IGN Yebes Technology Development Center

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Abstract The activities in technical development related to geodetic VLBI done during 2015 and 2016 at IGN Yebes Observatory were focused on different topics that are detailed below.

1 RAEGE Radio Telescopes

The RAEGE radio telescope at Yebes Observatory (Spain) is currently equipped with a VGOS-compliant broadband receiver. The broadband receiver, which was developed and tested in the laboratory during 2015, was installed on February 24, 2016.

The first fringe detection with the broadband receiver in the Yebes VGOS radio telescope was confirmed on April 28, 2016. Some more tests were performed during May and June. After this, it participated in seven VGOS sessions. The first observation using four sub-bands and four RDBEs was performed on December 19, 2016.

Regarding RAEGE station on Santa María island (Açores, Portugal), it is currently equipped with a tri-band receiver (S/X/Ka). The tri-band receiver was installed on November 7, 2016, after being developed during 2015 and 2016. Onsite works continued during 2015 and 2016, and the first light was delayed to the first half of 2017.

With respect to the next RAEGE radio telescope on the Canary Islands, its mechanical parts arrived on Gran Canaria island in 2016, where RFI tests are being performed to find a suitable location. Once the site is identified, civil works and assembly can start.

Finally, it has to be mentioned that the invariant points of the Yebes 40-m and 13.2-m telescopes were measured, as reported in [1].

2 VGOS Broadband Receiver

The cryogenic front-end of the broadband receiver consists of a Dewar with a dual-linear polarization quadruple-ridged flared horn (QRFH), directional couplers for calibration signal injection, and two ultra-low noise hybrid amplifiers, one for each polarization. The refrigerator is based on the Helium Gifford-McMahon closed-cycle approach, which cools the components down to 10 K.

The block diagram of the receiver is shown in Figure 1. The output signals from the Dewar are sent via RF-over-fiber optic links to the backend room, where they are distributed to four dual-channel frequency up/down converters. Each converter allows selection of a frequency sub-band in both polarizations, with 1.5-GHz bandwidth[1], in the range 2–14 GHz, and its conversion to baseband (DC – 1.5 GHz).

The converter design and construction has been accomplished and implemented by the engineers and technicians of the receiver group at Yebes Observatory, using the Haystack design as a starting point.

Figure 2 shows an internal view of the front-end, which was introduced in [2].

The noise temperature of the complete receiver was measured, and Tcal was calibrated. The results of the

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[1] The final bandwidth, either 500 MHz or 1 GHz, is selected in the backend.

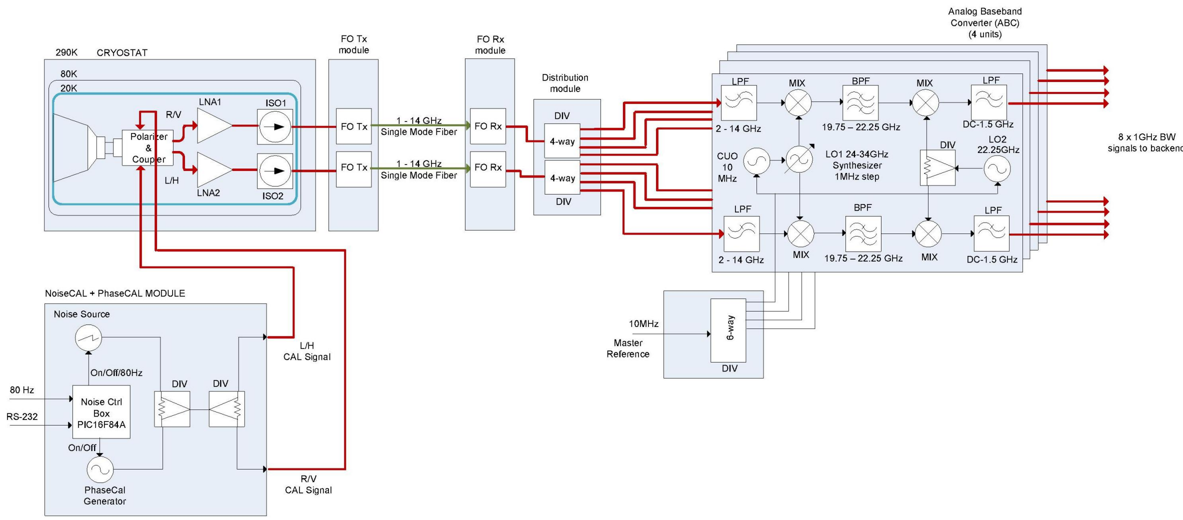

Fig. 1 Broadband receiver block diagram.

