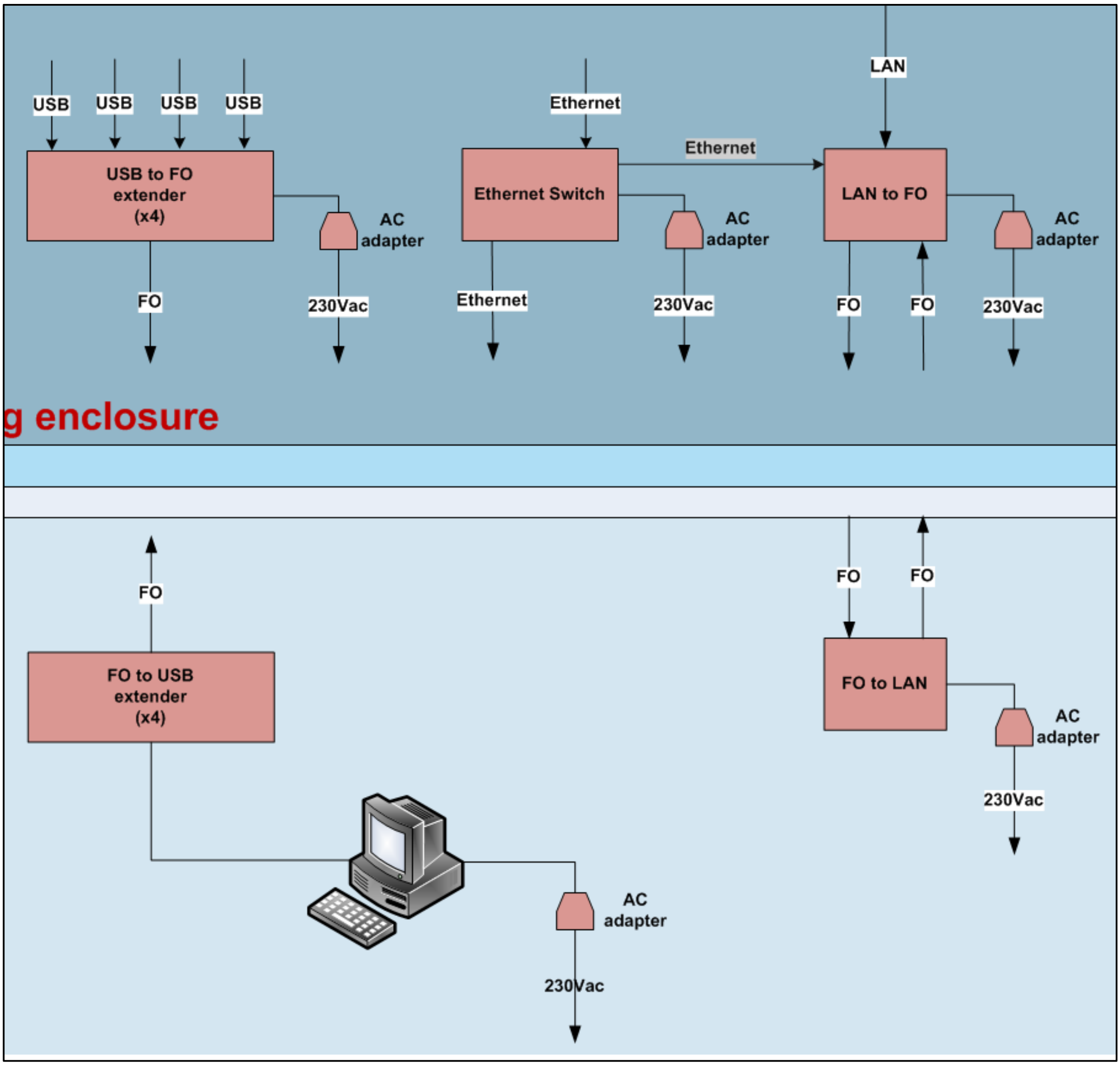


Figure 32. Final installation: Data link components.

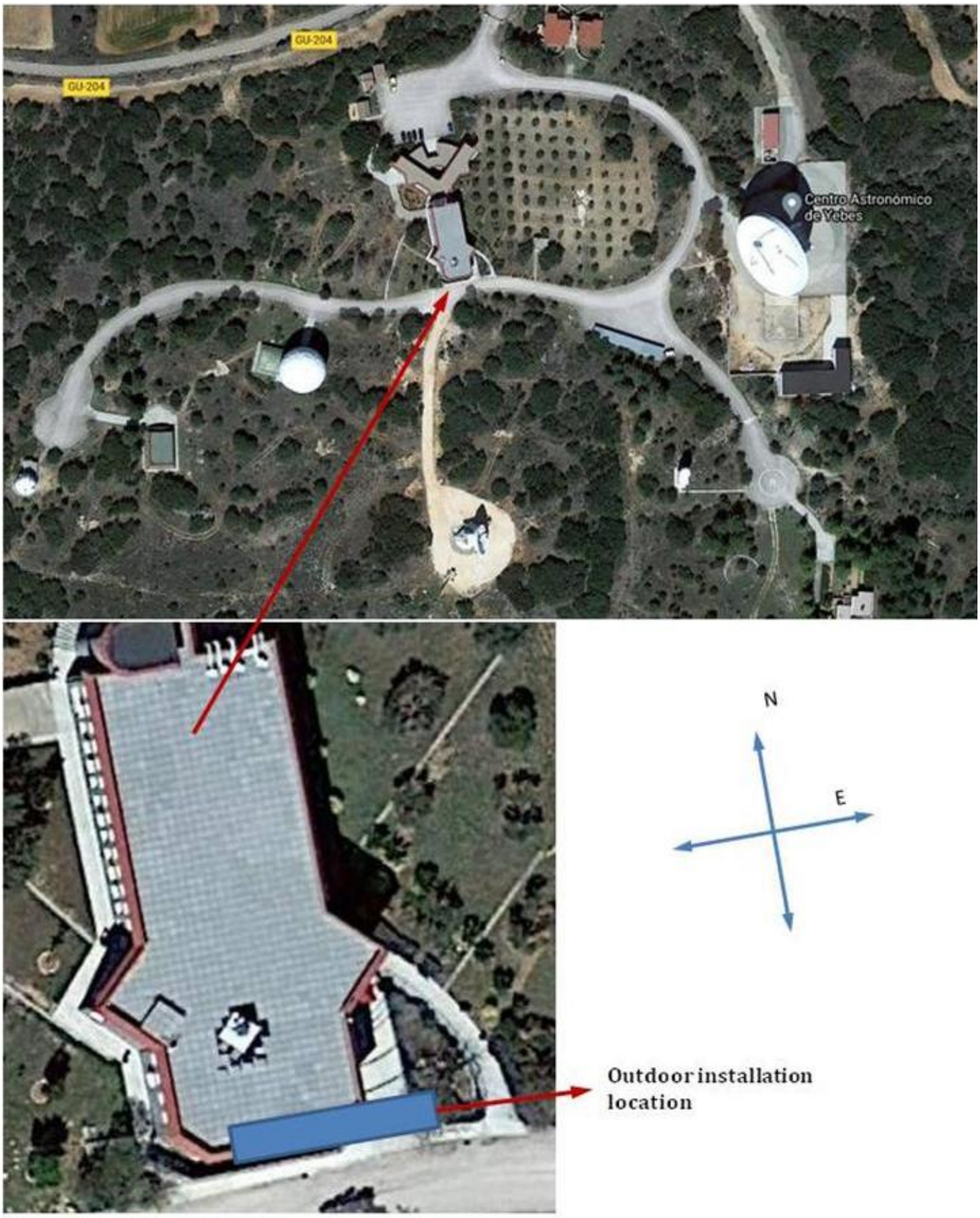


Figure 33. Final installation: location of the outdoor components on the building roof.

Figure 34. Outdoor installation: general view.

Figure 35. Outdoor installation: All sky camera.

Figure 36. Outdoor installation: cloud sensor.

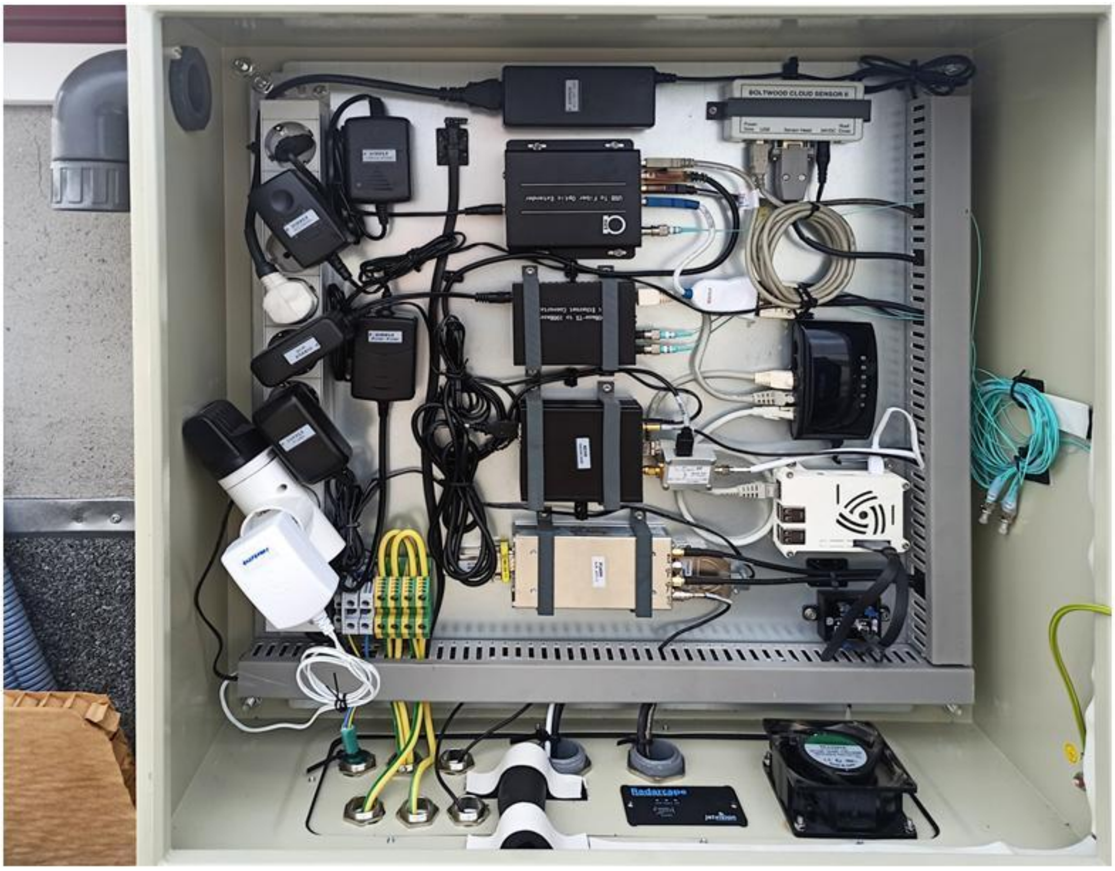


Figure 37. Outdoor installation: wall mounting enclosure in its final configuration.

5. Tests description

5.1. Internal tests

Just after its reception at the Observatory, the modules under test were checked (visual inspection, power on, device configuration familiarization and first light) and conveniently reported (RD14).

The first step during these internal tests was to connect all the modules under test to the PC and power them on just to check the communication between the control PC and them, the verification being successful.

Next, all equipment was tested to check their acceptable working order. These initial, basic tests were followed by a period of several months during which all equipment was powered on and their status monitored regularly. In addition to these basic checks, two of the modules (ADS-B receiver and all-sky camera) were tested more thoroughly. This responds to their higher importance for the regular operation of the future SLR station. Moreover, as the data gathered by these two devices is somewhat complementary, some efforts will be devoted to their integration for the characterization of their capabilities. While the analysis of the data collected will be reported elsewhere, here we will note observations deemed relevant from the installation and testing point of view.

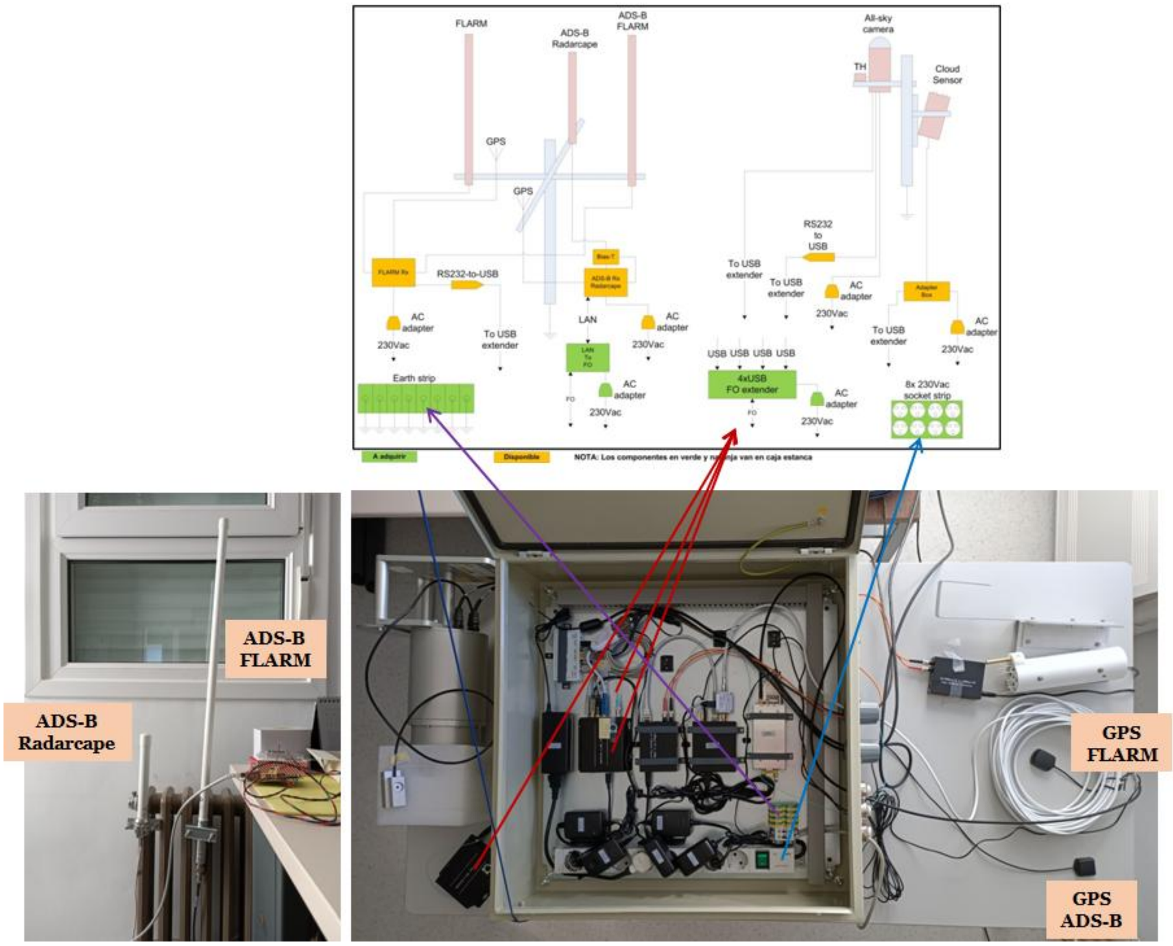


Figure 38. Enclosure with some of the modules under test during the internal tests period.

