Observatory of Yebes Technological Development Center 2017–2018 Biennial Report

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Abstract We present the main technical developments of the Observatory of Yebes (IGN) from years 2017 and 2018 related to geodetic VLBI.

1 General Information

The Observatory of Yebes was declared a Technological Development Center for the IVS in 2015. Its main contributions lay in the area of receivers covering low noise amplifiers, passive devices and cryogenics, microwave receivers, modules for receiver calibration, antenna control software, RFI measurements, and topographic measurements for the local tie.

The Observatory of Yebes also runs two radiotelescopes, 13.2-m and 40-m in diameter, respectively, which are integrated into the IVS. The first one regularly runs VGOS observations, and the second one has run legacy IVS observations since 2008. The details are explained by González et al. (2019) in this same volume. The 13.2-m radiotelescope belongs to the RAEGE (Red Atlántica de Estaciones Geodinámicas y Espaciales), and it is the first operative radiotelescope of the four foreseen within that network (Yebes, Santa María, Gran Canaria, and Flores). The Observatory of Yebes also manages two GNSS receivers: one integrated into the international network and a second one into the Spanish national one. It also runs two gravimeters, an absolute one and a relative superconductor one. We are also planning the installation of an SLR station in the next five years, which would convert the Observatory of Yebes into a GGOS core station. Around the 40-m and 13.2-m radiotelescopes and the associated equipment and instrumentation, a team of engineers and astronomers have developed and continue developing technology for radioastronomy which is used for our telescopes and for other institutes around the world. To achieve such a goal, the observatory hosts several laboratories and workshops with precision machines where these developments take place.

In the following sections we describe the most relevant activities and technical developments accomplished during 2017 and 2018. Most of these continue during 2019.

Observatory of Yebes, IGN

IGN Yebes Technology Development Center

IVS 2017+2018 Biennial Report

2 VGOS Broadband Receivers

The Observatory of Yebes received the mission to design and build three cryogenic VGOS broadband receivers: two for the Norwegian Mapping Authority (NMA) and one for the Finnish Geospatial Research Institute (FGI). These broadband receivers are cooled using a two stage cryostat (15 and 50 K) and operate between 2 and 14 GHz. They have cryogenic low noise amplifiers designed and built at the Observatory of Yebes and deliver a receiver temperature below 25 K along the whole band measured in an RFI-free lab environment. They provide two linear orthogonal polarizations simultaneously.

Two of them will be delivered by the second half of 2019, one to NMA and one to FGI, respectively. Figure 1 shows the schematics of one such receiver in which we can see its different modules. After the cryostat, the signal is split into two sub-bands: 2.1 – 5.6 GHz and 3.6 – 11.6 GHz following Haystack's approach to avoid the saturation of the optical fiber amplifiers from strong signals in the lower part of the band. The signals, once amplified, filtered, and transported through optical fiber links to the backends room, are directed towards two identical DBBC3 RF interface modules designed and built at Yebes. These modules split the signals from both polarizations into four frequency sub-bands ready to be injected into the DBBC3. The filtering and conditioning module for the DBBC3 does not use tunable LOs, and, in case the observing bands change, they can be adapted by replacing the band pass filters with new ones.

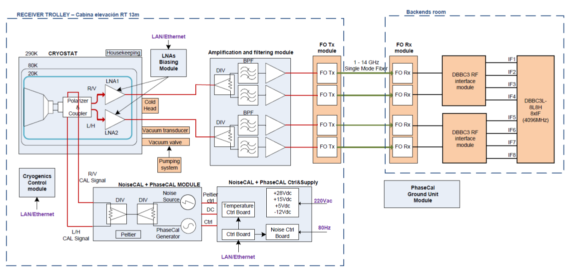

Fig. 1 Schematics of the VGOS broad band receiver for NMA and FGI.

Figure 2 shows the receiver temperature measured in both linear polarizations along the band. The peaks at low frequencies are due to RFI associated with WiFi, UMTS, Bluetooth, WiMax, and other sources of noise.

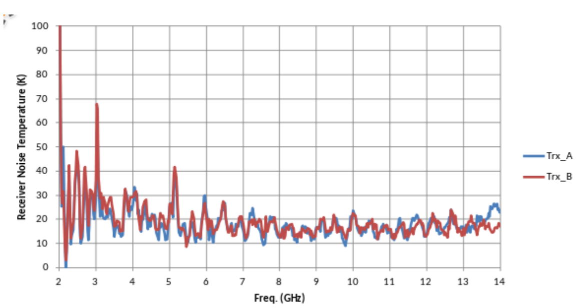

Fig. 2 Receiver temperature for the FGI broadband receiver along the band. The peaks at low freuencies come from RFI.

