RAEGE Santa Maria Station 2021–2022 Report

João Salmim Ferreira[1], Abel García-Castellano[1,2], Mariana Moreira[1,3], Diogo Avelar[1], Valente Cuambe[1,3], José A. López-Pérez[2], Guilherme Soares[1], Nuno Mata[1], Valério Pacheco[1], Sérgio Chaves [1], Raquel Ribeiro[1], Elsa Melo[1], Francisco Wallenstein[1], Sara Pavão[1], Luísa Magalhães[1]

Abstract The RAEGE Station of Santa Maria, located in the Azores archipelago (Portugal), is one of the four stations of the RAEGE Network. Highlights for this period include the installation of a new VGOS broadband receiver, the determination of the local tie pillars position, and the continuing improvements of the signal chain. In this report we present the station staff, equipment, and an activity summary for the years 2021 and 2022.

1 General Information

The RAEGE network (Portuguese/Spanish acronym for Atlantic Network of Geodynamic and Space Stations) is a cooperation project between the National Geographic Institute of Spain (IGN Spain) and the Regional Government of the Azores [1]. It is a unique geodesy project committed to the construction and operation of four Fundamental Geodetic Stations: Yebes and Gran Canaria stations in Spain and Flores and Santa Maria stations in the Azores, Portugal.

In 2017, the Government of the Azores created Associação RAEGE Açores (RAEGE-Az) to: a) implement RAEGE's infrastructures in the Azores and manage its activities; b) set up an R&D infrastructure and team dedicated to space and space-geodetic related activities, and c) communicate space science within the Azores, among other objectives. The RAEGE station of Santa Maria is managed by RAEGE-Az with direct support and supervision from the Government of the Azores and the IGN Spain [2].

Fig. 1 RAEGE Santa Maria radio telescope and control building.

The RAEGE station of Santa Maria is located in Santa Maria, the easternmost island of the Azores archipelago, in Portugal (Figure 1). The environment in the Azores is quite extreme in terms of humidity levels (above 78% relative humidity annual average) and in terms of salinity due to the islands' dimensions, orography, and exposure to oceanic winds. The station has a 13.2-m dish radio telescope (VGOS-like), and its invariant position is described in Table 1.

Table 1 Invariant position of Santa Maria VLBI radio telescope based on ITRF2020 solution [3].

LATITUDE	LONGITUDE	ALTITUDE
36°59′07.02463″	−25°07′33.22150″	301.741 m

1. RAEGE-Az—Associação RAEGE Açores, Santa Maria
2. National Geographic Institute of Spain
3. Atlantic International Research Centre, Terceira

Santa Maria Network Station

IVS 2021+2022 Biennial Report

2 Component Description

2.1 S/X Legacy Receiver

Until September 2022, the radio telescope was equipped with a tri-band (S/X/Ka) low-noise cryogenic receiver that operated simultaneously in the three distinct bands: S (2.2–2.7 GHz), X (7.5–9 GHz), and Ka (28–33 GHz). It produced dual-circular polarization, and its measured average equivalent noise temperature was 21 K for S-band, 23 K for X-band, and 25 K for Ka-band [4]. The output signals from the cryostat were sent to their corresponding room-temperature downconverters placed in the receiver trolley for later amplification, filtering, and mixing. The final IF signal ranged from 500 to 1000 MHz in S and Ka bands and from 100 to 1000 MHz in X-band. As backend equipment, a HatLab DBBC2 was used for digitization and channeling, and two MIT Mark 5B units were used for recording and sending data via e-transfer.

2.2 VGOS Broadband Receiver

In October 2022, the new VGOS ultra-broadband receiver developed by the Yebes Observatory was installed. The cryostat contains a Quadruple-Ridge Flared Horn (QRFH) from 2 to 14 GHz, providing dual-linear polarization and balanced low-noise amplifiers. The receiver trolley also includes filtering and pre-amplification modules (FPU). The measured average receiver noise temperature is 12.5 K in the 3–14 GHz range (see Figure 2).

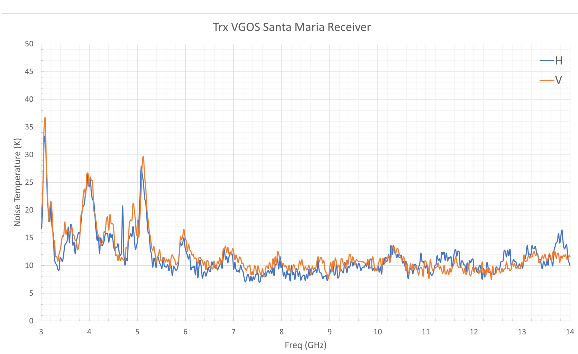

Fig. 2 VGOS receiver noise temperature [5].