5.2. External tests

Before reporting the tests performed for each individual device, we will describe the thermal management solution implemented in the outdoor enclosure.

5.2.1. Thermal management

Although the power dissipation of the set of devices installed in the enclosure is very modest, the limited airflow and the high ambient temperatures experienced at the Observatory may result in internal temperatures that exceed the operating ranges given by the manufacturers, detailed, when available, in Table 12. It also shows the relative humidity operating range, when available.

Device	RH (%)	T range (°C)	T storage (°C)
4 port USB2.0 Fibre Optic Extender - AN-USB-EXT-2.0-4	0 – 95	-20 – 70	-40 – 85
ST DX MM 10/100 2 km Media Converter - LM-CM110STM02	5 – 90	0 – 70	
Fibre optical cable - LMODUOM3X6		-40 – 60	-40 – 60
Fibre optic patch cords - LMPISTPM3SX020ZH09LT001AQ (Pigtail)		-40 – 85	
All sky camera - OMEA 8C		-35 – 45	
Cloud Sensor - Boltwood Cloud Sensor II (Power supply)	20 – 80	0 – 40	
Cloud Sensor - Boltwood Cloud Sensor II (Adaptor box)		0 – 70	
Air Traffic Receiver (FLARM) – AT-1	No severe	-40 – 55	
ADS-B Receiver - Radarcape	dry	-10 – 60	

Table 12. Operating temperature ranges

For some of them, there is additional information from the suppliers regarding this point:

- ADS-B Receiver – Radarcape.

  For normal operation a Radarcape requires a dry place with moderate temperatures.

- Air Traffic Receiver (FLARM) – AT-1.

  AT-1 does not require external cooling. However, lower operating temperatures extend equipment life. Reducing the operating temperature extends the mean time between failures (MTBF). Units tightly installed heat each other through radiation, convection, and sometimes by direct conduction. Even a single unit operates at a much higher temperature in still air than in moving air. Fans or some other means of moving the air around electronic equipment are usually a worthwhile investment.

  Category A – Standard humidity environment

  It ordinarily provides an adequate test environment for equipment intended for installation in civil aircraft, non-civil transport aircraft and other classes, within environmentally controlled compartments of aircraft in which the severe humidity environment is not normally encountered.

Description	Section	Category	Conditions
Temperature / Altitude D1	4.0	D1	
Low Ground Survival Temperature	4.5.1	D1	-55°C
Low Operating Temperature	4.5.1	D1	-40°C
High Ground Survival Temperature	4.5.2	D1	+85°C
High short Time Operating Temperature	4.5.2	D1	+70°C
High Operating Temperature	4.5.3	D1	+55°C

Table 13. Air Traffic Receiver (FLARM) – AT-1: Environmental tests are performed in accordance with RTCA DO-160G

- All Sky Camera.

  This kind of cameras are working at higher temperatures . As an example, there are systems installed outdoor in Arabia Saudi.

- Cloud Sensor - Boltwood Cloud Sensor II.

  The adaptor box and power supply are intended to be used at room T and near a computer.

  - The power supply is rated for 0 °C to 40 °C.
  - The adaptor box is rated for 0 °C to 70 °C. This means that using the power supply in an unheated observatory in very cold winter conditions or very hot summer conditions should be avoided. A -40°C rated adapter box may be available (consult Cyanogen if required).

  It is noted that in case of placing the adaptor box outdoors, a new adaptor box shall be purchased in order to be operated below 0 °C.

Since the outside temperature can reach up to 40 °C, a thermal management solution was deemed necessary to avoid potential damage to some of the equipment.

With a total of eight power supplies, seven individual devices, cabling and the support structure (back plate and cable routing), the free volume in the enclosure is sufficient, but not plentiful. Thus, heat dissipation by passive means was not foreseen to be sufficient. This was confirmed by indoors testing, which showed that the temperature inside the box was about 20 °C higher than room temperature.

A combination of passive and active cooling strategies was implemented:

- Installation of the enclosure against a south-facing wall.
- Installation of a screen to ensure the box was shaded at all times, with insulating material to minimise radiative heat from an existing metal flat surface that provided support.
- Active cooling system with fan, air duct, and temperature monitoring device (see description at §4.4, Heat removal subsystem).

The passive means ensures that no direct sun exposure could heat the enclosure, save for a few minutes in the morning, of no concern given the low ambient temperature at those times. In addition, the active cooling system helps to keep the inside temperature under a reasonable range during the warmer hours of the day.

Briefly, the active cooling system consists of a temperature and relative humidity sensor connected to a Raspberry Pi (Tbox in the Figure 39), which monitors the temperature values at regular intervals and controls an air fan. When the measured temperature exceeds a set point value, the Raspberry Pi switches on the air fan via a relay device. Air circulation is ensured with the installation of an air duct in the top part of the enclosure. Additionally, the internal temperature sensor of the Radarcape ADS-B (Trc in the Figure 39) receiver is also read by the Raspberry Pi. The temperature control can be set to operate automatically or to accept manual commands to provide readings of the various devices, set point temperatures, and check their status.

The temperature and relative humidity values recorded during a 12-day period are shown in Figure 39. All the traces are highly correlated, as they are all driven by the outside temperature (not shown). The internal temperatures of the boards (the Raspberry Pi and the Radarcape's BeagleBoard) are about 20 °C higher than the different temperatures recorded by the sensors inside the enclosure, and they are very similar to each other. In warm summer days there are a few hours where the temperature of the boards exceeds 60 °C, which in the case of the Radarcape is outside its nominal operating temperature. Given the limited time during which the highest temperatures occur, the temporary nature of the installation, and the lack of a straightforward solution, this situation was assumed with no further action.

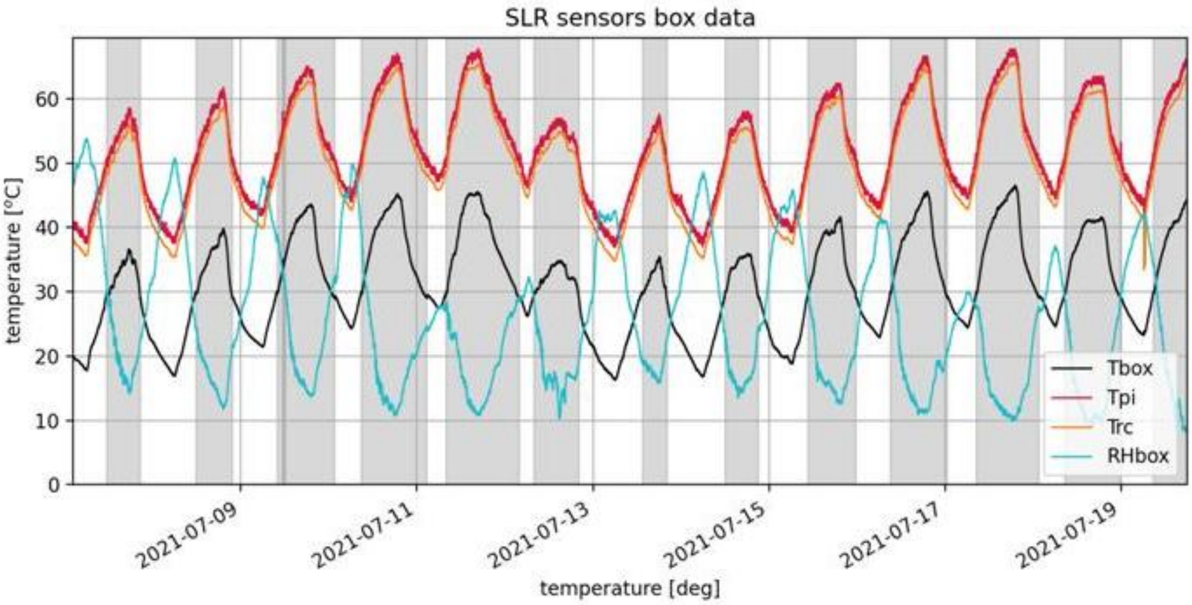


Figure 39. Temperature (°C) and relative humidity (%) readings from the various sensors available in the enclosure. Tbox: temperature inside the box. Tpi: temperature of the Raspberry Pi board. Trc: temperature of the Radarcape device. RHbox: relative humidity inside the enclosure.

Regarding the relative humidity inside the enclosure, the warmer temperature that develops inside ensures that it is never too high, and always lower than the outside ambient relative humidity (not shown).

5.2.2. ADS-B Receiver (Radarcape)

Basic communications testing

The Radarcape ADS-B receiver offers a number of different interfaces to access the data it collects. These are described by the manufacturer as:

- High level: web-based presentation of aircraft data.
- Medium level: aircraft data already processed easily accessible by user developed programs.
- Low level: raw Mode-AC, Mode-S, and ADS-B data with different levels of error checking.

The most basic testing of the communications and the device is simply done by accessing its web interface. Its configuration, also accessible in the same way, is straightforward and requires very little user input. For the testing period, the option to receive data from external sources was activated to collect aircraft data from the OpenGlider network in our geographic location. Additionally, the multilateration option (MLAT) was switched on as well.

The device appeared to be in perfect working order, reaching an acceptable GPS fix promptly and showing excellent geographic coverage (Figure 40).

Figure 40. Screenshot of the web interface of the Radarcape ADS-B receiver, showing the detected aircraft in real time.

Data retrieval

For anything other than the basic display of the aircraft data in the map view offered by the device, it is necessary to retrieve the data employing one of the lower-level interfaces. For the purposes of the present testing, and in principle also during regular operation of the future SLR station, there is no need to have access to the raw packets collected by the device. The decoding of these data is not trivial to perform, requires the implementation of multiple error checks, and increases the communication bandwidth and processing time needs. All this is implemented efficiently in the device itself programmed in an FPGA, which makes decoding the raw data unnecessary for our purposes. The medium level interfaces available are:

- Aircraft list JSON: decoded data in JSON
- Port 30003: decoded data in CSV
- deltadb.txt: similar to Port 30003, changes in the aircraft list since last request

The data access interfaces recommended by the manufacturer are the JSON and deltadb.txt ones, since use of the TCP stream of Port 30003 is discouraged due to its low efficiency and high processor load it entails. The JSON interface has been employed exclusively for our data retrieval.

The JSON interface is accessed via HTTP. It contains many fields present in the ADS-B data messages plus a few others added by the software running in the device (e.g. time of last message, distance, aircraft category). An up-to-date list of the fields can be found in the Jetvision online documentation (RD17). A Python program was written to retrieve the data at a suitable interval (1 second), display the aircraft list and plot it in real time in the local horizontal frame, and save the data to disk. From March to August 2021 the receiver was powered on most of the time, and data was collected continuously and saved for several periods of up to three weeks each. A preliminary, descriptive analysis of the data is presented below.

Geographical coverage

The placement of the aerials in an elevated position on the roof of the main building of Yebes Observatory offers an excellent line of sight, exceeding what is required for the intended use of the ADS-B receiver. As it is shown in the Figure 41, the horizon is essentially unobstructed by natural features: the only significant obstacles are the primary reflector of the 40 m radio telescope and the radome of the decommissioned 13 m antenna, towards the east and west directions, respectively.

Figure 41. Horizon of the Observatory from the location of the ADS-B, FLARM, and GPS antennas.

It must be noted that the eventual placement of both the equipment and its antennas will be in a nearby location within the perimeter of the Observatory, so the very local horizon will be different.

Figure 42. Geographical coverage of the ADS-B receiver from Yebes Observatory. a) Computed horizon line-of-sight contour at 2000 m (yellow) and 13700 m (blue). b) Actual coverage for a period of five days.

The set of geographical points visible from a given location is known as the viewshed, which can be computed to include points above ground at any arbitrary altitude. Viewshed analysis informs about the possibility of achieving signal reception from a certain location, excluding diffraction and reflection effects. A computation of the viewshed can be obtained from several online services, although few of them offer the possibility to compute it for points above ground. The website www.heywhatsthat.com has been used, primarily designed for the recognition of mountain ranges and computation of panoramas from digital elevation models. The visibility contour for two different heights from the location of the ADS-B receiver at Yebes Observatory is shown in Figure 42a. The blue line in the figure is the contour for points at 13700 m of altitude, which is approximately the highest-flying altitude of commercial aircraft. As the local horizon is quite flat, this contour approximates a circle, although the shadows cast by the mountains northwest of Madrid are evident.

The actual coverage achieved with our receiver is shown in Figure 42b, where the locations of a subset of aircraft positions collected during a 5-day period are plotted (+750k points). While the visible volume is by no means filled homogenously due to the finite flight paths in the air space, the reception limits are well defined. These are in good agreement with the expectations for line-of-sight communications obtained online. At these ranges, the signals received appear only limited by Earth's curvature and geographical obstacles.

The actual data contains a few radial shadows where little or no data are visible. These are caused by terrain features blocking the signals, and are of no practical concern for our application as they appear at very low elevations.

