Description of RAEGE Yebes VGOS Receiver Upgrades

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Abstract This contribution describes the upgrades to be implemented in the RAEGE Yebes VGOS receiver. Meanwhile, the Yebes radio telescope is operating with the VGOS receiver designed for the RAEGE Santa María station. The goal of these upgrades is to improve the overall receiver performance in terms of sensitivity, band-pass ripple, and phase calibration stability. For these purposes, the following components were redesigned and improved: 1) a new QRFH, with better input matching, 2) new balanced LNAs, with lower noise temperature and better input matching, 3) new cryogenic 30-dB directional couplers, more reliable than COTS units, 4) a new CDMS to improve the accuracy and stability of cable delay measurements, and 5) a new PhaseCal Antenna Unit with a new pulse generator and level control of calibration signals. Additionally, a new frequency converter is ready to be used with the R2DBEs. The upgraded receiver is expected to be installed in June 2022.

Keywords RAEGE, VGOS, VLBI, receiver, QRFH, LNA, PhaseCal, R2DBE, downconverter

1 Introduction

Yebes Observatory operates the 13.2-m RAEGE VGOS radio telescope located in the Iberian peninsula (see Figure 1). It is equipped with a broadband VGOS receiver for geodetic VLBI observations.

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Fig. 1 The 13.2-m RAEGE Yebes VGOS radio telescope (Credit: M. Gómez).

This receiver is under an important upgrade program in order to improve the overall receiver performance in terms of sensitivity, band-pass ripple, and phase calibration stability.

While these upgrades are being implemented, the RAEGE Yebes radio telescope is operating with the VGOS receiver designed for the RAEGE Santa María station.

The upgrade program includes the following components that were redesigned and improved:

- a new QRFH, with better input matching;
- new balanced LNAs, with lower noise temperature and better input matching;
- new cryogenic 30 dB directional couplers, more reliable that COTS units;
- a new CDMS to improve the accuracy and stability of cable delay measurements; and
- a new PhaseCal Antenna Unit with a new pulse generator and level control of calibration signals.

Additionally, a new frequency converter is ready to be used with the R2DBEs.

The upgraded receiver is expected to be installed in June 2022. After this, the RAEGE Santa María VGOS receiver will also be upgraded.

2 QRFH Upgrade

The QRFH feed was redesigned to improve the port matching (see Figure 2).

Fig. 2 Upgraded QRFH antenna.

In Figure 3, it can be seen that the matching of QRFH version 3 (solid lines) is better than 10 dB across the whole VGOS band, as opposed to the former version (dashed lines).

Regarding the aperture efficiency, the new feed provides a flatter value around 60%, when the RAEGE radiotelescope is simulated using Physical Optics from actual QRFH measurements performed in the Yebes anechoic chamber. Details can be found in [1].

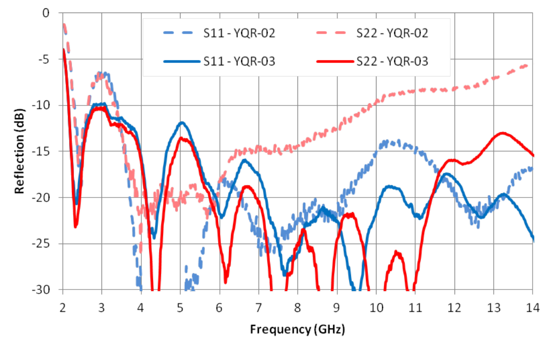

Fig. 3 QRFH matching.

The new QRFH implies a slightly larger dewar window to avoid edge effects, but it allows a 17% reduction in the dewar volume, from 59 to 49 liters.

3 Cryogenic 30-dB Directional Coupler

The next improvement is related to the directional couplers required for calibration signal injection in front of the LNAs. So far, we were using commercial units not specified for cryogenic temperatures. The connectors of these units may potentially fail, because they are not prepared for cooling.

Yebes has developed a specific cryogenic 30-dB directional coupler that solves these issues (see Figure 4). It was optimized in the range 3–14 GHz, but it is usable down to 2 GHz. It shows very good matching, flat coupling, and low insertion losses. Units are available to the community upon request.

Its performance is summarized as follows:

- Optimized in the range 3–14 GHz, usable down to 2 GHz;
- Specially designed to withstand thermal cycling and operate at cryo temps;
- Flexible location of the isolated vs. coupled ports;
- Port matching ≤ -20 dB;
- Coupling = -29.2 ± 1 dB;
- Insertion loss $\leq$ 0.3 dB @ 14GHz and 15K (connectors contribution $\sim$ 2 x 0.1 dB);
- Size: 21.3 x 14.5 x 17 mm;
- Weight: 22 grams.