The receivers use a cryogenics and vacuum control system which has been overhauled from a previous version used in the Yebes VGOS receiver. This new version has a remote ethernet connection to the Local Area Network that allows remote monitoring and control of both pumps (rotatory and turbomolecular), the cryogenic temperature, the vacuum sensors, the electrovalve, and the heat resistors and regenerators. This remote monitoring and control eases the operation of the receiver, adds stability, and provides a complete time log of the cryogenics. It is integrated into the control system of the telescope and can be used by third party software.

3 Tri-band Receiver for Ny-Ålesund

The NMA runs two twin VGOS radio telescopes at Ny-Ålesund station which were inaugurated during the last IVS General Meeting in June 2018. In order to test these radiotelescopes, NMA borrowed from the Observatory of Yebes one tri-band receiver which simultaneously works in the bands: 2.2–2.7 GHz, 7.5–9 GHz, and 28–32 GHz. The receiver was mounted first in one antenna and then in the second one to test the telescopes and determine the pointing and focusing model. The SEFD and the efficiency at X-band were estimated. Both telescopes were using the Yebes control software and the Yebes pipeline and reduction software. Receiver temperatures are below 25 K at S-, X-, and Ka-band in all cases.

4 QRFH Revisited

The Observatory of Yebes has worked in the optimization of the QRFH design from JPL used in the VGOS radiotelescopes. The Yebes design resembles the original design but has slightly changed the profile and the connectors (coaxial ones). The antenna works between 2.3 and 14 GHz in dual linear polarization. The schematics allow it to be manufactured easily. The efficiency is silghtly better than the original design, above 0.55 along the whole band, but the reflection is slightly worse (see Figure 3).

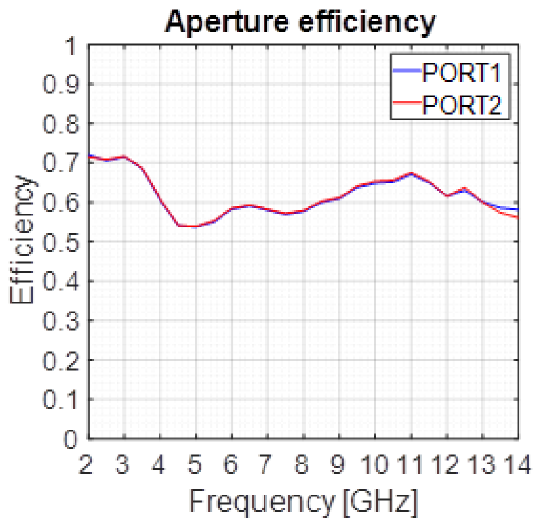

Fig. 3 Efficiency of the QRFH along the frequency band.

5 Linear to Circular Polarization: Hybrids and Software

One of the main drawbacks of the broadband receivers is the need to use linear polarization. This has prevented an easy simultaneous operation with the IVS legacy observations which only use Left Circular Polarization (LCP). The usage of linear polarization generates new problems to be taken into account like variable polarization coming from the paralactic angle which differs at the different radiotelescopes on the Earth. Sources may be totally or partially polarized, and because their paralactic angle changes with time, it is necessary to observe in both polarizations to recover the whole signal. Furthermore, instrumental effects should also be taken into account. The conversion from linear to circular polarization can be done either by software or by hardware.

The Observatory of Yebes has developed a solution based on cryogenic 3dB/90 degrees multi-octave stripline hybrids which can be used to obtain both circular polarization signals from linear polarization ones. The usage of such devices at cryogenic temperatures (15 K) only increases 1.5 K on average the noise temperature of the LNAs. This solution guarantees cross polarization below 25 dB, an axial ratio below 1 dB, an amplitude unbalance below 0.9 dB, and a phase unbalance lower than 3 degrees. To achieve such specifications the length of the lines has to be controlled with great accuracy, but this is achievable using special connectors. Figure 4 shows the hybrids' performance along the frequency band. This solution has not been implemented on a receiver yet, but the BRAND project from Radionet is considering it as a first option.