Distribution in elevation over OY

The data collected contains rich information about the aircraft equipped with ADS-B transponders. The information available includes position and velocity, vertical rates, heading, type and identity of aircraft, wind speed, outside temperature, and quality parameters of the broadcasted positions.

The coordinates transmitted by the aircraft are geographical, plus either or both barometric and geodetic height. It must be noted that of the two types of altitudes are available, for surveillance applications the most appropriate one is geodetic altitude, avoiding the need for meteorological corrections to apply to barometric height data. The geographical coordinates have to be transformed to the local horizontal plane (Alt/Az), which is the frame used by telescopes for pointing and the most appropriate one for aircraft location awareness.

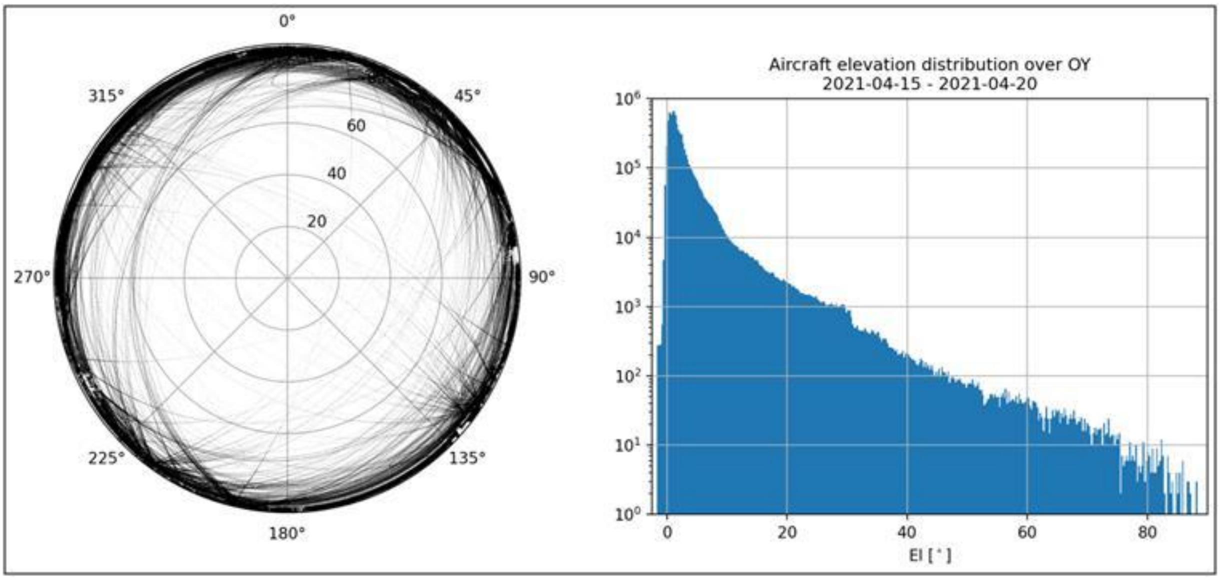


Figure 43. a) ADS-B positional data in the Az/El frame. b) Distribution in elevation of the data.

Figure 43a shows the positions in the Alt/Az frame of the same data set shown in Figure 42. Most of the ADS-B messages decoded by the device are at great distances from the Observatory, and therefore very low in the horizon. In fact, 95% of the signals detected belong to aircraft at elevations below 8.3°, and 98.9% below 20.0°. Clearly, the amount of data to process in real time for air traffic surveillance and avoidance of accidental laser illumination is a tiny fraction of the total. For context, the minimum operational elevation planned for the SLR station at Yebes Observatory is 15.0°. The right-hand side plot in Figure 43b shows the distribution in elevation of the positions in the dataset, in logarithmic scale.

Data reception

Power levels

The approximate signal level of each received message is available from the ADS-B device. No details about how these measurements are performed nor their expected accuracy are given in the documentation. The numerical values for the data set we have been working with in these sections are shown in Figure 44. The plot of signal levels against elevation shows that the highest power signals are not found at very high elevations. Nevertheless, the data with power levels above -40 dBm appear at short distances (<50 km). This indicates that the dispersion in the distribution of signal level received is largely dependent on the particular transponders equipped in the aircraft, and less so on the distance, as long as it does not exceed about 100 km. Beyond 100 km to 200 km the distribution of signal levels plateaus at about -75 dBm, but the frequency of very low signals at -90 dBm and below increases.

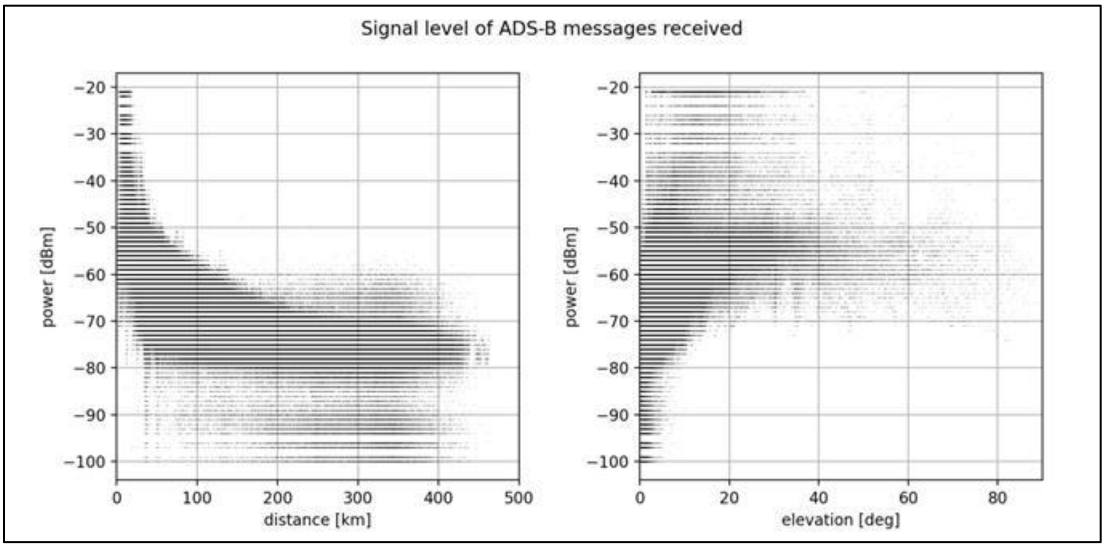


Figure 44. Power levels of the ADS-B packets, as reported by the device, by distance (a) and elevation (b).

Time interval

The plots shown so far are snapshots of all the aircraft positions collected over a time period of several days. It shows excellent geographical coverage which in principle appears limited only by line-of-sight reception. However, it is possible that there exist reception problems for individual aircraft, which would be masked in the aggregated plots. Discriminating single aircraft is necessary to detect these potential issues, which could give rise to erratic flight paths, unstable data reception times, or missing data.

A basic feature of the data indicating a solid and reliable reception is the time interval between consecutive ADS-B messages for each aircraft. The transmission rate of the ADS-B protocol is randomised between 0.4 and 0.6 seconds. This randomisation prevents aircraft from having synchronized transmissions on the same frequency, avoiding the overlap between transmissions. For all these tests the data was retrieved from the ADS-B device at intervals of 1 second, which should also be enough during actual operations. This does not mean that the time interval between consecutive messages will always be 1 s. The device keeps an internal buffer with ADS-B messages, so the timestamp can in principle be from up to 1 s old. The distribution of the time intervals should however be centred at 1 s.

Aircraft can be identified using various identification codes present in the data, which in addition with time constraints can be used to select individual flights. For instance, if the time interval between the received messages with certain identification code is greater than a large value, e.g. 1000 s, it can be inferred that it probably belongs to different flights. That potentially a small minority of flights are misidentified with this heuristic is irrelevant for our purposes.

In the data set used in previous plots, 4272 individual flights were identified. The time interval between consecutive messages for each of them plotted against ground distance and elevation is shown in Figure 45. The distribution centred at 1 s is the main feature at all distances, from less than 1 km to about 400 km. Time intervals greater than 2 s are visible throughout, with a somewhat higher frequency at longer distances, beyond 200 km approximately. At ~35 km there is a double feature with high density of time intervals that do not follow the predominant data distribution. These data messages belong to aircraft approaching or leaving the nearby airport of Madrid-Barajas. Aircraft at very low altitude are near the line-of-sight limit, and therefore the reception of their ADS-B signals is unreliable, causing this feature.

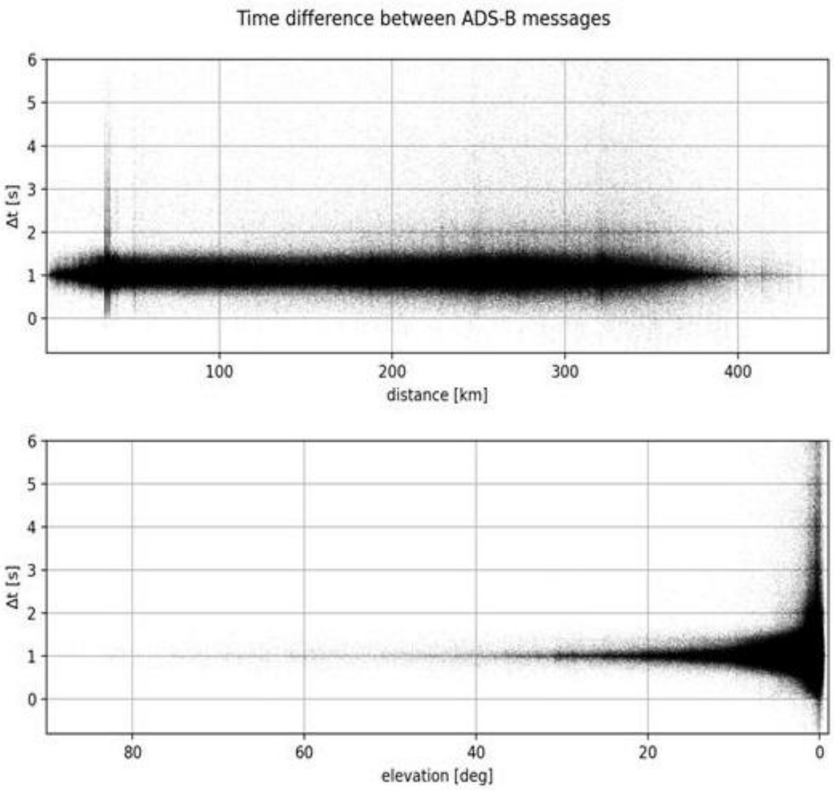


Figure 45. Time difference between consecutive ADS-B messages from individual flights, plotted against distance and elevation.

Examining the time intervals of the received messages according to the angular elevation of the aircraft reveals that the deviation from the regular 1 s interval takes place close to the horizon. At the elevation range where the SLR telescope of the future station will be operational (15 to 90 degrees), the reception of the ADS-B data is stable, as judged by the inter-message time intervals. The seemingly higher dispersion of the data at ~20–30 degrees is only apparent, caused by the higher density of points available at lower elevation.

Aircraft category

In addition to the identity of each aircraft given by their hex code, flight number, and registration, the aircraft category is checked against a regularly updated database and made available as another data field. This is not part of the ADS-B protocol, but an addition from the manufacturer of the device. The categories are defined according mainly to the take-off weight of the aircraft, as described in the user documentation [RD06]. The list of categories, shown in Table 14, contains three basic subdivisions: A[N] for powered aircraft, i.e. airplanes and rotorcraft; B[N] for lighter-than-air and drones; C[N] for surface vehicles or ground objects; and F[N] for vehicles relaying FLARM signals. Here [N] is a number that identifies the specific type of object within each main category.

Code	Type	Description
A1	ADS-B	Light (< 15500 lbs)
A2	ADS-B	Small (15500 >= lbs < 75000)
A3	ADS-B	Large (75000 >= lbs < 300000)
A4	ADS-B	Large (high vortex)
A5	ADS-B	Heavy (>= 300000 lbs)
A6	ADS-B	High performance
A7	ADS-B	Rotorcraft
B1	ADS-B	Glider/Sailplane
B2	ADS-B	Lighter than air
B3	ADS-B	Parachutist/Skydiver
B4	ADS-B	Ultralight/Hang glider/Paraglider
B6	ADS-B	UAV
B7	ADS-B	Space/Trans-atmospheric vehicle
C1	ADS-B	Surface vehicle - emergency
C2	ADS-B	Surface vehicle - service
C3	ADS-B	Obstacle - point
C4	ADS-B	Obstacle - clustter
C5	ADS-B	Obstacle - line

Code	Type	Description
A0	ADS-B	No category information
B0	ADS-B	No category information
C0	ADS-B	No category information
F0	FLARM	None
F1	FLARM	Glider/Motor glider
F2	FLARM	Tow/Tug plane
F3	FLARM	Helicopter/Rotorcraft
F4	FLARM	Skydiver
F5	FLARM	Skydiver/Drop plane
F6	FLARM	Hang glider
F7	FLARM	Paraglider
F8	FLARM	Aircraft reciprocating
F9	FLARM	Aircraft jet turboprop
F11	FLARM	Balloon
F12	FLARM	Airship
F13	FLARM	UAV
F15	FLARM	Static

Table 14. Aircraft categories.

It must be noted that the ADS-B receiver purchased for the YLARA project does not, on its own, receive FLARM signals. The option to connect an FLARM receiver is available, but unfortunately not of the kind purchased for the project (unless upon further investigation a way to integrate both devices is found). However, the Radarcape device does have the option to receive data from the Open Glider Network[3] (OGN). The OGN collects data using FLARM and OGN devices from contributing volunteers, and makes it available freely. The Radarcape can receive a live feed from

3 http://wiki.glidernet.org/

OGN and make the data available as its own. The usefulness of this is likely limited: the range of FLARM signals is quite low, and therefore the aircraft detected through the OGN feed will be close to the distant locations where the contributing receivers happen to be, therefore too low in the horizon to be a concern for SLR operations.

The proportion of aircraft from each category detected at OY is shown in Figure 42. Clearly, the vast majority of signals received belong to airplanes, as these not only are the most common aircraft in operation, but also include the categories that are or will soon be subject to mandatory equipment of ADS-B in many airspaces worldwide.