The backend data chain is now made of a filter bank that, together with three downconverters, results in baseband outputs with a bandwidth of 2 GHz, in each polarization, from 2 to 14 GHz. For the digitization and channeling, Santa Maria is now using a HatLab DBBC3, and for the recording, two MIT Mark 6 units with expansion chassis. Nowadays, the total recording capacity is approximately 384 TB.

3 Staff

During 2021–2022, the Santa Maria Station established a team of 10 people (Figure 3): one IT technician, two maintenance technicians, one administrative officer, one marketing and science communication officer, three engineers and one astrophysicist for technical coordination and R&D projects duties, and the station director.

Fig. 3 RAEGE Santa Maria staff 2021–2022.

Diogo Avelar (fourth from the left in the top row) and Abel García (last from the left on the bottom row) have an MSc degree in Electronics and Telecommunications Engineering, and both give support to hardware and software issues in the VLBI operation and for the signal chain technological improvements. Mariana Moreira (first from the left in the top row) has an MSc in Aerospace Engineering and is part of the RAEGE Analysis Group in charge of VLBI data post-processing and analysis. Valente Cuambe (third from the left in the bottom row) has a Ph.D. in Astrophysics and is the astronomer on duty to support the VLBI operations. João Salmim Ferreira (fourth from the left in the bottom row) has an MSc in Aerospace Engineering and is the Station Director. All of the above members are directly involved in the geodetic VLBI activity and are also responsible for the radio telescope operation.

4 Current Status and Activities 2021–2022

4.1 Corrective Maintenance

Due to the environmental conditions in the Azores, all the materials (especially the metallic parts) are extremely prone to corrosion. During the report period, several parts of the radio telescope had to be replaced by equivalent parts in stainless steel. Every year during spring, the antenna structure is subjected to a deep cleaning procedure to remove the moss that generally grows during winter and to general corrosion removal and repainting works. Concerning this topic, the major intervention performed was the replacement of the servomechanism container with a new one in early 2021 following the collapse of the container floor structure. The surrounding area of the new container was modified to improve the airflow and reduce condensation and zones with water accumulation.

Another major repair consisted of the recovery of the positioning encoder system in the azimuth axis in March 2021. The system comprises a large round tape and four encoder heads that read the tape marks at each axis of movement. The tape of the azimuth axis was found with scratches and with the marks faded in some areas, which caused the encoder heads to trigger errors at given radio telescope motion speeds. As no repair was possible, the encoder tape was replaced and the positioning system recalibrated.

The cable wrap is another system that must be inspected regularly for damages. After the rupture of the cable chain in the RAEGE Yebes antenna, an extensive assessment of the system in Santa Maria was made. It was found that when the antenna is in one of the azimuth extreme positions, the pins that support the wrap structure sometimes fail and get stuck, which can cause the rupture of the cable wrap chain. The support structure was tuned and repositioned at the end of 2022. The system range of operation is still limited between the 0° and 420° azimuth positions, and it will remain under monitoring until we are confident that it can return to full range of operation.

4.2 Legacy S/X Operation

From May 2021 to the end of September 2022, the RAEGE Santa Maria station participated in 109 IVS R1 and R4 sessions, contributing to the IVS legacy network. Among these sessions, 95% were successfully correlated, and 73% of the scheduled observations were used in the analysis. Notably, the comparison between 2021 and 2022 shows an increase of 12% in the scheduled observations used for VLBI data analysis, as shown in Figure 4. The improvement in the amount of data used in the analysis demonstrates the enhancement in the station's data quality over time.

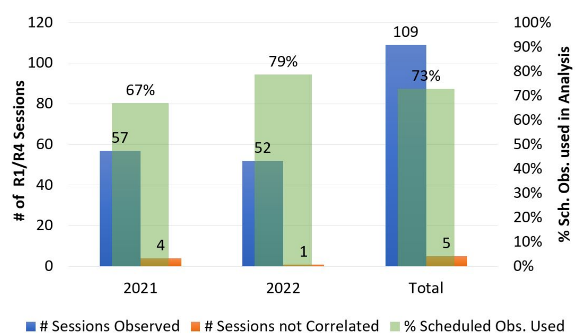

Fig. 4 Legacy S/X sessions 2021–2022 overview.

