Microwave and millimeter-wave technological developments at Yebes Observatory

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Abstract

This paper shows the latest technological developments at Yebes Observatory in microwave and millimeter wave instrumentation for radio astronomy.

1. Introduction

The technological activities at Yebes Observatory are focused in the development of ultra-low noise cryogenic receiving systems in the range of microwave and millimeter wavelengths. These system are installed in either the ARIES 40 meter radio telescope, covering the 2 - 120 GHz range, or the VGOS 13.2 meter one (see figure 1) [1].

Figure 1. Yebes Observatory radio telescopes.

2. Description of activities

The developments performed in Yebes Observatory cover the following technological areas: cryogenic front-ends, optics and feeds and ultra-low noise cryogenic amplifiers.

2.1 Front-end developments

Yebes Observatory is collaborating with the Korean VLBI network (KVN) in the construction of a multi-channel receiving system, which will allow simultaneous reception of 22, 43 and 86 GHz in dual circular polarization with the 40 m radio telescope [2]. For this purpose, a set of low-pass filters and dichroic mirrors, designed with quasi-optical techniques, have been developed (see figure 2) [3]. Currently, simultaneous observations at 22 and 43 GHz are implemented (see figure 3) [4, 5], while the 86 GHz channel is under construction, together with a cold load cryostat for calibration. This multi-channel receiving system will give reliable phase calibration of mm-wave VLBI, as well as simultaneous multi-frequency band observations. The receiver noise temperature is lower than 25 Kelvin in K-band and lower than 50 Kelvin in Q-band.

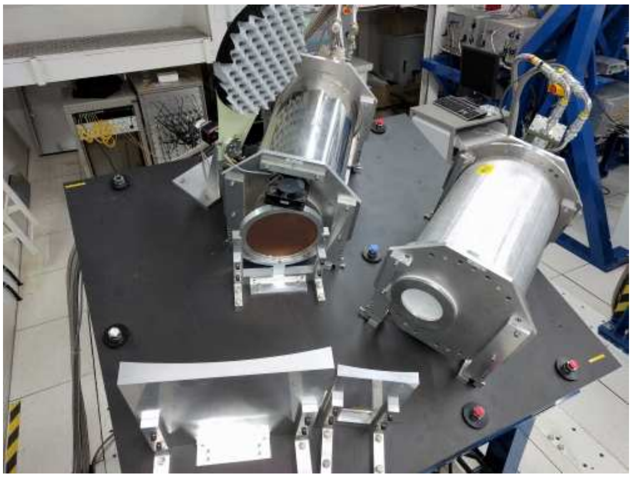

Figure 2. Simultaneous K&Q band receiving front-end.

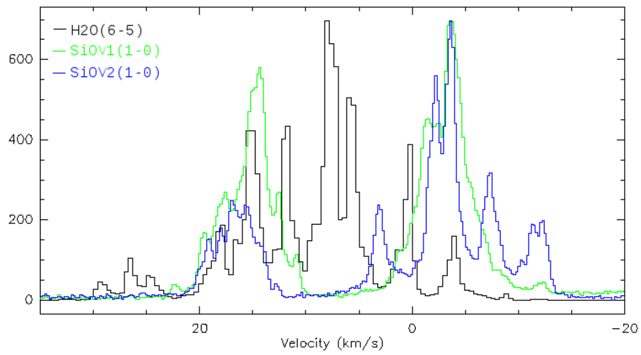

Figure 3. Simultaneous detection in K and Q bands of H_2O and SiO from Orion nebula.

In addition, it has to be mentioned the important contribution to NanoCosmos project, funded by the European Research Council through Synergy funds. Two sets of ultra-low noise cryogenic receivers are under construction, one set will work in Q (31.5 - 50 GHz) [6] and W (72 - 90.5 GHz) bands, with dual linear polarization, and it will be installed in the 40 m radio telescope. The second set will work in Q (31.5 - 50 GHz) and W (72 - 116.5 GHz) bands, with single linear polarization, and it will be installed in a spectroscopy laboratory belonging to the Spanish *Consejo Superior de Investigaciones Científicas* (CSIC). The receivers will have an instantaneous bandwidth of 18.5 GHz per polarization, so the spectral content of the signals will be analyzed by means of FFT spectrometers in that large bandwidth, in either two polarizations or two bands simultaneously.

The goal of NanoCosmos is to understand the process of creation of molecules and dust grain in the interstellar medium. For that purpose, the ambient of the interstellar medium will be simulated inside a gas cell (vacuum, temperature and UV radiation), where different substances will be injected and their interaction and reactions will be monitored with Q and W-band receivers. Then, with the help of the similar receivers installed in the Yebes 40 m radiotelescope, the existence of the reaction products will be confirmed [7].

Centimeter wavelengths have been developed too, with direct connection to geodetic VLBI (VGOS project) [8]. One of these developments is a tri-band receiver which allows simultaneous reception at S (2.2 - 2.7 GHz), X (7.5 - 9 GHz) and Ka (28 - 33 GHz) bands (figure 4). The receiver noise temperature is lower than 30 Kelvin in S-band and 35 Kelvin in X and Ka-band. This receiver has been used during the first light and commissioning of the new Yebes 13.2 m radio telescope.

