José A. López-Pérez et al.: A Tri-band Cryogenic Receiver for the RAEGE Project Antennas, IVS 2012 General Meeting Proceedings, p.66–70
http://ivscc.gsfc.nasa.gov/publications/gm2012/lopezperez.pdf

A Tri-band Cryogenic Receiver for the RAEGE Project Antennas

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Abstract

The Spanish Centro de Desarrollos Tecnológicos (CDT) is developing a tri-band cryogenic receiver for the first light observations of the first RAEGE project antenna in Centro Astronómico de Yebes observatory in the framework of the VLBI2010 project. The RAEGE project plans to install three new ring-focus 13.2 meter antennas in compliance with the VLBI2010 specifications. These antennas are under construction. The first light receiver envisaged for these antennas will operate in the S (2.2 — 2.7 GHz), X (7.5 — 9 GHz), and Ka (28 — 33 GHz) bands, simultaneously, in order to be backward compatible with non-VLBI2010 stations and forward compatible with new ones. The receiver feed designed to illuminate the ring-focus antenna is made of a coaxial waveguide, for the S and X bands, and a circular waveguide for the Ka band. Four outputs from their corresponding field probes at S and X bands must be combined with 180° and 90° hybrid circuits to get simultaneous dual-circular polarization. In the Ka band case, the two circular polarizations are split by means of a classical septum polarizer. The feed, hybrids, and polarizer will operate at cryogenic temperature in order to minimize their contribution to system noise. The estimated equivalent noise temperature for this receiver is lower than 15 Kelvin for S-band, 20 Kelvin for X-band, and 25 Kelvin for Ka-band. The output signals from the cryostat will be sent to their corresponding room temperature downconverters for later amplification, filtering, and mixing. The final IF signal will range from 500 to 1000 MHz, as in a classical geodetic VLBI receiver, to be backward compatible with non-VLBI2010 stations. An advantage of having the Ka band receiver is that it will allow the radiometric characterization (pointing, tracking, and efficiency) of these antennas during commissioning. In addition, simultaneous X/Ka operation would be possible. The first receiver of this type is planned to be finished by September, 2012. Currently the procurement of components is finished, and the integration has started. The receiver feed is under construction.

1. Advantages and Drawbacks of a Tri-band Receiver

This section shows the main advantages and the drawbacks of using a tri-band receiver for the new 13.2 meter RAEGE antennas. The main advantages are the following:

- S, X, and Ka bands are received simultaneously, so backward compatibility with older stations is fully guaranteed. In addition, simultaneous X/Ka will allow astrometric observations.
- The feed horn is cooled down to 20 Kelvin. As a result, its contribution to system noise is minimized.
- Simultaneous dual circular polarization is obtained, and there is no need to perform operations on digital data to retrieve circular polarization from linear ones.
- Traditional cryogenic low noise amplifiers (LNAs) are used, and there is no need to use balanced ones.
- Easy injection of NoiseCal and PhaseCal signal just in front of the LNAs.

- Less sensitive to radio frequency interference (RFI) than broadband receivers, which may need protection circuits at the input of their LNAs.
- The Ka-band receiver will be quite useful during antenna commissioning because radiometric characterization at high frequencies allows a more accurate verification of pointing, tracking, and efficiency than low frequencies.
- This receiver will be compatible with the tri-band one at Twin Telescope Wettzell (TTW).

However, the major drawbacks are:

- 180° and 90° microwave hybrid couplers are needed in S and X bands to combine the signals from the feed ports. In addition, they must operate at 20 Kelvin to minimize their contribution to system noise. However, a cryogenic 90° hybrid has been developed in house with very good properties. For the 180° ones, commercial units have been purchased and are being tested. Preliminary tests show that they can operate at cryogenic temperatures without substantial degradation of their performance.
- The receiver does not have fully continuous coverage of the 2-14 GHz broadband.

The weight of the advantages over the drawbacks was the key factor in the decision to go ahead with a tri-band receiver.

2. Tri-band Feed Design

The design of the tri-band feed is shown in [1] with more detail.

3. Cryostat Content

The cryostat will include the tri-band feed, the 180° and 90° microwave hybrid couplers, the NoiseCal injection couplers, and the six LNAs. Currently, the dewar is in the design phase.

4. S-band Receiver

This section introduces the work performed in relation to the S-band receiver channel.

4.1. S-band Low Noise Amplifiers

The S-band cryogenic LNAs have been developed and tested already. Their performance at 14 Kelvin is the following:

- Frequency range: 2.2 - 4.8 GHz.
- Equivalent noise temperature < 3.7 Kelvin.
- Average gain > 26.8 dB.
- Gain flatness > 1 dB pk-pk.
- Input return loss = -12.1 dB max.
- Output return loss = -17.8 dB max.

- Power consumption < 4.3 mW.
- Mass: 42 g.
- Interface: SMA-female.
- Bias connector: MDM 9PHSB.
- Dimensions: 58 x 32.3 x 9 mm.