Fig. 4 The cryogenic 30 dB coupler developed in Yebes.

4 LNA Upgrade

Regarding the low noise amplifiers, we have decided to install balanced LNAs (see Figure 5) in all VGOS receivers developed at Yebes instead of single-ended ones, because of its better performance in terms of matching and band-pass ripple.

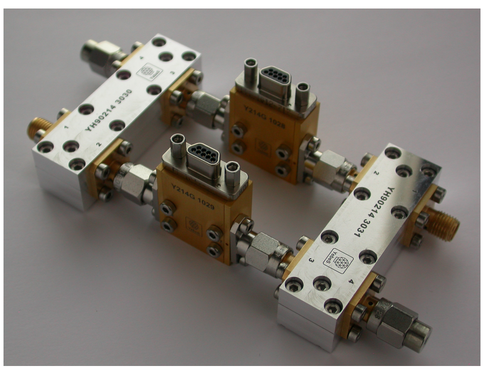

Fig. 5 Balanced LNA developed in Yebes.

Figure 6 shows that the input matching of the balanced configuration (red line) is much better than the singled-ended one (blue line). This is at the cost of a little extra noise of 1.5 K, due to the input hybrid. Details can be found in [2].

However, this penalty is largely compensated by the ripple reduction in the receiver's gain. Additionally, poor matching of LNAs will make phasecal tones to bounce back and forth between the QRFH and LNAs, and it may generate ghost pulses. For this reason we have improved the matching of both QRFH and LNAs.

Table 1 compares the performance of both types of LNAs.

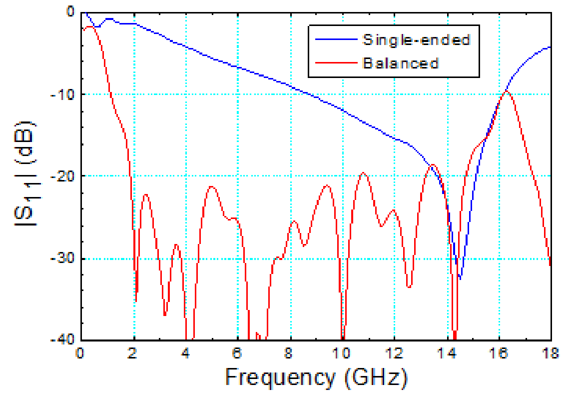

Fig. 6 Single-ended vs. balanced LNA input matching.

Table 1 Performance of single-ended vs. balanced LNAs.

Parameter	Single-ended LNA	Balanced LNA
Band	2–14 GHz	2–14 GHz
Noise Temp.	6.1 K	7.6 K
Gain	33.9 dB	33.8 dB
Input RL	−1.5 dB	−21 dB
Output RL	−16.9 dB	−23 dB

This balanced configuration was recently improved in terms of noise (from 7.6 to 5.6 K) with a flatter response across the band. A paper showing this improvement is in preparation.

5 PhaseCal Upgrade

Concerning the PhaseCal antenna unit, we have a new 10-MHz-spaced pulse generator with better phase stability. When the phase stability is measured in the center of each VGOS sub-band for 30 minutes at room temperature without thermal stabilization of the generator, the results shown in Table 2 were obtained. The worst value is 0.4° RMS at 10.46 GHz. In all cases, the drift during the measurement was lower than ±1° peak-to-peak.

Table 2 RMS phase noise of new pulse generator.

VGOS sub-band	RMS phase noise
A	0.11°
B	0.14°
C	0.2°
D	0.4°

Additionally, the spectrum of the pulses was equalized to get a flatter one. This will avoid large differences in pulse power between the VGOS sub-bands. Figure 7 shows the power of each single tone across the VGOS band with (red) and without (blue) the equalizer. The reduction in the spectrum slope is noticed.

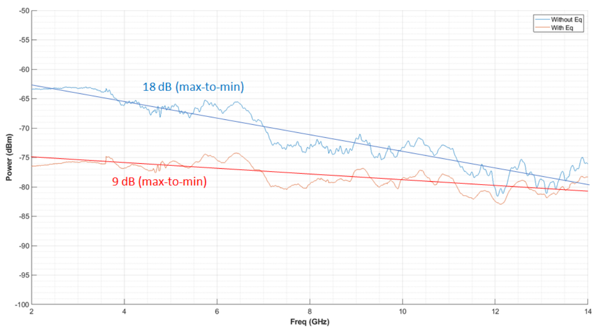

Fig. 7 Reduction of phasecal tones slope with equalizer.