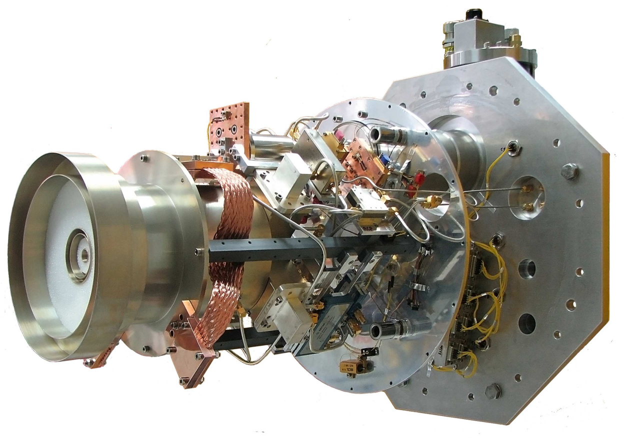

Figure 4. Internal view of tri-band receiver.

Currently, the tri-band receiver has been replaced by a broad-band receiver (2 - 14 GHz), which has been designed and built in our laboratories, too (figure 5) [9]. In this receiver, the transport of the broad-band signal, from the output of the cryostat to the down-converters in the back-end room, is performed via a RF-over-fiber link, to avoid the large attenuation and steep slope of coaxial cables. It allows geodetic VLBI observations with 8 GHz bandwidth (2 polarizations x 4 sub-bands x 1 GHz). The receiver noise temperature is lower than 25 Kelvin. However, the lower part of the band is polluted with RFI signals, and high temperature superconducting (HTS) filters are going to be developed to mitigate their impact.

It has to be mentioned that all the frequency down-converters associated to these receivers have been designed and developed in Yebes laboratories too, together with their remote control system.

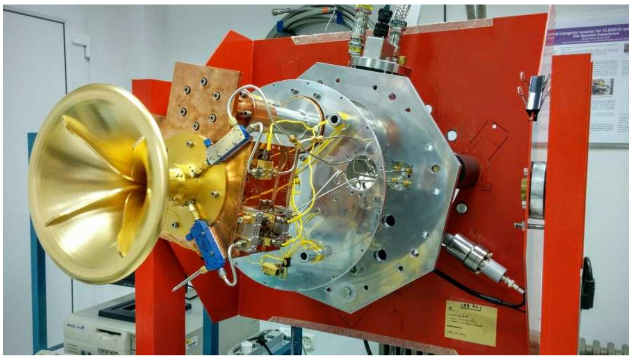

Figure 5. Internal view of broad-band receiver.

2.2 Antenna and feed developments

The feeds required for the receiver developments are designed and tested in-house. Several feeds have been developed for the Yebes radio telescopes in S, C, X, Ku, K, Ka, Q and W bands, and even for other observatories.

Starting from the specifications, the feeds are designed and simulated with different techniques (modal matching, FDTD or PO), depending on the type of feed and the frequency. After this, depending on the results, feed optimization can be carried out using genetic algorithms [10]. After fabrication in either Yebes workshop or external ones, the feeds are measured in the Yebes anechoic chamber, with spherical and planar near-field measurement capabilities up to 140 GHz [11].

Special attention has to be paid to the tri-band feed (S/X/Ka) and the ones in Q (figure 6) and W bands for NanoCosmos, which are under construction, with very broad bandwidths: 31.5 - 50 GHz in Q-band and 72 - 116.5 GHz in W-band.

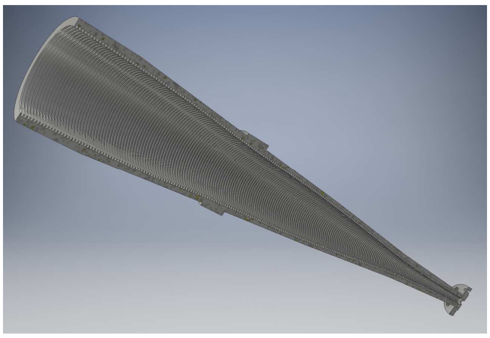

Figure 6. Nanocosmos Q-band feed.

In addition, orthomode transducers (OMT's) are under construction in Q and W bands for NanoCosmos project, too (figure 7).

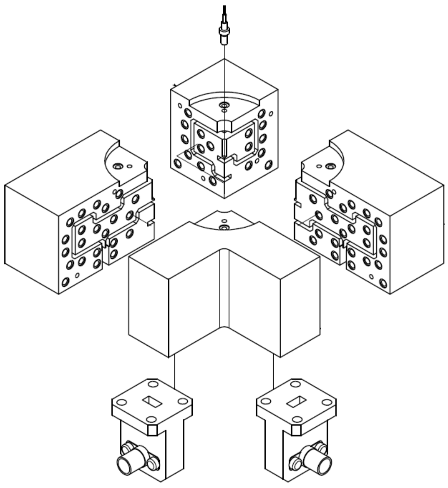

Figure 7. NanoCosmos Q-band OMT.

