IGN Yebes Observatory Technology Development Center Activities

José A. López-Pérez, on behalf of Yebes Observatory

Abstract The main technical developments of Yebes Observatory (IGN, Spain) in 2023 and 2024 related to geodetic VLBI are introduced.

1 General Information

Yebes Observatory has been a Technology Development Center of the IVS since 2015. The main areas of expertise include low-noise cryogenic receivers at centimeter and millimeter wavelengths, cryogenic low-noise amplifiers, antennas and feeds, passive devices (i.e., filters, OMTs, septums, microwave hybrids, and couplers), cryogeny and vacuum, modules for receiver calibration, antenna control software, microwave holography for large reflector antennas' surface characterization, RFI detection and measurements, and topographic measurements for the local tie.

Yebes Observatory operates two radio telescopes—RAEGE, 13.2-m in diameter, and ARIES, 40-m in diameter—which are integrated into the IVS (see Figure 1). The first one runs VGOS observations regularly, and the second one has run legacy IVS observations since 2008. The details are explained in the corresponding station report available in [1].

The 13.2-m radio telescope belongs to the RAEGE (*Red Atlántica de Estaciones Geodinámicas y Espaciales*, `https://raege.eu`), and it has been the first operative radio telescope of the four ones foreseen within that network (Yebes, Santa Maria, Gran Canaria, and Flores) (see [2] for details on RAEGE).

Fig. 1 General view of Yebes Observatory.

In May 2023, the new satellite laser ranging station at Yebes Observatory (named YLARA[1]) had its first laser shot, and its commissioning phase started. Later on, in October 2024, the International Laser Ranging Service (ILRS) confirmed that YLARA passed the quarantine and became a regular SLR station of the ILRS network. The next step is to equip YLARA with the required instrumentation for space debris tracking. A detailed description of the YLARA status can be found in [3].

As a result of this new space geodesy facility, Yebes Observatory has become a GGOS core site.

Santa Maria was the second operative RAEGE station. A detailed description can be found in [4]. Details on RAEGE Santa Maria operations are reported in its corresponding station report available in [5].

Finally, a DifX VLBI correlator for RAEGE baselines was installed at Yebes Observatory, which can

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[1] Yebes LAser RAnging

also be part of VGOS and EU-VGOS distributed correlation. Details are provided in [1].

All these activities are performed by an amazing group of engineers and technicians assisted by excellent administrative staff.

2 VGOS Broadband Receivers

The construction, characterization, and installation of the VGOS receivers for the new stations at Hartebeesthoek (SARAO[2], South Africa), Matera (ASI[3], Italy), and Songkhla (NARIT[4], Thailand) were the main focus of the work at the Yebes TDC. Additionally, the RAEGE Santa Maria VGOS receiver and the Ny-Ålesund NMA1[5] VGOS receiver were upgraded, too. Part of this work was presented in [6].

2.1 RAEGE Santa Maria VGOS Receiver

After the installation of the VGOS receiver in the Santa Maria radio telescope in October 2022, a very harmful interference that fully blinded the receiver was detected. This interference comes from a space debris radar located 1.75 km away, with a frequency centered at 2.95 GHz and an emitted power of 50 kW. As a result, it was decided to design high-temperature superconducting notch filters to reject this signal. While they were being developed, commercial 4-GHz high-pass filters were installed in January 2023 to reject the signal (see [7]), so Santa Maria started its participation in VGOS observations, although only in B, C, and D bands.

The development of the superconducting notch filters took nine months. After this, they were installed in the receiver in September 2023, which allowed the radar signals to be rejected by 33 dB, and A-band was recovered for VGOS observations. The first complete VGOS session was VO3278 (10/05/2023), and, since then, RAEGE Santa Maria (Sa) has been part of the VGOS core network. Table 1 summarizes the filter performance. More information on these filters can be found in [8], [9], and [10].

[2] South African Radio Astronomy Observatory

[3] Agenzia Spaziale Italiana

[4] National Astronomical Research Institute of Thailand

[5] Norwegian Mapping Authority

Table 1 RAEGE Santa Maria HTS filter measured parameters.