Another upgrade of the PhaseCal antenna unit is the control of the power level for both NoiseCal and PhaseCal signals by means of variable attenuators. Using a chip from Analog Devices, we developed the module shown in Figure 8. It works from 0.1–40 GHz in steps of 0.5 dB up to 31.5 dB. It will be very convenient to optimize the level of the injected calibration signal in front of the LNAs.

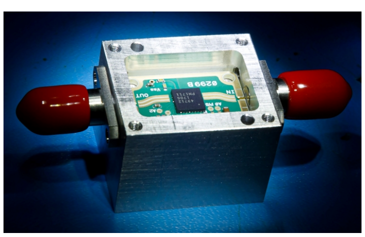

Fig. 8 Variable attenuator developed in Yebes.

6 CDMS Upgrade

Concerning the Cable Delay Measurement System, or PhaseCal Ground Unit, we have developed a new system which solves the issues of the previous one, in particular the digital noise associated with ultra-fast comparators.

Fig. 9 New CDMS developed in Yebes.

The new system is described in detail in [3] and shown in Figure 9. It is based in the design of Haystack from the 1980s, but the difference is that a 20-bit digital voltmeter reads the control voltage of the phase-locked loop, and this voltage is proportional to the two-way delay that we want to know. It incorporates a couple of electromechanical switches that insert an extra path of calibrated delay to compute the scale factor required for the conversion from volts to picoseconds.

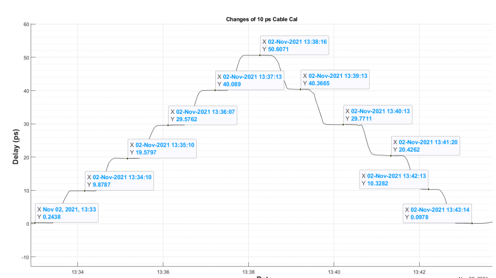

Fig. 10 CDMS response to 10-ps steps.

Figure 10 shows the delay measurements with a manual phase shifter in the cable path when 10-ps steps are applied. The system is very accurate and repeatable.

The RMS noise in a thermally controlled environment is lower than 1 ps.

Currently, we are developing a system using optic fiber only, instead of coaxial cable, similar to the system implemented at Onsala.

7 New Frequency Converter

Additionally, we have developed a new frequency converter that will be compatible with both R2DBE and dBBC3 backends.

It follows the approach proposed by Petrachenko some years ago. It has a single frequency conversion, as opposed to the current Up/Down converters, which have two (see Figure 11). As a result, the phase stability is much better. We have measured 3.4° RMS at 10.5 GHz over 30 minutes.

It is ready to be used with our R2DBEs as soon as we can get the firmware of this backend.

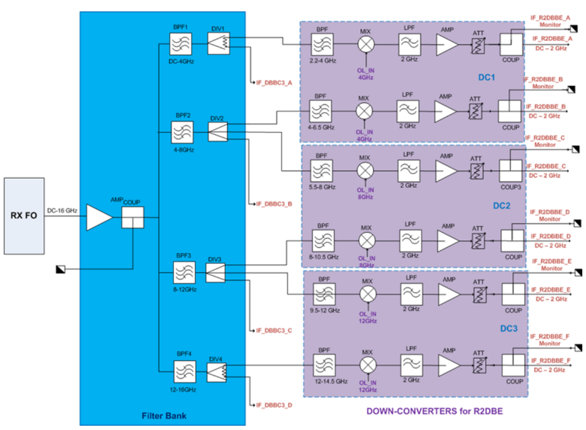

Fig. 11 Block diagram of new downconverter.

8 RFI Power Limiter

A very recent development began in Yebes labs related to an RFI power limiter based on a PIN diode (see Figure 12). The purpose is to protect the RF-over-fiber optic transmitters from strong RFI signals that could potentially destroy them.

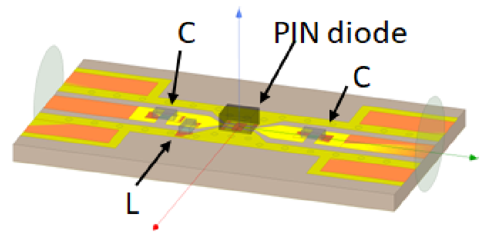

Fig. 12 Design of RFI power limiter.

9 Conclusions

Yebes Observatory is upgrading the VGOS receiver of the RAEGE radio telescope with new devices in order to improve the overal receiver's performance in terms of sensitivity, band-pass ripple, and phase calibration stability.

We are planning to install the upgraded receiver in June 2022. After this, the RAEGE Santa María VGOS receiver, currently in use at the Yebes VGOS antenna, will be upgraded, too, and shipped to Santa María to become a new VGOS station.

Acknowledgements

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