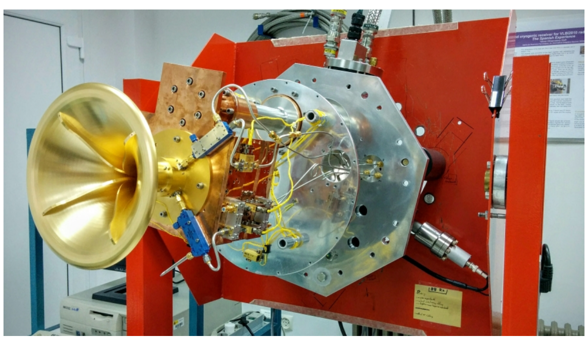

Fig. 2 Broadband receiver internal view.

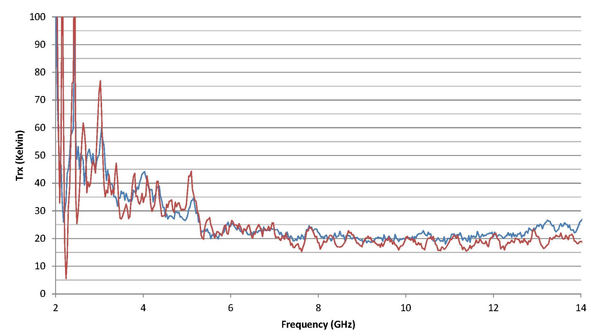

Fig. 3 Broadband receiver noise temperature.

receiver noise measurements are shown in Figure 3. The blue trace shows the result for one polarization with a balanced low-noise amplifier configuration, while the red one corresponds to the other polarization with a single low-noise amplifier. The matching of the balanced configuration is much better. As a result, the ripple across the band is lower than in the channel with a single amplifier. The measured receiver noise temperatures are lower than 25 K for most of the band. However, the existence of RFI signals in S and C bands, due to WiFi, UMTS, Bluetooth, and WiMax, among others, provides anomalous values for the low frequency range.

Finally, a digital phasecal generator was developed, using the Haystack design as a starting point.

3 Tri-band (S/X/Ka) Receiver for Santa María Station

A second cryogenically cooled tri-band receiver has been successfully developed [3, 4, 5]. At this time, three of these receivers have been built: two of them for the RAEGE radio telescopes, in Yebes and Santa María, and one for GSI's Ishioka station in Japan. The tri-band receiver allows simultaneous dual-circular polarization observations at S (2.2–2.7 GHz), X (7.5–9 GHz), and Ka (28–33 GHz) bands. It can be used in legacy S/X mode, in X/Ka mode, and, in addition, at Ka-band, allowing accurate measurements of pointing, tracking, and antenna efficiency during the commissioning phase.