2.3 Ultra-low noise amplifier developments

The amplifier's laboratory in Yebes Observatory develops the ultra-low noise cryogenic amplifiers needed for the receiver development and those requested by other observatories and institutions like IRAM, ALMA or ESA, for instance.

These amplifiers have been developed for L, S, C, X, K, Ka, Q and W bands. Broad-band designs, 1 - 18 GHz, have been developed too. Figure 8 summarizes some of the achievements in this area for different projects, showing state-of-the-art performances.

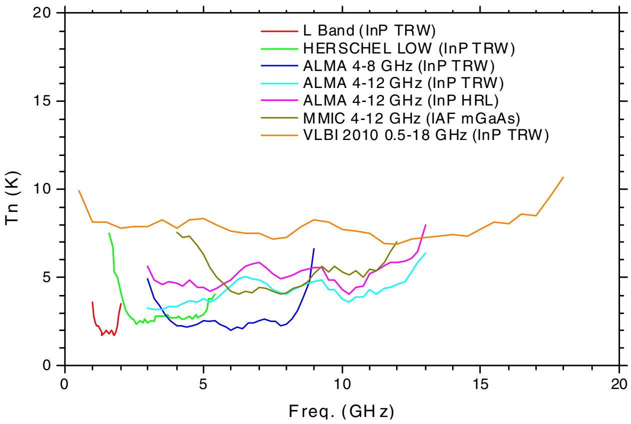

Figure 8. Noise temperature of LNAs developed in Yebes Observatory.

The latest developments include low noise amplifiers for NanoCosmos project in Q (31.5 - 50 GHz) and W (72 - 116.5 GHz) bands.

Some of these developments have been carried out through agreements with foundries like ETH (Zurich) or IAF (Germany), as the laboratory is deeply involved in the development of European cryogenic active devices in collaboration with these institutions.

Figure 9 shows one low noise amplifier developed for AETHER project in the 4 - 12 GHz band in the frame of Radionet FP7 project. It is a 3-stage HEMT amplier, being the first one an InP transistor from ETH. Figure 10 shows its performance in terms of noise, whose average value in the band is 5.1 Kelvin and its average gain is 34 dB. No cryogenic isolator is needed at its input to improve matching.

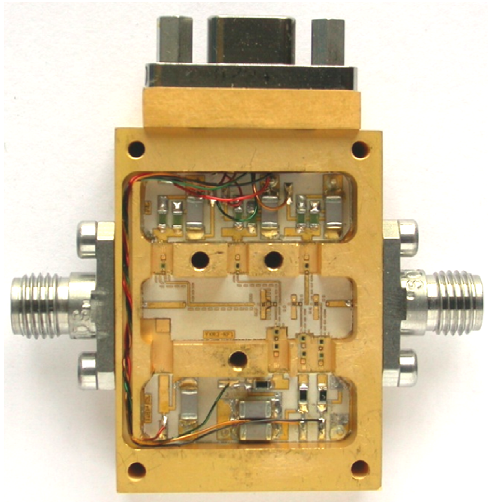

Figure 9. LNA 4 - 12 GHz for AETHER project.

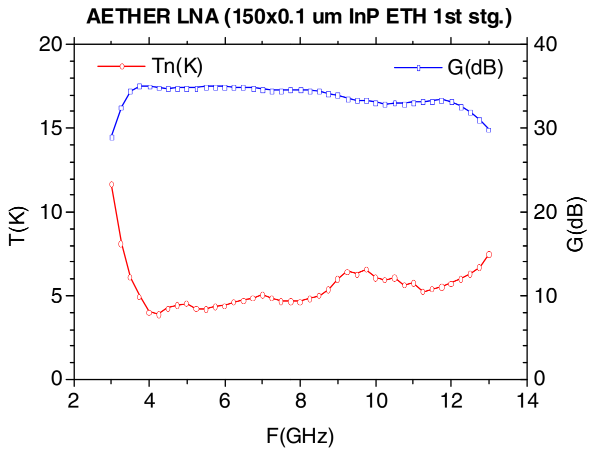

Figure 10. Noise and gain of LNA for AETHER project.

3. Future developments.

New challenging projects are being addressed like RADIONET AETHRA (Advanced European Technologies for Heterodyne Receivers for Astronomy) which aims at exploiting new technologies, such as highly integrated microelectronic semi- or superconducting circuits. In this project, Yebes staff, in collaboration with other institutions, will develop and build a 1 mm Focal Plana Array (FPA) receiver demonstrator using highly integrated 2SB SIS mixer with large IF/RF bands.

Yebes mm-wavelengths activities also extent to higher frequencies as in the ALMA Band 9 project (602 - 720 GHz) or Band 7 (273 - 370 GHz). The participation of Yebes observatory was focused to the development of Low Noise 4 - 12 GHz IF amplifiers for both frequency bands.

Finally, in the centimeter wave regime, Yebes is contributing to the development of a broad-band receiver (1.5 - 15.5 GHz) for the EVN network of radio telescopes, in the frame of RadioNet4 project (work package called BRAND-EVN) [12].

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