4.3 VGOS and Y-Intensives Operation

In November and December of 2022, the RAEGE Santa Maria Station participated in a series of Intensive sessions in collaboration with the Goddard and Yebes observatories. These included five one-hour sessions and five 15-minute test sessions, all conducted using the newly installed VGOS receiver. In these sessions, the correlators successfully detected fringes on the Santa Maria baselines. During the same period, Santa Maria did not participate in any IVS sessions for the VGOS network due to the ongoing tests and calibrations of the new equipment on the same days of the VGOS sessions correlated by the Haystack Observatory.

4.4 Tri-Band Receiver Stability Tests

In 2021, with the tri-band receiver still installed, the signal chain gain stability was studied. We found that the system temperature (Tsys) measured varied significantly in the short term, even when observing the same reference source (such as TAU-A) successively at the same elevation. To confirm if the noise calibration diode was the reason for this issue, Tsys calibrations were compared with the System Equivalent Flux Density (SEFD) calibrations carried out in sequence.

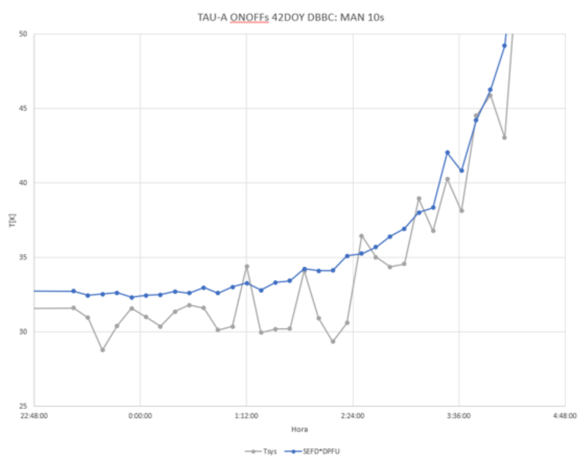

Fig. 5 System temperature (gray) vs SEFD*DPFU (blue) measured observing TAU-A [6].

Both curves present the same behavior, but the Tsys curve is noisier. Two hypotheses could explain this effect: a) the noise calibration diode isn't stable or b) the sensitivity is limited, and this is notable with the diode (Tcal = 1.2 K), and it isn't when tracking TAU-A (16 K approximately). To confirm this, the same test was done with a weaker source (3C84, with 50 Jy at X-band – see [6]). Fluctuations in Tsys and SEFD are comparable, which suggests that the receiver gain stability was limiting its sensitivity (refer to [6] for more information).

4.5 Maser Behavior

In October 2022, after a checkup of the maser by the manufacturer, the drift of the maser was adjusted to be on the order of 10^{-13} when compared to the GPS signal. With such a small drift, an unexpected, non-linear behavior was identified when looking at long data sets.

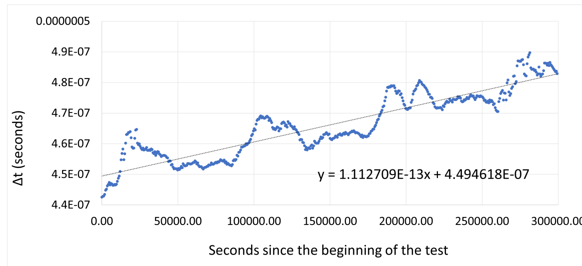

Fig. 6 Time difference between GPS and Maser PPS signal during 84 hours in December 2022.

After checking the signal frequency response, it was clear that the repeatability had a daily frequency (see Figure 6). Some additional tests led us to conclude that there is a direct relation between the GPS-Maser difference and the ambient temperature measured by the sensor in the maser room. It was also concluded that the maximum daily deviation from the linear regression is about 13 ns.

4.6 RFI Measurements

During the period of 2021–2022, several RFI measurements were carried out in the RAEGE station of Santa Maria. An RFI survey from 0.5 to 20 GHz was done in January 2022 and compared to the one performed in 2010. Additionally, RFI measurements were performed at 2.9 GHz after receiving a new RFI signal from a radar installation in the surroundings.