In the case of the EU airspace, the European Commission has introduced certain requirements for aircraft operators, geared towards the modernisation of the European surveillance infrastructure. In short, aircraft operating under instrumental flight rules exceeding 5.7 tons maximum take-off weight or 250 kn true airspeed are subject to the mandate to equip ADS-B. All new aircraft had the deadline to comply by December 2020, but exceptions apply for retrofits (June 2023 as a general, or indefinitely for aircraft ceasing operations by October 2025). The current equipage level in the EU airspace, excluding state aircraft, is 87.6% (as of August 2021). It should reach essentially 100% by October 2025[4].

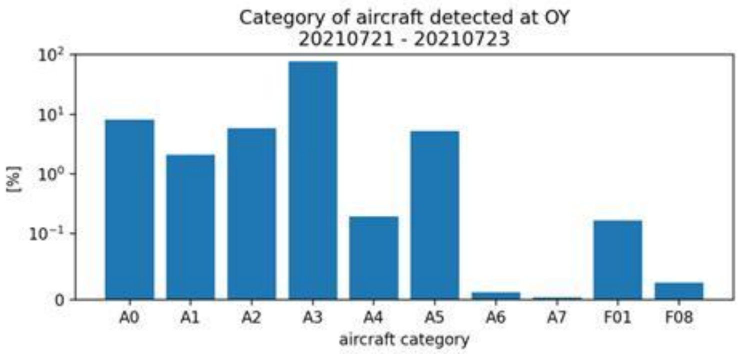


Figure 46. Proportion of aircraft detected by category. Note the logarithmic scale in the vertical axis.

Application: aircraft angular speed distribution

The data and plots shown in the previous sections attest, prima facie, the fitness for purpose of the Radarcape ADS-B device. An analysis of the data quality with the various integrity indicators included in the data, as well as the cross-validation with other independent means of the positions received, will be part of a future report.

Leaving therefore aside at this point the important question of positional data accuracy, we present here a brief analysis of one parameter of utmost importance for the operational purposes of having an ADS-B receiver at the observatory: the angular speed of aircraft as seen from the ground.

[4] https://ads-b-europe.eu/18

During SLR operations, it is imperative to count with some means to detect the presence of aircraft and cut off the emission of laser light in situations of potential illumination. For all kinds of safety measures employed, short of the establishment of a prohibited airspace, the angular speed of the aircraft is a key parameter to inform the adequate operational settings and safety margins of the equipment. Along with the expected uncertainties in the aircraft state vectors, the angular speed determines the minimum laser cut-off radius affordable by a given detection system, taking into account its response time.

Here we have used the positional data collected with the ADS-B receiver to determine the distribution of angular speeds of the aircraft. The apparent angular speed of an object depends only on its velocity and its distance. For illustrative purposes, we show in Figure 47 the speed values from each data point in a 5-day dataset, plotted against their altitude above ground. Several kinds of air traffic can be distinguished in the figure. Different flight levels are evident as vertical lines, particularly at the high end of the altitude axis. Air traffic traversing flight levels is seen throughout, from the lowest to the highest altitudes registered. Most of the lowest altitude traffic corresponds to aircraft departing or taking off the airport in Madrid, some 35 km westwards of the Observatory. Light aircraft traffic from an area NW of Madrid is visible as points at low altitude and speed (~2 km and 200 km/h).

As discussed previously, only a tiny subset of all the data received corresponds to positions visible from the Observatory above certain elevation. The points in the plot whose elevations are greater than 20 degrees are coloured in red. This indicates that very few flights will ever be a concern once their altitude is lower than ~3 km.

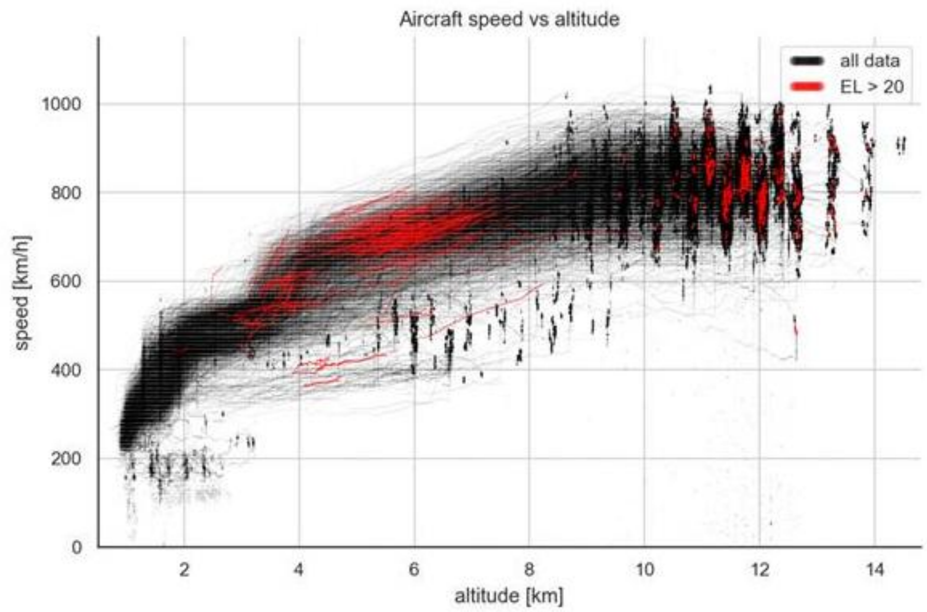


Figure 47. Speeds of aircraft detected from Yebes Observatory over a 5-day period, plotted against altitude. The points in red indicate data whose position in elevation was greater than 20 deg.

Although it would be straightforward to compute the angular velocities for each detected position as actually seen from the Observatory, we have computed instead the angular speeds as would be seen from ground points directly below the aircraft. This follows a worst-case scenario logic: regardless of the positions at which aircraft have been observed in any particular data set, we concern ourselves with the maximum angular speeds those aircraft could possibly have relative to a ground observer.

The resulting values are displayed in Figure 48. The greatest angular speeds are those from the nearest and fastest aircraft, which in practice is traffic incoming from or bound to the main airport, with angular speeds in excess of 5 deg/s. Using the same colour code as in the previous plot, it is apparent that angular speeds above 4 deg/s are not likely to be observed from Yebes, since the combination of aircraft altitudes and speeds required to achieve them appear to be very infrequent, if at all.

The subset of the data corresponding to light aircraft is visible in the lower left corner of the plot (~2 km altitude). Due to their low altitude, they appear with angular speeds reaching up to values comparable to those from heavy commercial aircraft transitioning flight levels (main central curve of the distribution). However, they seem to not exceed 3 deg/s most of the time. At the lower end of the angular speed distribution are the high altitude flights, which regardless of their highest air speeds they are too far away to move with apparent angular speeds higher than 1.5 deg/s.

The particular value for the laser cut-off angle to apply during SLR operations must be decided on the basis of the range of aircraft angular speed values—provided by this kind of analysis—, the capabilities of the surveillance system employed (e.g. accuracy of ADS-B positions), and the response time of the system to avoid accidental illumination.

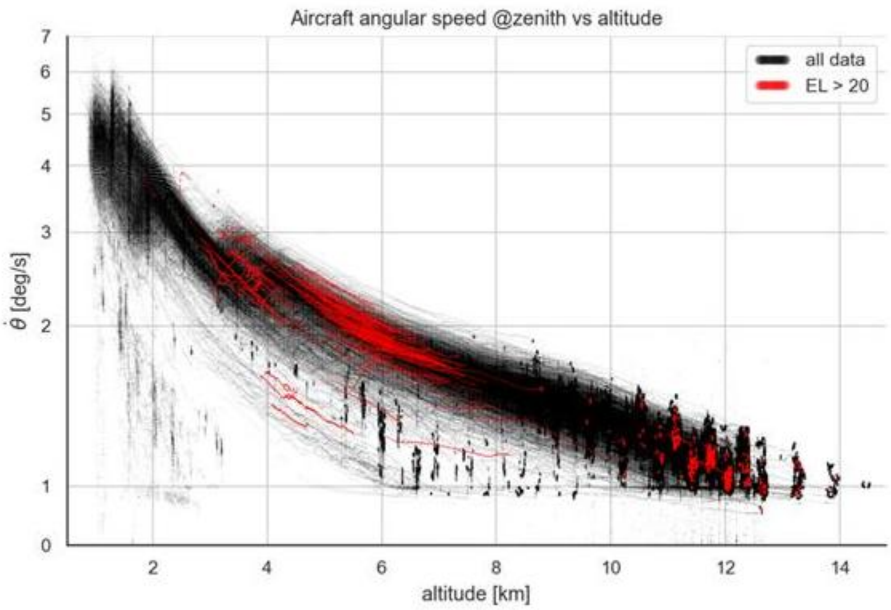


Figure 48. Angular speeds of aircraft detected from Yebes Observatory over a 5-day period, plotted against altitude. The points in red indicate data whose position in elevation was greater than 20 degrees.

5.2.3. Air Traffic Receiver (FLARM) (AT-1)

The FLARM receiver was tested at a basic level, due to limitations in the data that could be collected with this device, as explained below. The initial configuration of the Air Avionics AT-1 is best performed through a web interface accessible via a Wi-Fi connection (RD14, §6). This interface allows the user to check the status of the device, the GPS fix, number of ADS-B and FLARM data packets received, etc. Additionally, a set of flashing patterns from the LED lights on the device provide the user with a number of informative status, warning, and error messages.

Communication with the device is done through the serial port, for which a simple Python code was written to retrieve the data and to get status messages upon request. The details of the data interface and configuration settings are given in RD15 and RD16. The AT-1 supports NMEA and FLARM proprietary protocols, of which only NMEA was tested. NMEA 0183 is a data specification, controlled by the National Marine Electronics Association, employed for communications between different kinds of devices such as GPS receivers. The protocol is proprietary, although large portions of it have been reverse-engineered. For the present testing, the Python library pynmea2[5] was used, and a FLARM-specific proprietary type added to the library following the specifications in RD08.

The testing of communications and data retrieval was satisfactory, although limited due to the lack of reception of FLARM messages. Several reasons explain this:

- There are no nearby airfields for light aircraft.
- The location of the Observatory does not seem to intercept recreational flight routes.
- The testing period coincided with the Spanish COVID-19 restrictions, which severely limited all kinds of air traffic.

In lieu of FLARM packets, the testing involved retrieving ADS-B data, since the AT-1 device also has an ADS-B receiver and outputs the positional information in the same way and format as the FLARM data. The aircraft positions from the ADS-B messages were compared cursorily with the data from the dedicated ADS-B Radarcape device, which matched.

The performance of the FLARM device in terms of range and coverage remains therefore untested, and will be evaluated once the SLR station is built and the auxiliary equipment in place. We note at this point that the suitability of the FLARM system for air surveillance remains therefore to be confirmed. The purpose of FLARM is to provide an anti-collision system for flying aircraft. This goal, along with signal power constrains, limited computation capabilities of the board, and the choice of a proprietary, closed and encrypted communications protocol, make this system rather inflexible. For instance, the positional data received upon interrogating the device is not a complete snapshot of the internal list of detected aircraft, and priority is given to objects whose trajectories could pose

[5] https://github.com/Knio/pynmea2

a collision danger (which obviously does not apply here). There may be some way to extract the full information instead of a partial list, but it was not found in our tests[6].

RF emission

The FLARM device, being an aircraft anti-collision system, is both a receiver and a transmitter. The device broadcasts regularly its own position, for other suitably equipped aircraft to detect. The communication frequency employed is in the SRD860 band (868.2–868.4 MHz). It is therefore a short-range device, i.e. a transmitter with low capability of causing harmful interference to other radio equipment, limited to 25–100 mW effective radiated power. Additionally, the duty cycle allowed is limited (0.1%, 1%, or 10%). The range of the transmitted FLARM signals is usually under 5 km, although the latest versions (PowerFLARM) can reach over 10 km. According to the installation manual, the AIR Avionics AT-1 device emits between 10–25 mW.

Regardless of the low power of the signals emitted, these might pose an RFI problem within the context of the VLBI operations in the Observatory. To ascertain its operation will be safe from this point of view, the emission of the device was characterised with a spectrum analyser. The FLARM device was connected to the spectrum analyser, with a 25 dB attenuator between them.

The main signal at 868 MHz is found at the expected frequency (see Figure 49), with a peak power level of 13.3 dBm, or 21.5 mW (taking into account the attenuator). This frequency is outside the lowest observational band used with the two VLBI systems in the observatory (S-band, 2–4 GHz). Nevertheless, of some concern is the possibility of the presence of harmonics of the main frequency, which at sufficiently high levels could be problematic. Indeed, both the second and third harmonics, at ~1.74 GHz and ~2.6 GHz, were observed in our tests. The peak power levels of these harmonics were measured as -25 dBm and -40 dBm, respectively (3.2 μW and 89 nW), or 40 dB and 55 dB below the main peak.

[6]Baud rate settings may have an effect on the length of the positional data received with each call.

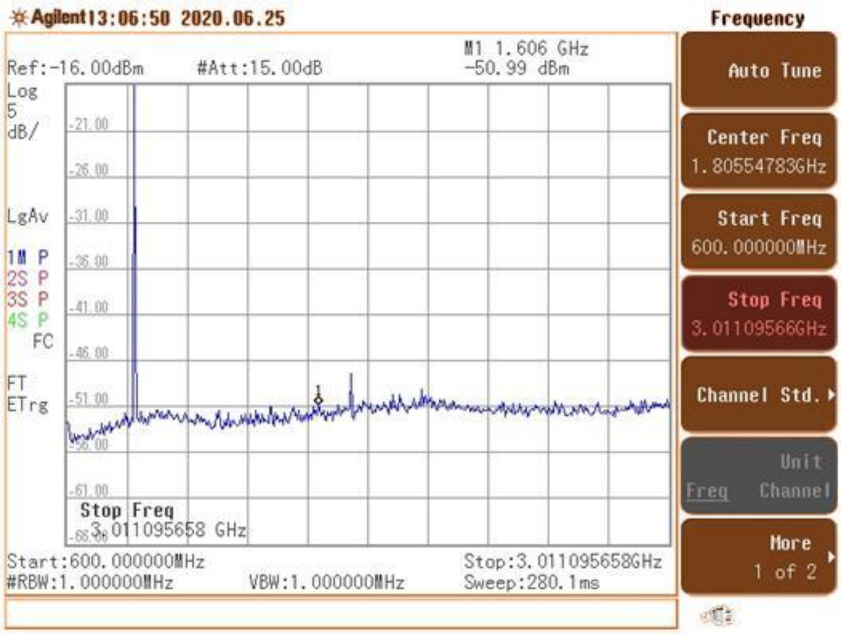


Figure 49. Emission spectrum of the FLARM device. The main peak at 868 MHz and its first harmonic at 1736 MHz are visible. NB. an external 25 dB attenuator was used.