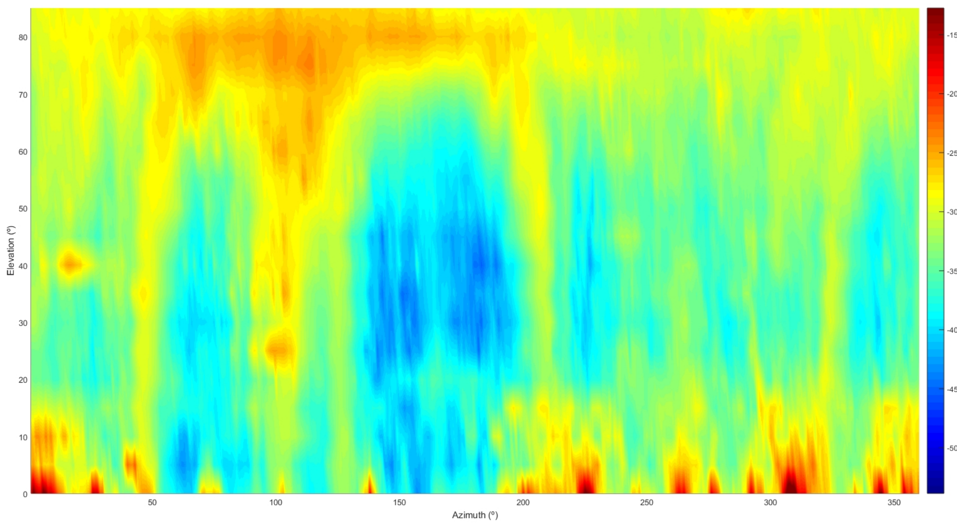

Fig. 4 Elevation over azimuth map of RFI power.

The receiver noise temperatures are lower than 25, 35, and 35 K, respectively. The receiver is fully integrated into a frame box positioner that facilitates the installation at the radio telescope feed cone, together with the downconverters, tri-band noisecal and phasecal, LNA biasing modules, and cryogenics and vacuum monitoring equipment.

The current receiver will be replaced by a new VGOS broadband receiver by 2018.

4 RFI Measurements

First tests of the VGOS broadband receiver, after installation in the 13.2-m radio telescope, showed saturation issues due to RFI signals in the lower part of the band [6]. The initial room temperature amplifiers, in front of the fiber optic link, were under saturation, and, in addition, they were saturating the fiber optic link, too. These amplifiers had to be removed. However, an increase of the system noise temperature was detected, due to the high noise figure value of the fiber optic link.

The RFI power at the output of the Dewar was measured with a total power detector up to 6 GHz, where the RFI signals are more powerful. The radio telescope was driven to acquire an elevation-over-azimuth map which is shown in Figure 4 for the vertical polarization. It can be seen that, at elevation angles under 10 degrees, approximately, the power at the output of the Dewar can be as high as -15 dBm.

Spectral measurements were performed as well, showing that the most relevant RFI comes fron GSM, UMTS, fixed service radio-links, WiFi, Bluetooth, and WiMax [7]. Several other tests were performed with different filters at the output of the Dewar, showing better performance. As a result, a custom filter is going to be installed to solve this issue.

5 LNA Development

During the reporting period, several cryogenic S and X band amplifiers of receivers from Wettzell and AGGO (former TIGO) were inspected and repaired (when needed) using Yebes dedicated laboratory cryostats. New cryogenic amplifiers for the Santa María tri-band receiver, based on the same design used in Yebes, were produced and delivered.

Regarding new developments, the activity with the 2–14 GHz wide-band cryogenic amplifiers for VGOS stations has continued. The 2014 report presented the results obtained with a Yebes design built using US InP NGST HEMT devices. The performance was excellent, but the experimental InP devices used are subject to se-

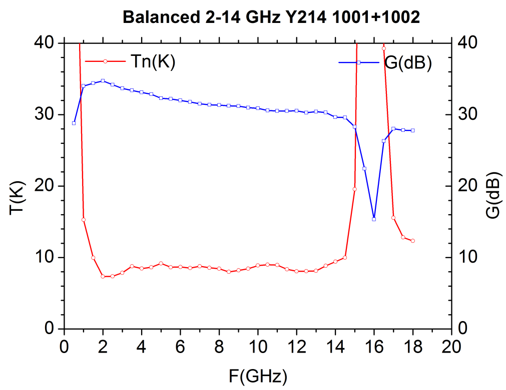

Fig. 5 Gain and noise temperature of a balanced 2–14 GHz cryogenic amplifier as measured in a test cryostat.

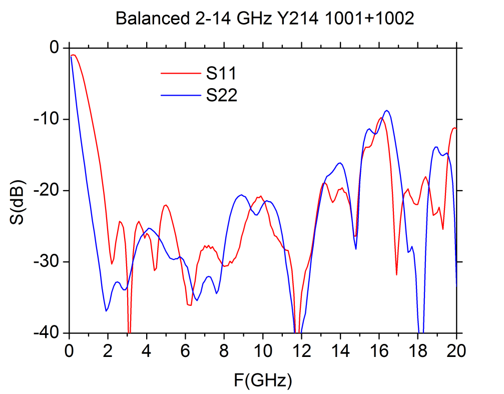

Fig. 6 Input and output matching of a balanced 2–14 GHz cryogenic amplifier as measured in a test cryostat.

vere ITAR regulations and could not be exported freely. During the reporting period it has been possible to obtain the same level of performance using European InP devices developed by ETH Zurich, Switzerland. This opens the door for providing this design to other IVS stations with the need for hard to procure, reliable, and state-of-the-art wideband cryogenic amplifiers.