Parameters	Measured value
Operating frequency	2–14 GHz
Operating temperature	10 Kelvin
Input/output matching	≤ -12 dB
Insertion losses in 2.94–2.96 GHz	≥ 20 dB
Insertion losses in A-band (3–3.5 GHz)	≤ 0.4 dB
Insertion losses in B-band (5.2–5.7 GHz)	≤ 0.2 dB
Insertion losses in C-band (6.3–6.8 GHz)	≤ 0.2 dB
Insertion losses in D-band (10.2–10.7 GHz)	≤ 0.3 dB

2.2 Ny-Ålesund VGOS NMA1 Receiver Upgrade

The VGOS NMA1 receiver for Ny-Ålesund was sent to the Yebes Observatory for an upgrade. This work involved replacing the single-ended LNAs with balanced ones, along with their corresponding biasing stages. Additionally, the commercial off-the-shelf 30-dB directional couplers were removed and replaced with custom-built units specifically designed for VGOS at Yebes (see Section 5). The vacuum and cryogenics control and monitoring unit was also upgraded. Finally, an equalizer was installed in the PhaseCal to flatten the spectrum of the tones, and a complete measurement of Trx and Tcal was performed on the receiver before it was returned to Ny-Ålesund on October 31, 2024.

2.3 VGOS Receivers for Matera, HartRAO, and NARIT

Yebes Observatory was commissioned to build three complete new cryogenic VGOS broadband receivers, from the dewar and frontend (QRFH and LNAs) to the room temperature signal chain up to the input of the backends, including the PhaseCal and NoiseCal modules, the Cryogenics and Vacuum Control Unit, and the receiver control software.

These receivers were delivered to the Hartebeesthoek VGOS station in South Africa (SARAO), the Matera VGOS station in Italy (ASI), and the next Songkhla VGOS station in Thailand (NARIT). For NARIT's VGOS receiver, only the frontend was provided, according to the scope of supply.

NARIT's VGOS receiver was shipped in December 2023. From February 12 to 23 2024, a team of Yebes engineers and technicians traveled to the Hartebeesthoek VGOS station for the installation of the VGOS receiver in the new VGOS radio telescope. The work was done in close collaboration with Hartebeesthoek staff. Similarly, from April 2 to 12 2024, the Yebes team traveled to the Matera station for the installation of the VGOS receiver in the new VGOS radio telescope. The work was done in close collaboration with the OHB Digital Connect staff and the Matera station staff.

Upon the delivery of these receivers, Yebes Observatory has built eight receivers for the VGOS community. This number will increase to ten after the completion of the RAEGE Gran Canaria and Flores stations within the next few years.

3 Broadband Feeds

Yebes Observatory has been optimizing the design of its QRFH[6] antenna to achieve reflection coefficients better than −10 dB and aperture efficiencies better than 55% throughout the entire band of VGOS (2.2–14 GHz). To achieve such improvement, a new design methodology has been proposed to optimize the feeding section and the flared section of the horn separately. More details can be found in [12]. This optimized QRFH feed model has been installed in the VGOS receivers recently developed by Yebes Observatory.

In addition, a study carried out by SARAO, in collaboration with Yebes Observatory, has served to validate the performance of the optimized QRFH feed in the 13.2-meter radio telescope at the Hartebeesthoek Radio Astronomy Observatory [13]. The main conclusions obtained in such research can be extrapolated to other VGOS radio telescopes with equivalent geometry.

4 Low-noise Broadband Amplifiers

During the 2023–2024 period, Yebes' amplifier laboratory has manufactured and delivered four single-ended cryogenic amplifiers and six microwave hybrids for VLBI applications in the VGOS 2–14 GHz band.

In the previous IVS biennial report, we described the development in collaboration with Diramics[7] of a new generation of InP transistors with improved cryogenic noise performance. These devices are now being used in the first stage of redesigned VGOS LNAs and for an expanded 2–18 GHz band [14].

Another interesting development with potential applications in the VLBI community is a unique 4–20 GHz LNA with an average noise temperature of 3.8 Kelvin, in the context of the new generation ALMA receivers. This amplifier profits from state-of-the-art noise characteristics and very low power dissipation. It has an input reflection below −15 dB that would allow its direct insertion into a receiver without the need of an isolator. These LNAs could be good candidates for future expansions of the band in the high end.