Of these peaks, only the third harmonic could be of concern for the operations at the Observatory. This spectral region, around 2.6 GHz, is already polluted with RFI of mainly telephony sources. An assessment of the need to eliminate this signal will be made consulting the Yebes RFI team. If positive, a simple solution is to use a low pass filter to exclude emissions at frequencies higher than e.g. 1 GHz.

5.2.4. All Sky Camera (OMEA-8C)

The setup outdoor of the All Sky Camera (the "camera" along this paragraph) comprises several steps.

Camera positioning

Camera Levelling

The camera shall be levelled (local horizon) by means of its gimbal table (Table 5 and Figure 35). For that, a high precision bubble level was used. It is noted that this is mandatory for allowing the alignment of the overlay grid (see below this paragraph).

Camera Orientation

In order to help to orientate the camera East-West, by example, it would aid to have the detector (rectangular) aligned with the external mechanical components of the camera (the camera manufacturer's stand, by example). Unfortunately, this is not the situation. Due to that, it is recommended to add a rotational stage to the camera gimbal mount for helping with this. Having done that, it should be also convenient to materialise the cardinal points on the camera by means of labels. During these tests, they were materialise by means of attached plastic cable ties in the West direction (Figure 50 and Figure 52).

Figure 50. Outdoor installation: materialisation of the West direction on the camera body.

A correct knowledge of the camera positioning is needed to correctly integrate the spatial information coming from the other modules (aircraft positions) and satellite ephemerides in the same image.

Camera configuration

A summary of how to configure the camera for its operation can be found at its reception report (RD14). Information on some points of this configuration is expanded.

Camera focus encoder setup

It shall be setup to a value of **1270**, as it was found at the factory. Nevertheless, as the value can vary along the camera life, it is recommended to perform during the night a focusing test, as described in the camera user manual (RD05).

Overlay grid setting

Once the camera correctly positions, the overlay grid showing the stars and cardinal points can be properly done during the night. During the tests, the next grid configuration was selected.

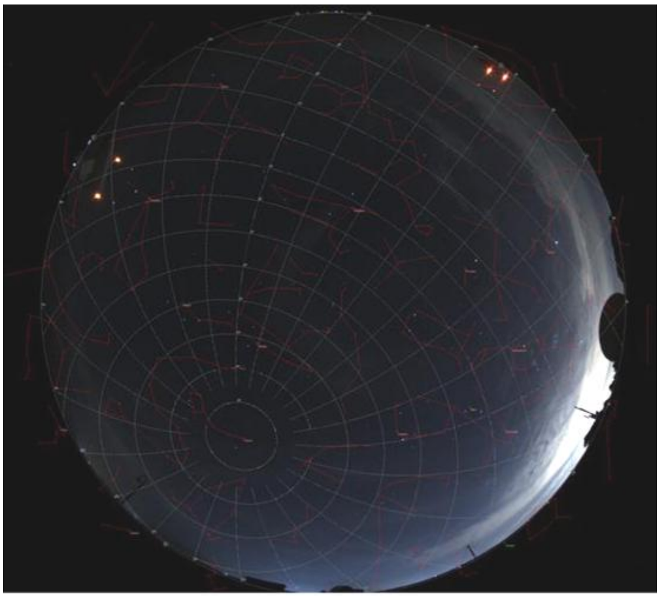


Figure 51. All Sky Camera: camera grid superimposed to the image (approximate setting).

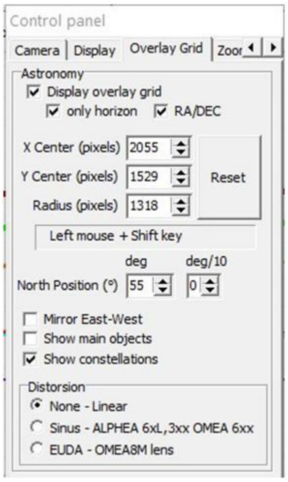


Table 15. All Sky Camera: grid configuration.

Image size

The image taken by the camera presents a circular contour due to an internal circular aperture (Figure 51). In the other side, the detector is rectangular. In order to save reading time, it is strongly recommended to trim the image in both sides in order to read only the square central part where the circular aperture image lies and, consequently, to speed up the image reading/download. During the tests, values in Figure 53 were setup.

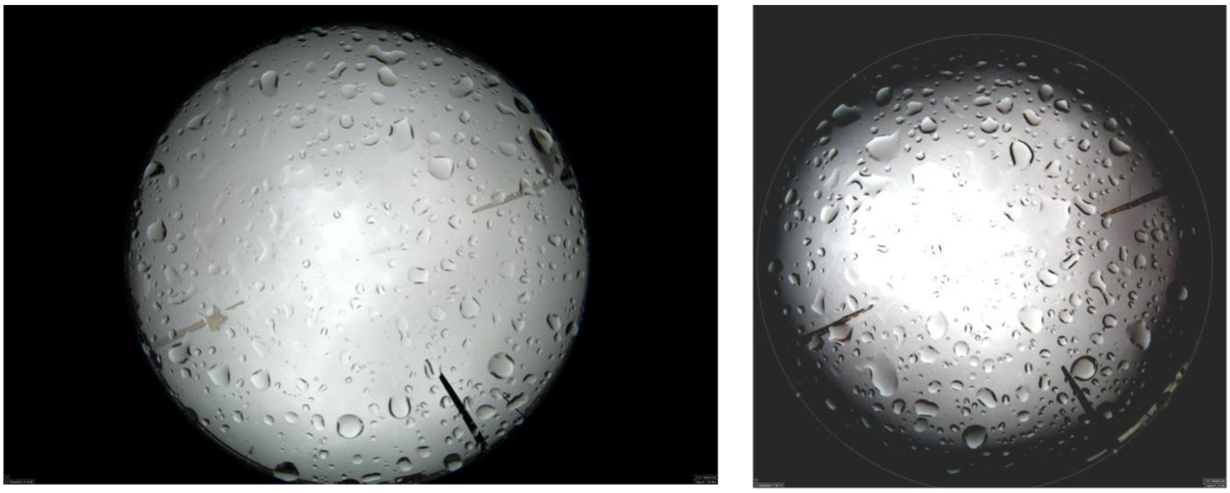


Figure 52. All Sky Camera: original (rectangular) versus modified (square) image shapes.

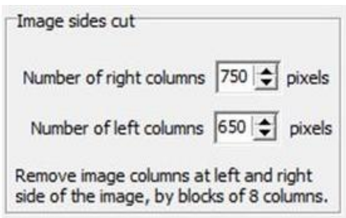


Figure 53. All Sky Camera: recommended image shap.

Camera baffling

Due to the high level of light pollution in the Observatory surroundings´, mainly coming from Madrid, images taken for the camera present an unwanted level of signal close to the horizon in the direction of both cities (Figure 51). In order to minimise it, a baffle was added to the camera around its dome. Although this baffle reduces the Field of View of the camera in elevation (Figure 54), this is not important as at low elevations the increased air mass renders the information coming from these elevations less useful.

Figure 54. All sky camera: night images taken without (left) and with baffled (right) camera. A small part of the camera field of view is lost for the baffled option. Stars in the field are better seen due to the increase of contrast of the image.

Camera operation

Camera image acquisition parameters

The next values have been selected for night and day images:

	f/#	Exposure time	Gain
Day	f/8	5 ms	0
Night	f/2.8	10 s	100

Table 16. All Sky Camera: image acquisition parameters.

The exposure times during the twilights shall be adjusted properly in order to avoid saturation/underexposures during them.

It is noted that the time between exposures cannot be done null being 5 s the minimum selectable value.

Camera data link

It is noted that the camera-PC link used to be lost from time to time. Although it used to restart automatically, sometimes it did not. A point to be investigated during the final installation.

Camera cleanliness

It is noted that the accumulation of dirtiness on the camera domo can degrade the image quality. Figure 55 shows the state of the camera domo after some "dirty" rains and its impact on the night and day images taken with it.

Facilitating access to the final position of the camera would help keep its dome clean.

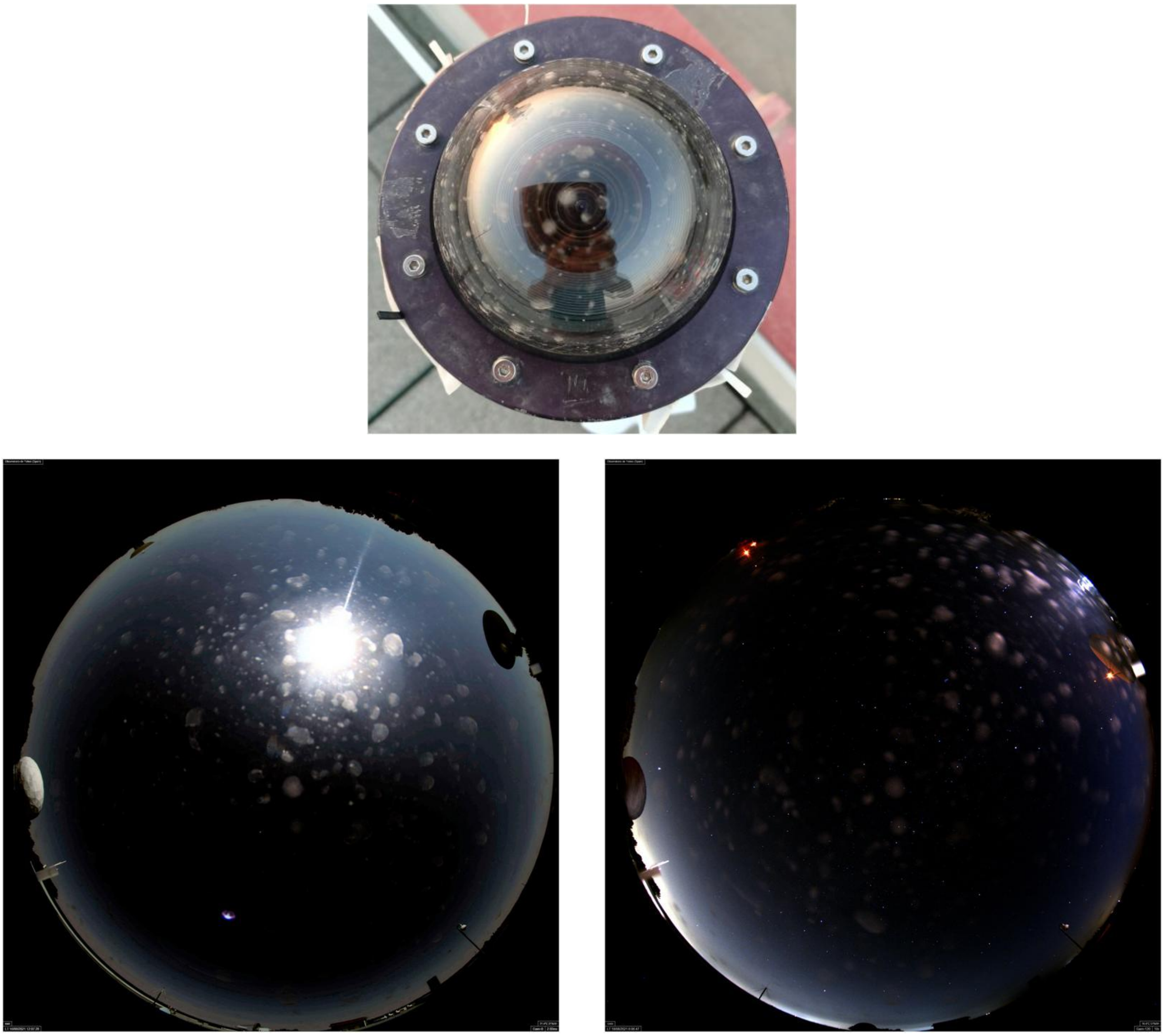


Figure 55. All Sky Camera: Dirt accumulated on the camera dome and its impact on the quality of day and night images.

Examples of images taken with the camera

Day image

It is noted the ghost image of the Sun (centre down).

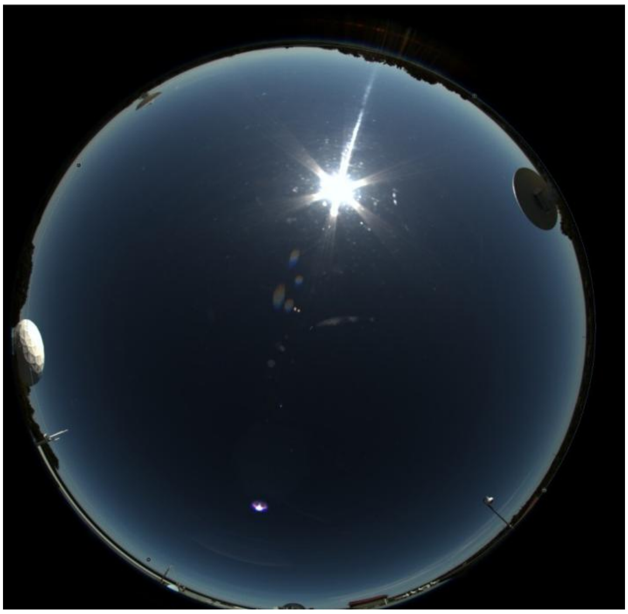


Figure 56. All Sky Camera: day image.

Cloudy night image

These night images show an aircraft crossing the zenith. The station laser shall avoid to illuminate them.