One of the problems of wideband 2–14 GHz receivers is the poor match (high reflection coefficient) of the feeds and the amplifiers in the low frequency region, which causes ripples in noise and gain. To avoid this problem, a balanced configuration using two amplifiers and specially developed 90° cryogenic hybrid couplers has been designed, produced, and tested. The input and output reflection is drastically improved to the level of -20 dB in most of the band, with a slight penalty in noise w.r.t. a single-ended unit (see Figures 5 and 6). The peak in Figure 5 around 16 GHz is due to the 90° cryogenic hybrid. Another application of the 90° hybrid could be to obtain circular polarization from the combination of the two linear polarization outputs of the feeds.

A new prototype of the Ka-band amplifier has been built using novel InAs HEMT devices developed at ETH. This exotic semiconductor has the potential of obtaining even lower noise and power dissipation at cryogenic temperatures than InP. A noise temperature of less than 10 K was measured in the 32–35 GHz VLBI band.

The existence of reliable sources willing to produce adequate HEMT devices for the cryogenic low noise amplifiers needed in radio astronomy is of maximum importance for maintaining the competitiveness of our instruments. In this respect, Yebes has been involved in cooperation agreements with some European institutions (foundries) such as IAF (Germany) or ETH (Switzerland), allocating significant funding and resources within our limited possibilities. Perhaps a more dedicated effort with additional funding from other institutions would be needed to keep this technology alive and evolving in the future.

6 Software Developments

The installation of the broadband receiver required the development of software code to monitor and control its frequency and attenuation, the noise diode, and the phase cal system. The integration in the antenna control system and the data acquisition in single-dish mode was also developed and tested. The aperture efficiency of the system was measured in different bands between 3.5 and 14 GHz, and it ranges between 60% at lower frequencies to 40% at the higher end. The SEFD also ranges between 2000–5000 Jy along the frequency band. The results are summarized in [8].

The control system for the VGOS twin telescopes at Ny-Ålesund has been designed and developed, based on the Yebes 13.2 m one. The design allows both telescopes to be controlled independently or linked together. The software to monitor the Vaisala weather station, equipped with several sensors, a continuum detector for single dish observations, and a counter for measuring the cable delay, was developed too. All of this software together with the underlying infrastructure was installed at Yebes on the computers sent from the Norwegian Mapping Authority (NMA). A description of the works peformed is available in [9].

Onsala Space Observatory (OSO) asked Yebes Observatory for a report on the tests performed at the VGOS Yebes antenna to use it as a guide for testing their recently built VGOS twin telescopes at Onsala. Tests performed to check the servosystem and the control system developed at the Yebes VGOS telescope are described in [10].

7 Other Activities

Yebes Observatory has been in charge of refurbishing three S/X receivers from the German *Bundesamt für Kartographie und Geodäsie* (BKG) under a collaboration agreement. Receivers belong to the Wettzell, O'Higgins, and AGGO stations. For the latter, Yebes offered support for both the installation and commissioning on site. Vacuum, cryogenic, and RF performances have been improved by either the repair or replacement of some parts (e.g., cold heads, sensors, LNAs, and thermal transitions). Examples of these works can be found in [11, 12, 13].

In 2016 Yebes observatory supported our colleagues in Ny-Ålesund (Svalbard, Norway) during the site acceptance test (SAT) of their twin radio telescopes. This collaboration will be extended to support the installation of a tri-band receiver (S/X/Ka) to characterize and carry out their commissioning during 2017.

Yebes Observatory will also participate as a partner in the EU financed project H2020 RADIONET4 grant agreement 730562, for the development of a broadband VLBI receiver from 1.5 GHz to 15.5 GHz (WP BRAND-EVN), with a strong connection to VGOS [14].

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