5 Cryogenic Directional Couplers

A 30-dB cryogenic directional coupler especially suited for cryogenic operation was developed by Yebes TDC, optimized in the 3–14 GHz range because of the high level of RFI present in the lower part of the VGOS band, although it works well from 2 GHz. See [16] for details.

Four units have been built to meet the needs of the NARIT (TNRO, Thailand) and NMA (Ny-Ålesund) VGOS receivers. Two additional units have been manufactured for the Celestia-Callisto company in charge of the cryogenic RF system refurbishment of the AGGO[8] radio telescope in Pereyra, Argentina.

6 CDMS Developments

In relation to the CDMS, a new system has been developed for the Matera VGOS station using 5-MHz signal transport over single-mode optical fiber with the corresponding fiber optic transceivers. This system not only takes advantage of the inherent benefits of fiber optics, such as a lower thermal coefficient than coaxial cable, better RFI isolation, and galvanic insulation, but it also incorporates a novel phase detection system. This new

[6] Quad-Ridged Flared Horn

[7] Diramics AG, Switzerland (https://diramics.com)

[8] Argentine-German Geodetic Observatory

method, different from the coaxial version described in [17], introduces a lower RMS noise in the detection, which allows equivalent results to be obtained without the need for post-processing or filtering. As a result, a significantly shorter processing time is achieved, and real-time delay measurements are obtained.

7 HTS Filter Developments

For aircraft security reasons, some SLR stations have an active radar emitting at 9.41 GHz, which can cause saturation problems in VGOS receivers, as previously reported in [8]. Both the HartRAO and Matera stations, for which Yebes Observatory has manufactured their VGOS receivers, have this type of radar. For this reason, a high-temperature superconducting notch filter able to reject the radar frequency without affecting the remaining VGOS band was developed. Its measured specifications are given in Table 2. More information on this filter can be found in [18].

New HTS filter topologies are under development at Yebes Observatory TDC.

Table 2 Measured parameters for the SLR radar notch HTS filter.

Parameters	Measured value
Operating Frequency	2–14 GHz
Operating Temperature	10 Kelvin
Input/output matching	≤ -14 dB
Insertion losses	≤ 0.3 dB
Insertion losses in 9.37–9.44 GHz	≥ 50 dB
Insertion losses in 9.385–9.42 GHz	≥ 60 dB

8 Compact Down-converters

Yebes Observatory started the development of compact down-converters for VGOS in order to save volume and power consumption and reduce RFI effects.

A decision was made to slice the range DC-16 GHz into four sub-bands: A (DC-4 GHz), B (4–8 GHz), C (8–12 GHz), and D (12–16 GHz), and dual-channel down-converters with common LO and an IF of DC-4 GHz have been designed for each sub-band. This way, the IFs can be directly connected to dBBC3 base-band inputs.

As a first approach for these designs, pre-fabricated PCBs from X-Microwave were selected, as they integrate amplifiers, attenuators, and filters into small boards, facilitating the initial design and characterization of the frequency converter. Due to X-Microwave's lack of isolators, these were sourced externally with drop-in format, and the low-pass filters (LPF) were replaced by customized ones designed and manufactured in-house.

The whole set of four down-converters will be integrated later on into a 19-inch 1U chassis, including a microcomputer for monitoring and control, power supplies, and LAN connectivity. This configuration allows fitting four frequency converters into just a 1U chassis, significantly reducing the required space compared to the conventional coaxial-based converters, which occupy 8U in total.

9 Concrete Tower Height Laser Measurement System

The RAEGE 13.2-meter radio telescopes are supported on top of a concrete tower that is 9.5 m in height. In order to monitor height changes of the concrete tower that may potentially impact geodetic measurements, a laser measurement system is under design. The installation and tests will be performed in 2025.

10 RFI Measurements

Several monitoring campaigns were carried out in 2023 to assess the impact of satellite signals in the 10.7–12.75 GHz frequency range from geostationary and non-GEO satellites (so-called mega-constellations, such as Starlink and OneWeb) on 24-hour VGOS sessions. A report on the results from session VO2307 (July 26, 2023) is available in [19].

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