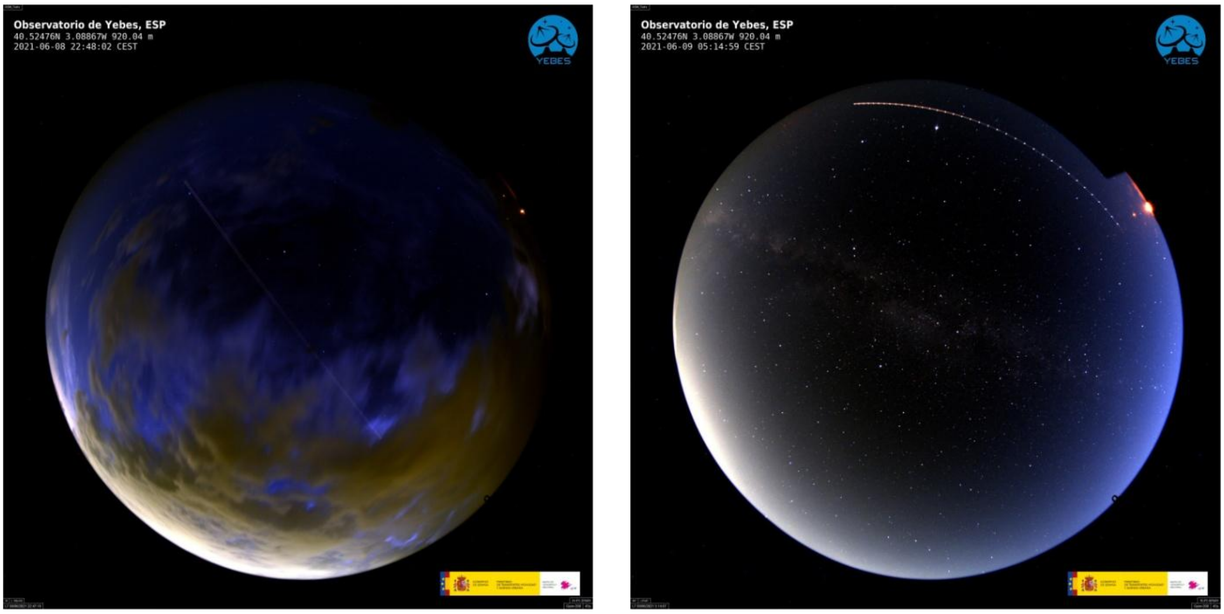
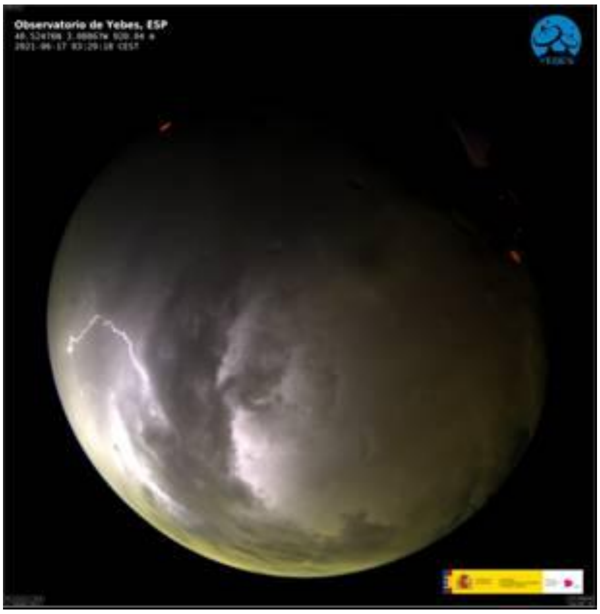


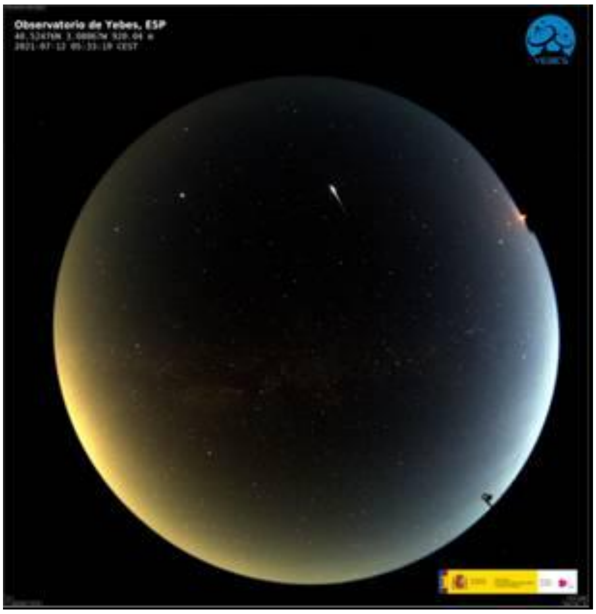
Figure 57. All Sky Camera: night images (1).

Other night images

While the first two are shown as examples of astronomical phenomena acquired with the camera, the last two show artificial objects whose illumination during the operation of the station shall be avoided.



Summer thunderstorm



Bright bolide

Starlink-28

International Space Station, ISS

Figure 58. All Sky Camera: night images (2).

5.2.5. Cloud Sensor (Boltwood Cloud Sensor II)

After being configured, some basic tests were carried out with this device.

The Cloud Sensor can display both their instant and temporal evolution parameters.

The instant data output are shown in Figure 59 and Table 17. The green labels give a quick assessment of the instantaneous state of the cloudiness (clear, cloudy, very cloudy), wind (calm, windy, very windy), air wetness (dry, wet, rain) and the daylight brightness (dark, light, very light).

For any of them, an alert (visual, beeper, sound) can be stated to trigger the associated action. This status values are complemented by the instant values of these parameters (boxes).

During the tests, the consistency of the application's output data with the environmental conditions associated with each of them was verified.

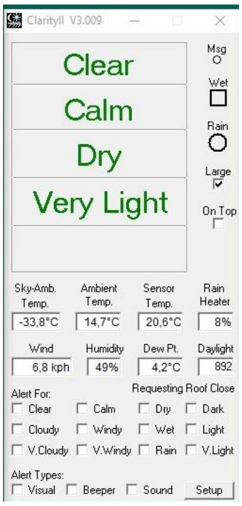


Figure 59. Cloud Sensor: instantaneous values of the outputs.

Parameter	Values
Sky status	Clear / Cloudly / Very cloudy.
Temperatures (°C)	Ambient T / Sky-Ambient T / Sensor T / Dew point (when T ambient get close to Dew Point, dome shall be closed). As measured.
Relative Humidity (%)	As measured.
Wind speed (km/h)	As measured.
Daylight	Luminosity of the sky. As measured.

Table 17. Cloud Sensor: output information.

In addition the application shows the time evolution of these parameteters(Figure 60). Table 18 shows the information shown by each output graph, from top to bottom:

Graph	Values
Graph 05	State of the cloudiness. Three ranges are associated: clear, cloudy, very cloudy. Air wetness (dry, wet, rain)
Graph 04	Ambient T. Dew point.
Graph 03	Air relative humidity
Graph 02	Wind speed
Graph 01	Daylight brightness value. Three ranges are associated: dark, light, very light.

Table 18. Cloud Sensor: output information.

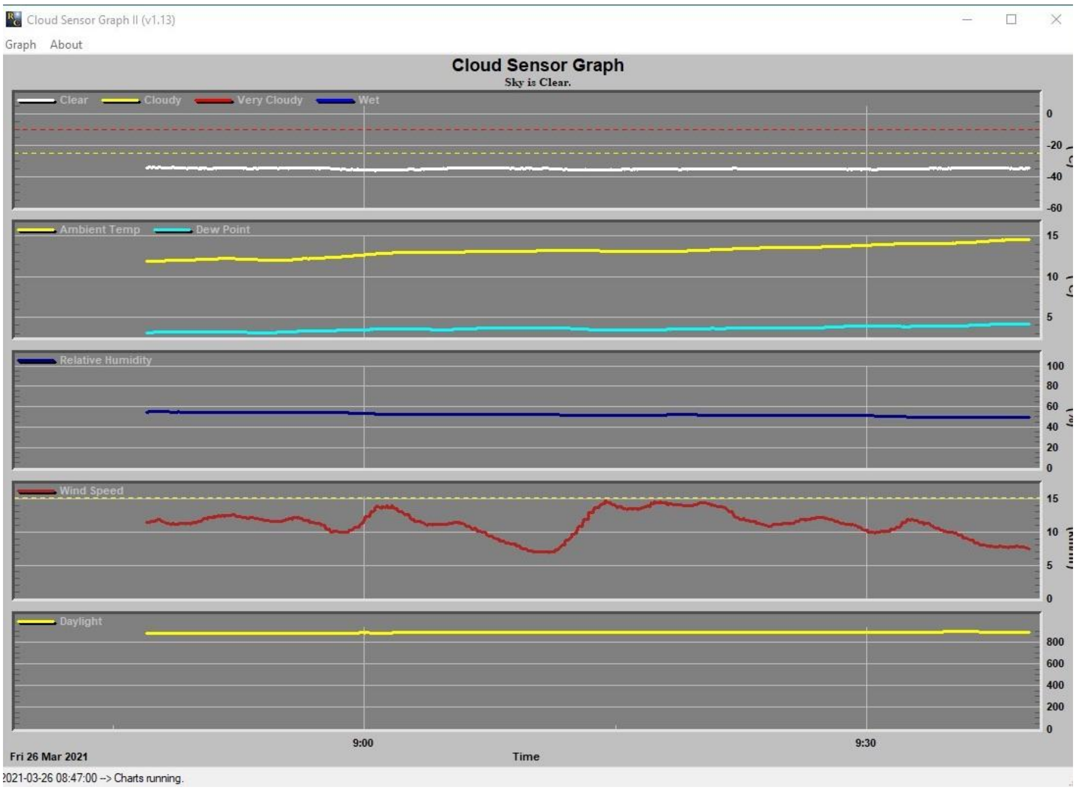


Figure 60. Cloud Sensor: time evolution of the outputs.

As a check of their consistency, output time evolution was compared with the one provided by the All Sky Camera (Figure 61) and no discrepancy was detected.

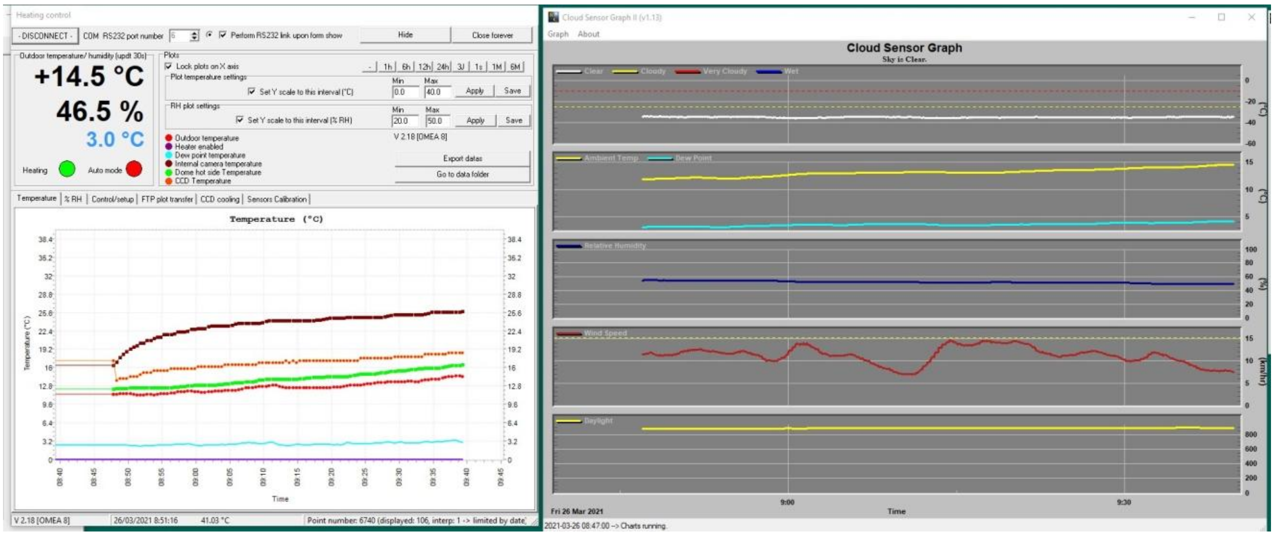


Figure 61. Cloud Sensor: time evolution of the outputs.

6. Summary

This report describes the different indoor and outdoor tests carried out with four of the outdoor modules of the future (construction in progress) Yebes Satellite Laser Ranging Station.

It also includes the full description of the temporary installation setup for accommodate all the modules being tested as well as the heat removal subsystem, not originally planned but identified as necessary as soon as the first outdoor tests were carried out.

Regarding the objectives of the tests, as set out in the introduction (§1), they all have been achieved. During the several months the different devices have been in operation at the Observatory, the SLR team has gained valuable experience in their operation. The installation setup, data links, and ancillary data gathering and monitoring tools have all proved to be satisfactory.

Once finalised the tests, all the modules have been dismounted and sent to contractor, the company providing the turn-key station, for integrating and testing them in the station control software, Scope. Detailed analyses of some of the datasets collected, in particular with the ADS-B receiver and all-sky camera, will be presented in a separate report.

Finally, the authors would like to thank to the Observatory staff members which helped us with some aspects of the installation: Adrián Alonso, Marta Bautista, Carlos Almendros, Pablo García, and Francisco Valle.