These amplifiers are ready to be integrated, and more units could be available to other observatories upon request.

4.2. S-band 90° Cryogenic Microwave Hybrids

The S-band 90° cryogenic microwave hybrids are a Yebes in-house development. These hybrids are ready to be integrated, and more units could be available to other observatories upon request.

The corresponding S-band 180° hybrids are being tested at cryogenic temperatures. They are commercial off-the-shelf (COTS) units which have been purchased for testing. Preliminary tests show that their behavior is not degraded at cryogenic temperature, and, hence, they could be used in the receiver.

4.3. S-band Downconverter Module

The follow-up receiver for the S-band frontend is already integrated. It is not a frequency agile downconverter. The integration of the monitor and control digital board is missing but will be carried out in the next few weeks. Then, it will be ready for testing in the lab.

5. X-band Receiver

In relation to the X-band receiver, the following sections describe the work performed up to now.

5.1. X-band Low Noise Amplifiers

The X-band cryogenic LNAs have been developed and tested already in Yebes laboratories. They follow the same design as those provided by Yebes for the Atacama Large Millimeter Array (ALMA) project in band 9. They incorporate InP transistors, and the measured performance at 15 Kelvin is the following:

- Frequency range: 4 - 12 GHz.
- Equivalent noise temperature < 5.3 Kelvin.
- Average gain > 34 dB.
- Input return loss = -3 dB max (to be improved with a cryogenic microwave isolator).
- Output return loss = -12.5 dB max.
- Interface: SMA-female.

These amplifiers are ready to be integrated, and more units could be available to other observatories upon request.

5.2. X-band 90° Cryogenic Microwave Hybrids

The X-band 90° cryogenic microwave hybrids are a Yebes in-house development also. These hybrids are ready to be integrated, and more units could be available to other observatories upon request.

The corresponding X-band 180° hybrids are being tested at cryogenic temperatures. They are commercial off-the-shelf (COTS) units which have been particularly purchased for testing. Preliminary tests show that their behavior is not degraded at cryogenic temperature, and, hence, they could be used in the receiver.

5.3. X-band Downconverter Module

The room temperature electronics of the X-band receiver is going to be integrated in the next few weeks, as all the components are available now. It is a frequency agile downconverter, which allows the selection of any 500 MHz bandwidth across the full 7.5 - 9 GHz band.

6. Ka-band Receiver

In relation to the Ka-band receiver, the work performed is summarized in the following sections.

6.1. Ka-band Low Noise Amplifiers

These LNAs are a microwave monolithic integrated circuit (MMIC) design which is in the testing phase. The expected performance is the following:

- Frequency range: 25 - 35 GHz.
- Equivalent noise temperature: 15 - 16 Kelvin.
- Average gain > 34 dB.
- Gain flatness $\pm$ 1 dB.
- Input/output return loss $<$ -10 dB max.
- Interface: 2.9 mm - female.

6.2. Ka-band Downconverter Module

The integration of the Ka-band downconverter will start in the next few weeks as all its components are available. It is a frequency agile downconverter, which allows the selection of any 500 MHz bandwidth across the full 28 - 33 GHz band.

7. NoiseCal Module

In the NoiseCal module, two separate noise sources are considered. The first one is a broadband noise source for S and X receivers, which is split four ways (two receivers x two polarizations) after the addition of the PhaseCal signal. This source can be switched at 80 Hz. The second one is a Ka-band noise source for the Ka-band receiver channels. The possibility to add a test tone is included. The integration of this unit is also pending, although all the components are available.

8. Estimated Receiver Performance

The estimated receiver performance is summarized in Table 1. These estimations will be compared with equivalent noise temperature measurements and will be performed with the Y-factor method once the receiver is fully integrated.

Table 1. Estimated performance of RAEGE receiver.

Frequency Band	**Range (GHz)**	**Trx (Kelvin)**	**Rx gain (dB)**	**Bandwidth (MHz)**
S	2.2 - 2.7	13	58 - 89	500
X	7.5 - 9	18	53 - 84	500
Ka	28 - 33	25	57 - 88	500

9. Future Work

The following work packages have to be carried out in order to comply with the deadline for this receiver, which is scheduled by September 2012.

- Tri-band feed tests in our anechoic chamber.
- Integration of X and Ka-band downconverters.
- Integration of NoiseCal module.
- Dewar design, construction, and assembly.
- Full cryostat integration and test.
- Receiver monitor and control software.
- Receiver lab test.

Acknowledgements

The authors would like to acknowledge the help and support provided by all the Centro Astronómico de Yebes staff involved in the RAEGE project. Their work in relation to the development, integration, and tests of the tri-band receiver and its components is very valuable and appreciated.

References

[1] F. Tercero, J. A. López-Pérez, J. A. López-Fernández, S/X/Ka coaxial feed for the tri-band receiver for RAEGE antennas, In: 7th IVS General Meeting Madrid (Spain), March 4-9 2012.