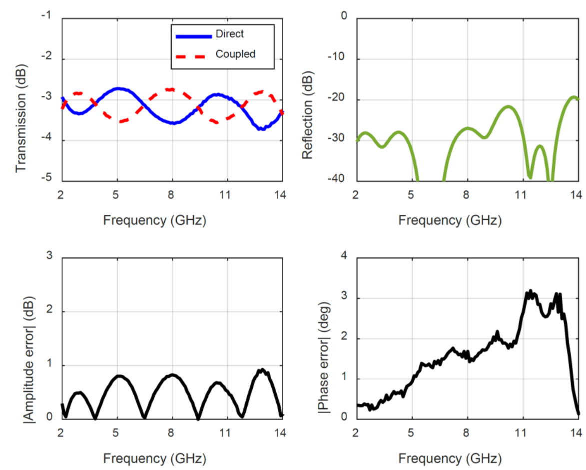

Fig. 4 Hybrid performance: transmission, reflection, amplitude error, and phase error, along the frequency band.

The alternative approach to convert linear to circular polarization is by software using PolConvert software by I. Martá-Vidal. This task is part of the effort started by the EU-VGOS project which aims to create a pipeline that performs the correlation, polarization conversion, instrumental polarization calibration, and fringe fitting along the whole band to estimate the dispersive effects of the ionosphere. The goal is to obtain the final observable: the broadband delay for each scan and baseline from which the length of the baselines is estimated. EU-VGOS observes regularly with the European antennas from Onsala, Wettzell, and Yebes to test this pipeline currently under development.

6 Ultra Low Noise Wide Band Amplifiers

We have developed two kinds of low noise cryogenic ultra wide band amplifiers in the band between 2 and 14 GHz. The first option is a compact, light single ended amplifier which is usable in a much larger band, between 0.5 and 18 GHz. The average noise temperature is 6.1 K and the gain 33.9 dB, with an input IRL of -1.5 dB and an ORL of -16.9 dB. The consumption is 36 mW. This amplifier has a large input reflection, and an alternative solution was investigated using a balanced amplifier.

The balanced amplifier uses 3dB/90 degree hybrids, and the results are excellent. The penalty for using the hybrids is very low. The noise temperature increases only 1.5 K on average, up to 7.6 K, and the gain stays at 33.8 dB, but the IRL drops to -21 dB and the ORL to -23 dB. We have developed two versions, one for the 2-14 GHz band and another for the 1.5-15 GHz band (BRAND receiver).

The behavior of both amplifiers are shown in Figures 5 and 6 for an easy comparison.

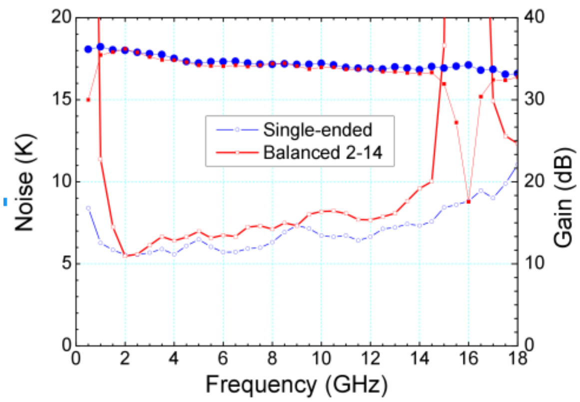

Fig. 5 Noise temperature and gain of single ended and balanced amplifiers.

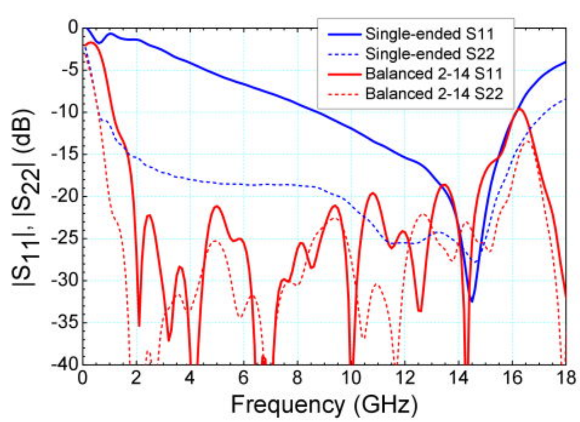

Fig. 6 S parameters for single ended and balanced amplifiers.

7 Phase Cal Developments

The phase cal system for VLBI is composed of two subsystems: the antenna unit, which injects phase cal tones used for calibration of the instrumental phase along the observing band, and the cable delay measurement system, which estimates the variable delay in the signal caused by the cables between the receiver and the VLBI backends. This system devised by A. Rogers is very powerful, and it is in use at the IVS radiotelescopes.