The integrated power flux between 2.92 and 2.98 GHz is -46.5 dBW/m^2, which becomes 2.7 dBm at the input of the low noise amplifier in the worst case (pointing the radio telescope towards the radar). This power level is 37 dB above the gain compression and very close to the LNA damaging input level, making it impossible to perform any observation. In the Fu-

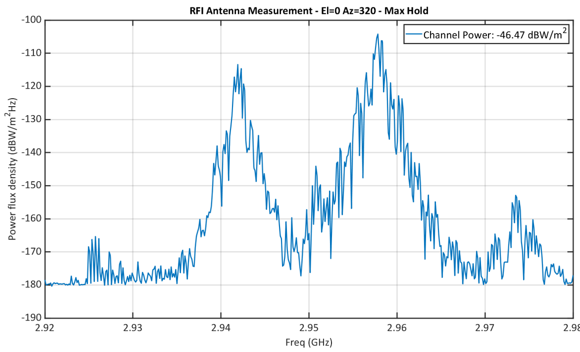

Fig. 7 Radar RFI spectrum.

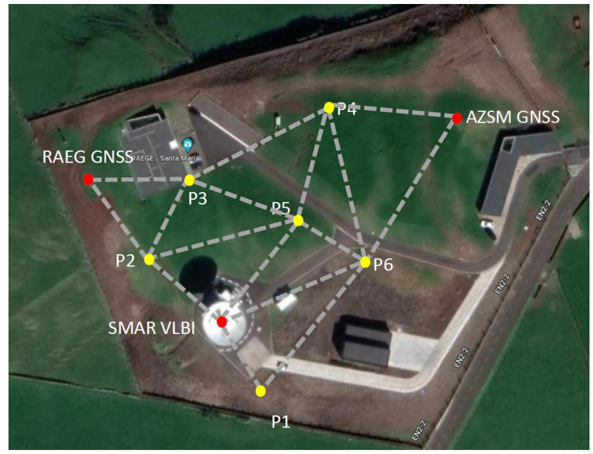

Fig. 8 RAEGE Santa Maria future local tie network [9].

ture Plans section, some mitigation solutions are introduced.

One of the problems solved when still doing legacy observations was a noisy phase cal tone. One of the RFI sources was the radio telescope motor system, injecting an 8-kHz tone through the electrical power supply line. The problem was solved by installing one line filter at the elevation cabin power supply line and another in the receiver trolley power supply line (refer to [6]).

4.7 Local Tie

In September 2022, IGN Spain staff were in Santa Maria station to develop a plan for establishing the local tie pillars position. The differential coordinates, or local tie vectors, between the invariant reference points of the instruments present at the station, namely RAEG GNSS, AZSM GNSS, and the VLBI radio telescope, were determined. The local ties were surveyed precisely in three dimensions using classical and GNSS surveying techniques. The planning process concluded that six pillars are needed to link the station's current geodetic techniques and accommodate potential future installations (see Figure 8).

4.8 RAEGE Analysis Group

The RAEGE Project does not focus only on instrumentation and on operating the observations but also on developing analytical skills that allow RAEGE observatories to exploit the geodetic observations. Hence, a RAEGE Analysis Group was established in 2021. This group includes collaborators from the IGN Spain, the RAEGE observatories of Yebes and Santa Maria, and two researchers from the University of Alicante who joined in 2022. The group aims to promote VLBI analysis activities within the RAEGE Project, expand research activities, and facilitate participation in international projects and interactions with other groups.

The primary research focus during 2021 and 2022 has been on R1, R4, and VGOS sessions as well as multi-technique analysis by comparing VLBI and GNSS products at co-location sites. The RAEGE Analysis Group presented several contributions, including "Consistency of VLBI estimates in the CONT17 campaign" at EVGA 2021 [7] and "Analysis of VGOS sessions: Evaluation of performance with different software" at the IVS 2022 General Meeting [8], among others.

5 Future Plans

For the near future, the focus will be on calibrating all the new backend equipment to cope with VGOS quality requirements. Due to the strong RFI signal transmission near the Santa Maria station, a high-pass COTS filter rejecting 2—4 GHz will be installed in early 2023 to allow the operation of the radio telescope with no danger of damaging the receiver LNAs, entailing the loss of VGOS band A data (filter already installed at the time of writing). A superconducting notch filter is being developed by the Yebes Technological

Development Center [5] and is planned to be installed in mid-2023. Meanwhile, the admission of Santa Maria as a tag-along to the VGOS network is in discussion. For 2023, it is also planned to construct the local tie pillars. Concerning the RAEGE Analysis Group, exploring the capabilities of the complete RAEGE network in 'stand-alone' mode will be one of the main topics.

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