7. Appendix

7.1. ADS-B Receiver (Radarcape)

7.1.1. Mounting antennas outdoor

As per RD03,

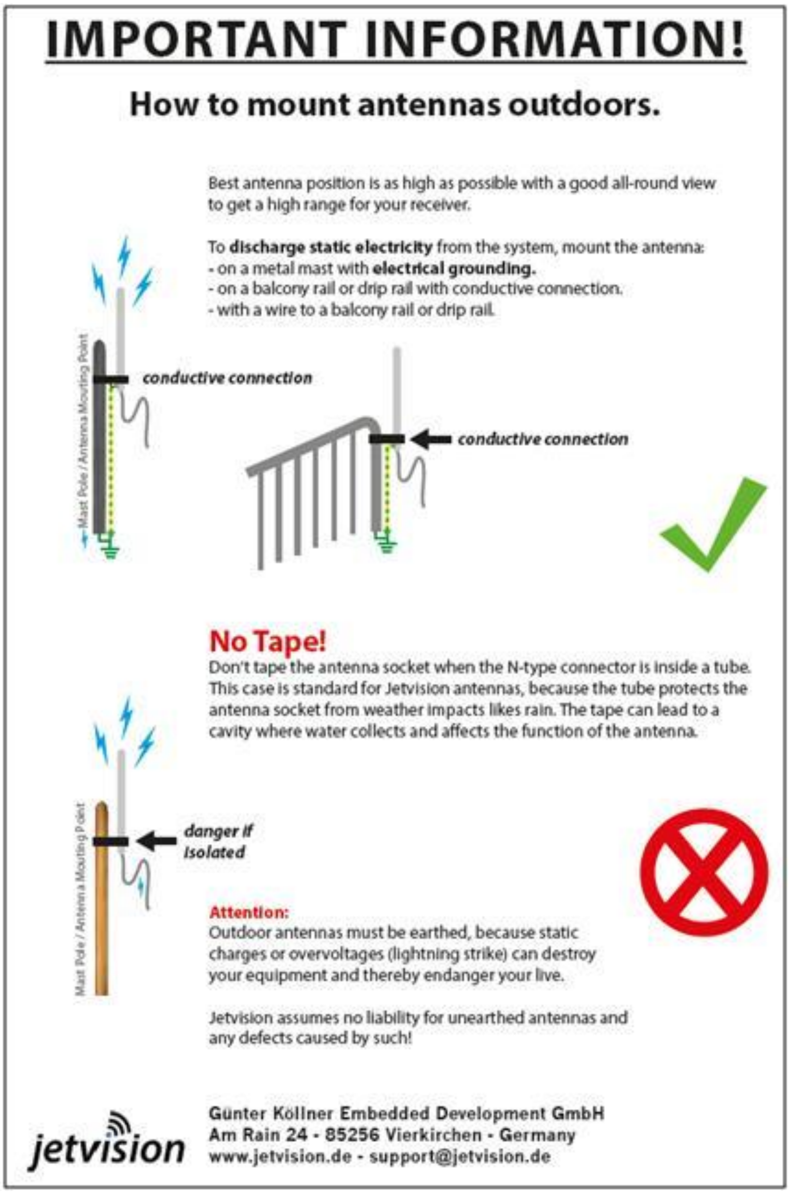


Figure 62. ADS-B Receiver: considerations on outdoor antennas installation (01).

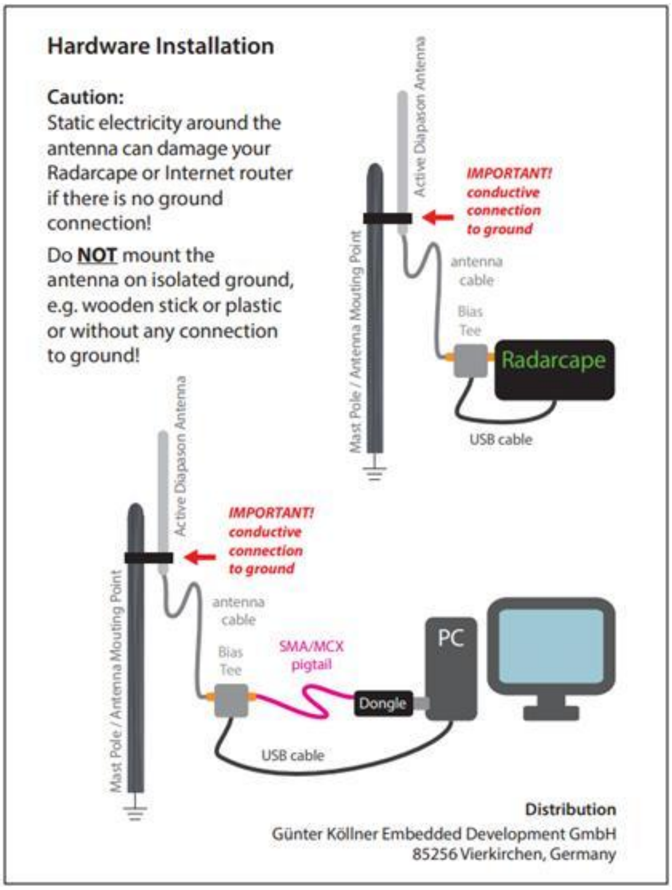


Figure 63. ADS-B Receiver: considerations on outdoor antennas installation.

7.1.2. Antenna characteristics

Active diapason antenna (1090 MHz): 1090 MHz with 2.5 dBi gain; LNA amplifier, ca. 21 dB gain. This antenna can be used outdoors.

More data can be found at:

- Diapason-Mainpage.
- https://web.archive.org/web/20140906045038/http:/h2204566.stratoserver.net/SmartStore.NET/en/diapason-antennen-fuer-1090-mhz
- http://web.archive.org/web/20180814080428/http://f5ann.pagesperso-orange.fr/PCBActiveAntenna/index.html

Measured receive pattern is not available. Horizontal pattern is a circle because it is an omni-antenna. Vertical pattern is very similar to any monopole antenna because it is only a single element inside.

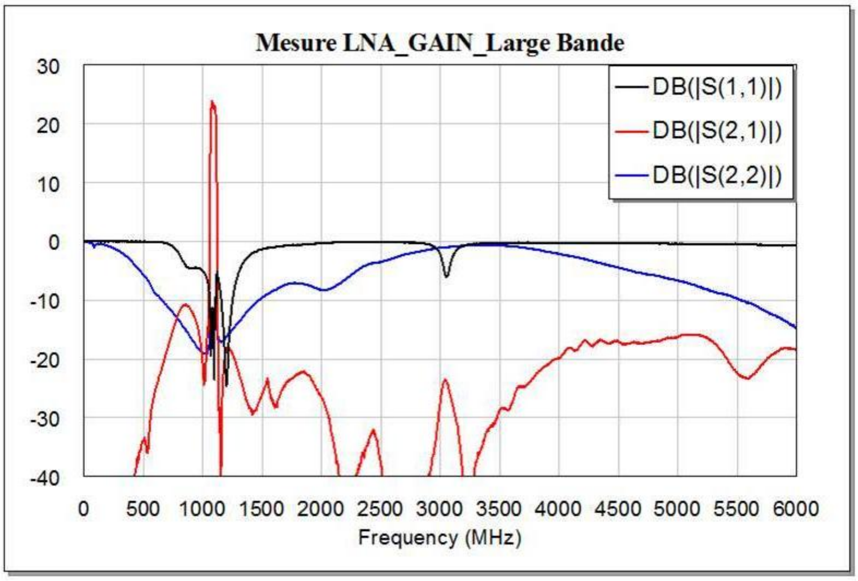


Figure 64. ADS-B Receiver antenna gain (wide band).

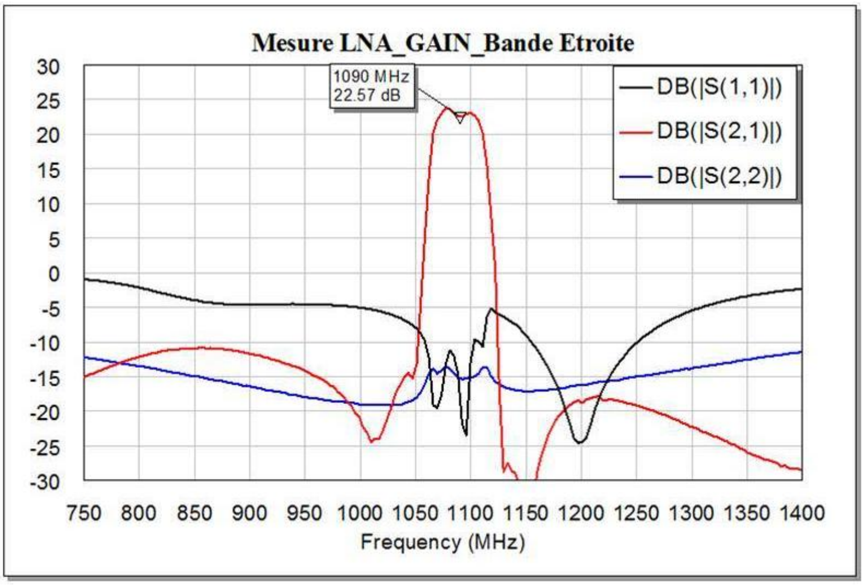


Figure 65. ADS-B Receiver antenna gain (narrow band).

7.2. Air Traffic Receiver (FLARM) (AT-1)

7.2.1. Antennas considerations

RD04 informs about the considerations applicable to the following antennas:

Antenna	Internal (cockpit)	External
ADS-B		R
FLARM	R	R
GPS	R	It is assumed equal to the interior

R: received YLARA baseline configuration

4.4 Antenna Considerations

Good antenna placement and installation is important. FLARM signals are transmitted with very low power. Therefore, a good antenna installation is critical for equipment performance. Also the 1090 MHz and GPS antennas do have to be installed following certain requirements. If antennas are not installed in an optimum position, range and coverage are limited.

Cockpit antennas for installation inside the cockpit are included with delivery of AT-1 (dipole antennas). Cockpit antennas are fairly easy to install and in some aircraft types provide decent results. Yet, depending on the signal type, external antennas are recommended.

4.4.1 Antenna cable installation

- Route the antenna cable as appropriate, avoid sharp bends.
- Secure all cables in order to minimize vibration.
- The antenna cable should not be located near flight control cables and controls.
- The antenna cables must never be squeezed or chafed.

4.4.2 FLARM Antennas

In Europe, FLARM signals are transmitted with an output power of roughly between 10 and 25mW. This is about 10,000 times weaker than a typical transponder signal or 200 times weaker than a VHF radio. Therefore, especially the FLARM antenna installation is crucial. Please ensure that all of the below-mentioned requirements are met as closely as possible.

FLARM Cockpit Antennas

The FLARM cockpit antenna included with delivery is a dipole antenna that has an adhesive pad in the center.

1. Always install FLARM antennas vertically.
2. Ensure that the antenna cable is routed away from the antenna in an orthogonal way in the first 15 cm (6 inches) or use angled antenna connectors.
3. Do not coil the antenna cable. Make sure it is as short as possible. Only experts with professional tools may shorten the FLARM antenna cable.
4. Ensure that no conductive parts (metal, carbon fiber) are close to the antenna.
5. Install the antenna in a location where it has a clear view and is not obstructed by structural parts.
6. If using multiple FLARM antennas, please make sure that they are located far away from each other to increase coverage. The reception range is not increased by multiple antennas, only the reception coverage is increased. Therefore, it makes little sense installing two FLARM antennas closely to each other, because then they cover the same area. Ensure that both antennas cover different areas for good results, e.g. on the top and on the bottom of the aircraft fuselage.

> One cockpit antenna comes included with delivery. Using a second FLARM antenna may provide better results as the reception coverage would be increased.

The following locations have proven to be good places for installation of cockpit antennas. Other places may be suitable as well.

- Attached to the front windshield or the side windows. This only works for windows or windshields that allow vertical installation of the antenna. For example, in Cessna/Piper aircraft, a good place would be on the side of the front windshield with adequate distance to metal structures.
- Inside fiberglass nose cones of most twin engine aircraft or gliders.
- Inside fiberglass structures like wingtips.

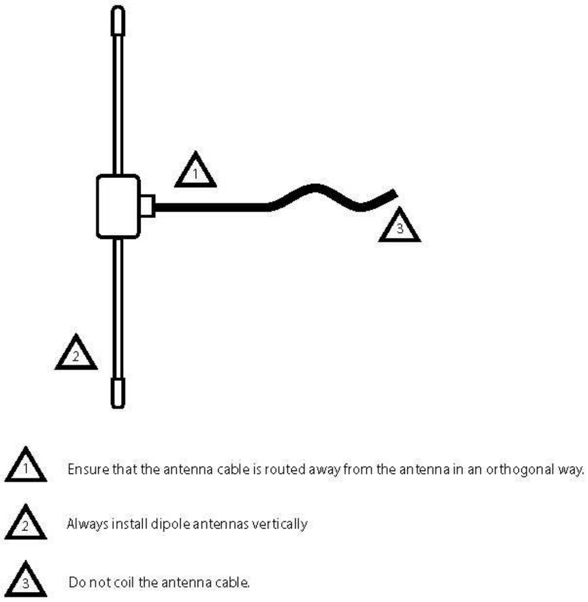


Figure 4.1.: Cockpit antenna and required orientation.

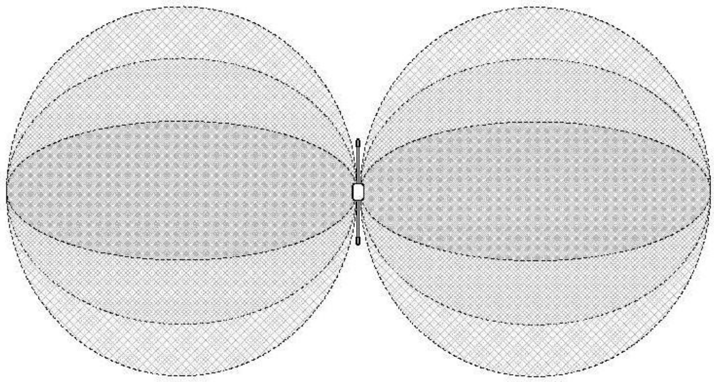


Figure 4.2.: Cockpit antenna reception/radiation pattern

FLARM External Antennas

In aircraft that are mostly made of conductive materials such as metal or carbon fiber, we recommend the installation of at least one external antenna for FLARM. Normally, such an external antenna would be placed underneath the fuselage of the aircraft.

In larger metal aircraft, coverage can be significantly increased by using two external antennas on the top and on the bottom of the fuselage.