We have optimized the antenna unit system by providing extra features. The noise and phase unit at Yebes is installed at the receiver trolley, very close to the cryostat. It uses short semirigid coaxial cables to decrease the variability caused by temperature variations in the receiver cabin. The system generates pulses 10 MHz apart and works between 2 and 14 GHz. The pulse generator is based on Hittite ultrafast logic gates, a similar approach as at Haystack. The noise cal can be switched at a 80 Hz rate. The whole unit is shielded, and it is temperature stabilized using a Peltier cooler and passive insulation. The control of the Peltier is done with a PR59 control module from Laird Technologies and the noise cal with a PCB designed and built at the Observatory of Yebes. The final control and monitoring of the pulses, noise cal, and the Peltier is done with a Raspberry Pi using Python scripts. Yebes labs has built nine units for BKG, AGGO, NMA, FGI, and Yebes and is integrating this system into the VGOS receivers in construction for NMA and FGI.

The Cable Delay Measurement System (CDMS) is based on the legacy design, but it has been adapted in a single PCB to simplify its usage. A new CDMS is being developed and is still undergoing tests; it does not require a frequency counter. The system compares the 5 MHz reference signal from the generator module with the 5 MHz signal coming from the antenna unit installed in the receiver trolley. Both signals are phase compared in a phase detector, whose DC output is read by a 24-bit ADC. The achieved RMS is < 5 ps, which corresponds to < 0.003 degrees in phase. This system yields higher sensitivity and lower phase noise. It is currently being tested at the 13.2-m Yebes antenna and will be extended to other telescopes once it is validated.

8 RFI Measurements

After several tests to avoid a Tsys increase due to RFI, the configuration shown in Figure 7 was adopted. A 3 GHz high-pass filter was installed at the dewar's output. In addtion, a PIN diode power limiter (+6 dBm) was installed at each optic fiber link input, in order to protect them from damage due to strong RFI which is present and could enter the receiver during antenna maintenance 0-deg elevation. With this configuration, we managed to reduce Tsys from 70 K down to 50 K.

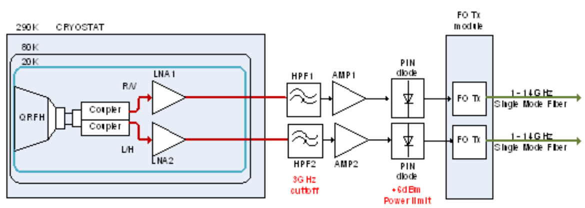

Fig. 7 Yebes VGOS receiver configuration.

In addition, a line of research on high temperature superconducting filters (HTS) began at Yebes labs (Huang et al., 2018). The initial project was a sharp HTS filter for the legacy S-band, which is the worst one in terms of RFI. The specifications for this filter were very selective in order to reject high power radiolinks close to this band:

- Center frequency: 2295 MHz
- Bandwidth: 2215 - 2375 MHz
- Max insertion loss: 0.1dB @ 20 Kelvin
- Rejection $>$ 60 dB at 2115 $<=$ f $<=$ 2180 MHz
- Rejection $>$ 30 dB at f $>$ 2400 MHz
- Max VSWR in/out: 1.4:1
- In/Out impedance: 50 ohms
- Temperature of operation: 20 Kelvin.
- Input connector: coaxial SMA-female
- Output connector: coaxial SMA-male

After this, the simulation of an HTS filter for VGOS is underway with promising results. The current configuration considered for VGOS is a band-pass filter (2–14 GHz) with one notch at a pre-defined frequency.

Finally, it has to be mentioned that a new RFI monitoring station has started operations on the roof of the laboratory building. It allows the monitoring of RFI from 1 to 40 GHz.

9 Large Future Plans

Two large and ambitious goals for the Observatory of Yebes are planned for the next four years using European funds from regional development. The first one is the construction of a future Satellite Laser Ranging station at Yebes. In the next months we will make a study of the requirements for the telescope and ancillary equipment and the software. Once this is decided, the acquisition of the equipment will take place, and later the building that hosts the telescope will be erected.

The second goal consists of the extension of the current building of laboratories and workshops. The new building, whose civil work will start shortly, will host several laboratories, including a clean room and workshops to host precision milling machines and lathes as well as metrology equipment.

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