1. Always install FLARM antennas vertically on a conductive surface of at least a 15 cm (6 inches).
2. Ensure that the antenna cable is routed away from the antenna in an orthogonal way in the first 15 cm (6 inches) or use angled antenna connectors.
3. Do not coil the antenna cable. Make sure it is as short as possible. Only experts with professional tools may shorten the FLARM antenna cable.
4. Ensure that no conductive parts (metal, carbon fiber) are close to the antenna on the outside.
5. Install the antenna in a location where it has a clear view and is not obstructed by structural parts like the landing gear.
6. If using multiple FLARM antennas, please make sure that they are located far away from each other to increase coverage. The reception range is not increased by multiple antennas, only the reception coverage is increased. Therefore, it makes little sense installing two FLARM antennas closely to each other, because then they cover the same area. Ensure that both antennas cover different areas for good results, e.g. on the top and on the bottom of the aircraft fuselage.
7. Try to avoid placing the antenna closer than 1 m from the aircraft's transponder, DME, and TAS antennas. Try to avoid placing the antenna closer than 30 cm from the aircraft's VHF antennas.

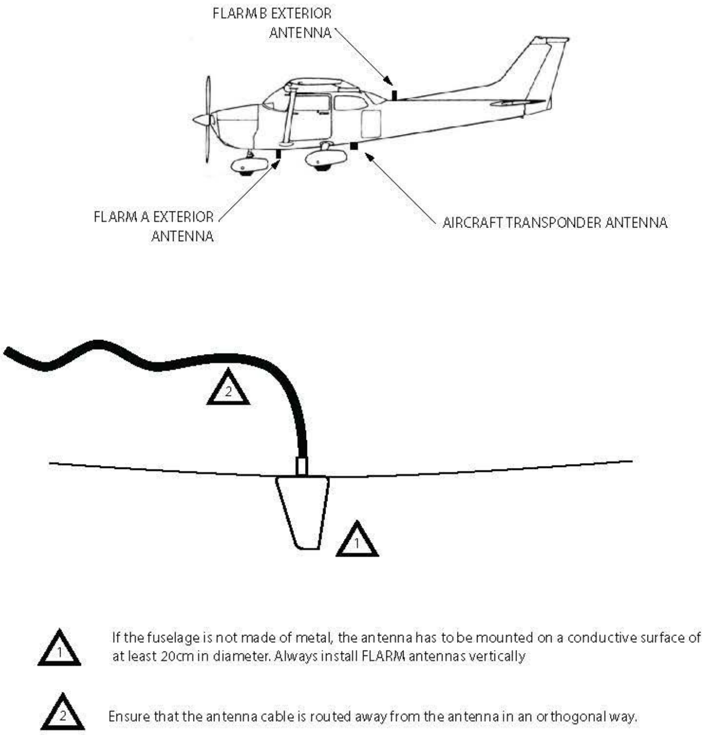


Figure 4.3.: External antenna (dual FLARM antenna setup)

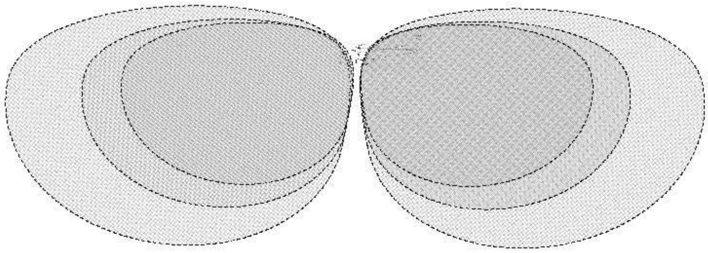


Figure 4.4.: External antenna reception/radiation pattern

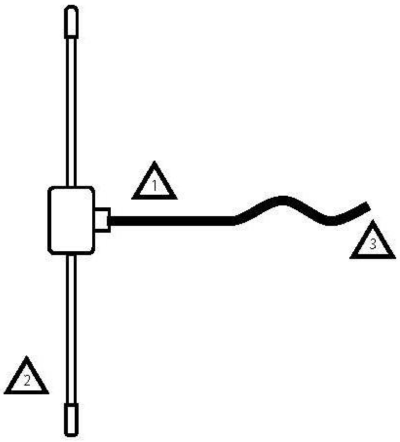
4.4.3 1090 MHz Antennas

Transponder and ADS-B signals are sent with a high output power. Therefore, even in suboptimal antenna installations good reception ranges can be achieved.

1090 MHz Cockpit Antennas

In most cases, the cockpit antennas included with delivery are sufficient for good operation. Although not being as critical as FLARM antennas, make sure the requirements below are met for optimum performance.

1. Always install 1090 MHz antennas vertically.
2. Ensure that the antenna cable is routed away from the antenna in an orthogonal way in the first 15 cm (6 inches) or use angled antenna connectors (for external antennas).
3. Do not coil the antenna cable.
4. Ensure that no conductive parts (metal, carbon fiber) are close to the antenna.
5. Install the antenna in a location where it has a clear view and is not obstructed from nearby structural parts.



1 Ensure that the antenna cable is routed away from the antenna in an orthogonal way.

2 Always install dipole antennas vertically

3 Do not coil the antenna cable.

Figure 4.5.: Cockpit antenna and required orientation.

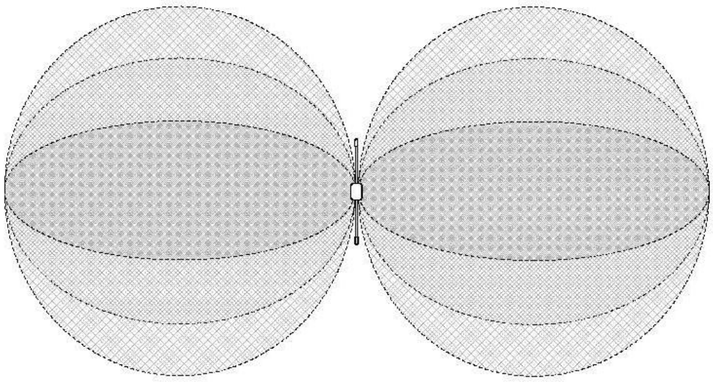
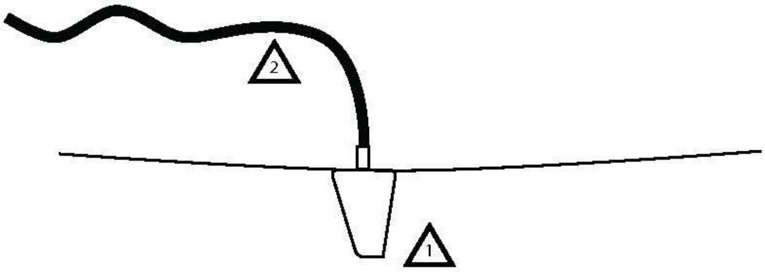


Figure 4.6.: Cockpit antenna reception/radiation pattern

1090 MHz External Antennas

In larger aircraft that are mostly made of conductive materials such as metal or carbon fiber, installing an external antenna for 1090 MHz may be beneficial for optimum performance. Normally, such an external antenna would be placed underneath the fuselage of the aircraft.

1. Always install 1090 MHz antennas vertically on a conductive surface of at least a 15 cm (6 inches) diameter.
2. Ensure that the antenna cable is routed away from the antenna in an orthogonal way in the first 15 cm (6 inches) or use angled antenna connectors (for external antennas).
3. Do not coil the antenna cable.
4. Ensure that no conductive parts (metal, carbon fiber) are close to the antenna.
5. Install the antenna in a location where it has a clear view and is not obstructed from nearby structural parts like the landing gear.
6. Try to avoid placing the antenna closer than 1m from the aircraft's transponder, DME, and TAS antennas.



1 — If the fuselage is not made of metal, the antenna has to be mounted on a conductive surface of at least 20cm in diameter. Always install 1090MHz antennas vertically

2 — Ensure that the antenna cable is routed away from the antenna in an orthogonal way.

Figure 4.7.: External 1090 MHz antenna

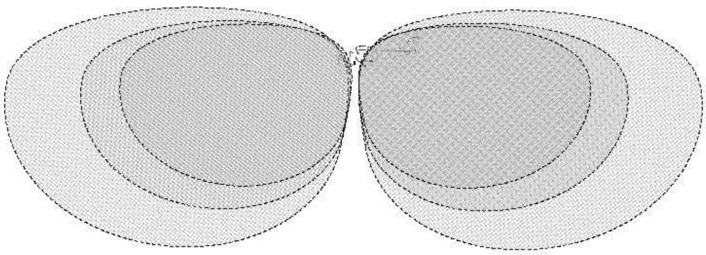


Figure 4.8.: External antenna reception/radiation pattern

4.4.4 GPS Antennas

AT-1 comes with a cockpit GPS antenna with an adhesive pad. It can be installed on the instrument panel glare shield or any other place with unobstructed view of the sky. Good GPS performance is important for correct operation. Please make sure that the requirements below are met as closely as possible.

In larger aircraft that are mostly made of conductive materials such as metal or carbon fiber, or for aircraft with heated windshields, installing an external GPS antenna may be required for optimum performance. Normally, such an external antenna would be placed on top of the fuselage of the aircraft.

1. Always install the GPS antenna lying flat horizontally and facing upwards.

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2. Do not coil the antenna cable.
3. Do not paint or cover the antenna.
4. Ensure that no conductive parts (metal, carbon fiber) are located above of the antenna. Conductive, grounded parts below of the antenna may improve GPS antenna performance.
5. Install the antenna in a location where it has a clear view of the sky and the largest unobstructed possible opening angle.
6. Do not install the antenna closer than 30 cm (1 ft) away from another active GPS antenna.

Figure 4.9.: GPS antenna reception angle

7.2.2. Antenna characteristics

ADS-B building antenna

High performance receiving antenna for ADS-B ground stations. Thanks to the antenna gain of 6dbi, this antenna can reliably receive signals from long distances. Thanks to the weatherproof design, the antenna can be used all year round.

- Centre frequency: 1090 MHz
- Impedance: 50 Ohm
- 6 dBi antenna gain
- Standing wave ratio (VSWR): > 1.5
- Horizontal aperture angle: 360 °
- Vertical opening angle: 25 °
- Stable weatherproof design: white Fibreglass rod, stainless metal base

FLARM Building Antenna

Exterior, weather-resistant, high gain antenna to be installed o masts or buildings for ground receivers.

- Frequency: 868 MHz
- Impedance: 50 Ohm
- 9 dBi Gain
- VSWR: > 1.5

- Horizontal aperture: 360°
- Vertical aperture: 25°
- Length (without cable): 83 cm
- Connector: N-female

The antenna is omni-directional and have a gain of 6dBi. No datasheet or similar is available.

7.3. Electrical power budget: additional information

7.3.1. Air Traffic Receiver (FLARM) (AT-1)

Source: RD04

3.5 Power Supply and Enable Interface

3.5.1 Power Supply

The power inputs on connector 1 provide power. It is recommended to connect multiple power pins and multiple ground pins.

[1] To obtain the required specification, please contact "Stock Flight Systems" via *http://www.stockflightsystems.com*

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Pin Name	*Pin number*	*I/O*
Aircraft Power	1.1/1.10	In
Aircraft Ground	1.5/1.9/1.23/1.26	–

We recommend the installation of a 3A manually resettable circuit breaker in the power supply line, e.g. a *Sensata Klixon 7277-2-3*. Using such a circuit breaker ensures that the AT-1 can be switched off by the flight crew if required. Additionally, in the case of a non-permanent malfunction the power supply can be restored. The circuit breaker shall be clearly labeled.

> Connection of the input power to incorrect pins can cause damage to the unit that will require return to the factory for repair. Ensure that the power supply is connected to the correct pins and does not short to any adjacent pins prior to applying power to the unit.

3.5.2 Power Output

Connector 2 features a supply power output. The output pins directly connect to the VIN pins on connector 1. Its main intention is to supply an AIR Traffic Display (ATD-11, ATD-57, or ATD-80) if the AT-1 is directly attached to such a display.

Pin Name	*Pin number*	*I/O*
Power Output	2.1/2.6	Out
Ground (GND)	2.5/2.14	–

3.5.3 Enable Interface

Both connectors feature a pin that enables power when pulled to ground/low. For AT-1 to power up, at least one of these two pins must be connected to ground (GND). Active-Low discrete inputs like the Enable Interface are considered active if either the voltage to ground is below a certain minimum or if the resistance to ground is below approximately 300 Ohms.

Pin Name	*Pin number*	*I/O*
Enable	1.22/2.4	In (Active Low)

If the AT-1 is installed in combination with an AIR Traffic Display (ATD-11, ATD-57, or ATD-80), the pin is automatically pulled to ground/low when the ATD is powered up.

An external switch can be connected if AT-1 is to be switched on/off manually.

3. Interfaces avionics

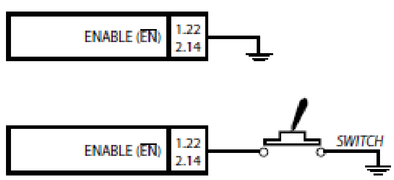

Figure 3.3.: If the AT-1 is not installed in combination with an AIR Traffic Display, or another device compatible to the enable-interface, either Pin 1.22 or pin 2.4 have to be connected to GND. Connection can be made permanently (the AT-1 is always switched on if supply power is present) or over a switch (AT-1 is only switched on if the connection to GND is made)

7.3.2. Cloud Sensor (Boltwood Cloud Sensor II)

Source: RD06

22.2 Power

The switching wall plug power supply provided has:

- Rated input voltage 100V to 240V AC at 50 to 60 Hz.
- Output 24VDC at .75A, well regulated and low noise.
- Allowed operating temperature 0°C to 40°C and humidity 20 to 80%.

If you are considering supplying your own 24V power the maximum current needed according to the Cloud Sensor design is .63A when the wetness or rain sensor heater is on and everything at worst case. Measurements on an actual unit (not worst case) were .39A with the heater on and .12A at other times with a zero length cable. The pulse currents are higher. Longer cables require more current.

People that have tried to supply their own power have had trouble from noise their power supply generated, especially at lower frequencies. In that case the wetness sensor did not work properly. Your supply needs to be as clean as the supply we include with the unit.

YLARA Sensors installation and outdoor tests
Yebes Observatory, May 2022