Implementing High-Temperature Superconducting Filters at the RAEGE Station in Santa Maria for VGOS Receiver Resilience

A Success Story

Abel García-Castellano[1,2], Pablo García-Carreño[2], João Salmin Ferreira[2], Mariana Moreira[2], Valente Cuambe[2], Gabriel Gómez-Molina[1], Inmaculada Malo-Gómez[1], Marta Bautista-Durán[1], Francisco Javier Beltrán-Martínez[1], Javier González-García[1], Carlos Albo-Castaño[1], Luísa Magalhães[2], José Antonio López-Pérez[1]

Abstract The Santa Maria station, equipped with a broadband receiver (2–14 GHz), experienced operational challenges after the VGOS receiver installation in October 2022. A strong Radio Frequency Interference (RFI) signal from a nearby space debris radar in S-band posed a high risk of low-noise amplifiers (LNAs) destruction or saturation and intermodulation when not pointing to the source, rendering observations impossible. Some work was carried out to mitigate the impact on station operations. Initially, commercial high-pass filters were installed in January 2023 to protect the LNAs, resulting in the loss of the VGOS A-band (3–3.5 GHz). Simultaneously, high-temperature superconducting (HTS) notch-like filters started to be developed at Yebes Observatory laboratories with the specific aim of rejecting only that particular RFI signal, enabling the recovery of the VGOS A-band. The HTS filters were successfully installed in October 2023. Following initial tests and measurements, the station resumed regular VGOS operations in November 2023.

Keywords RFI, HTS Filters, RAEGE

1 Introduction

The RAEGE station in Santa Maria, Azores, is part of the RAEGE network, a cooperation project between the National Geographic Institute of Spain (IGN) and the Regional Government of Azores (GRA). The project's goal is to establish and operate four Fundamental Geodetic Stations: Yebes and Gran Canaria stations in Spain, and Flores and Santa Maria stations in the Azores [1, 2].

RAEGSMAR station has a VGOS-type 13.2-m radio telescope, constructed in 2014, and is part of the International VLBI Service for Geodesy and Astrometry [3]. In October 2022, a VGOS broadband receiver developed at Yebes laboratories [4] was installed, allowing the participation in VGOS sessions. However, VGOS operations were not possible until the installation of two high-temperature superconducting (HTS) filters due to a strong Radio Frequency Interference (RFI) signal at S-Band from a nearby space debris radar. We present here a comprehensive overview of the station, highlighting the efforts related to the implementation of the HTS filters to finally join the VGOS core network.

2 Motivation

In 2022, a space debris radar started to operate at a distance of 1.75 km from the Santa Maria RAEGE station, as it is indicated in Figure 1. The frequency range of the signal is from 2.93 to 2.97 GHz. In the spectrum that is shown in Figure 2, two carriers can be identified. The measurements were taken with a portable RFI system pointing towards the radar. The total integrated power density due to the radar rises to -46.47 dBW/m^2.

Considering a 70% aperture efficiency, this power density results in 3.34 dBm at the input of the low-noise amplifiers of the receiver. This level is 30 dB above the 1 dB compression point and probably very close to the destruction level.

1. National Geographic Institute of Spain, Madrid, Spain
2. Estação RAEGE de Santa Maria, Associação RAEGE Açores, Santa Maria – Azores, Portugal

Fig. 1 Santa Maria station and space debris radar positions.

Second, third, and fourth harmonics of every carrier were also detected but the levels were much less significant.

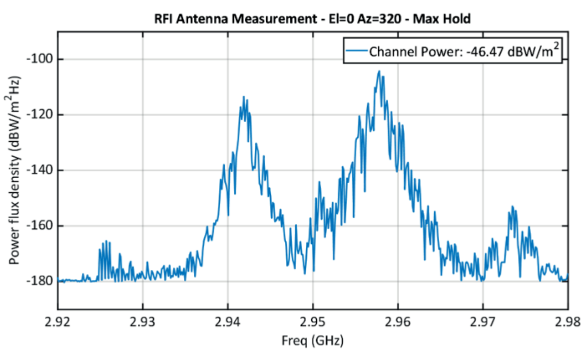

Fig. 2 Spectrum of the RFI signal.

3 COTS Filters

As a first step towards operation, two COTS (commercial off-the-shelf) filters were installed in January 2023 [5]. These filters were installed inside the cryostat and cooled down to cryogenic temperatures, reducing the insertion losses.

Figure 3 shows the measurement of S21 at cryogenic temperature. The rejection of the RFI signal is about 50 dB (red zone); however, this results in the loss of VGOS Band A (yellow zone).

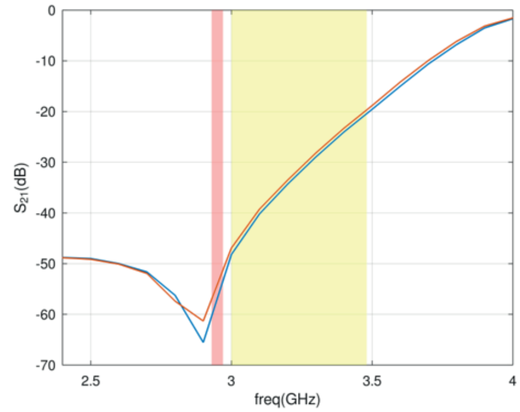

Fig. 3 Measurement of S21 COTS filters.

4 HTS Filters

During 2023, two HTS filters were designed and constructed by Yebes Observatory. The filters were installed in September 2023. Figure 4 shows a photograph of the two filters already mounted in the cryostat.

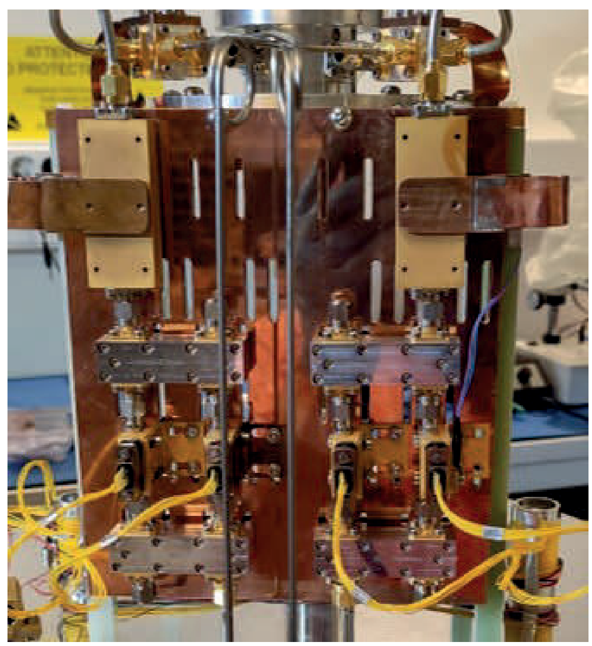

Fig. 4 Photograph of the HTS filters.

Additional measurements were carried out at different elevations to see how the levels were reduced.

Just with an elevation of 5 degrees, the total power was reduced by 18–20 dB.

4.1 Estimation

Before the installation, filter S-parameters and RFI signal measurements were taken to estimate the total power at the input of the low-noise amplifiers. Figure 5 shows the RFI spectrum, S21 parameter of one filter, and the resulting spectrum of the RFI signal with filter suppression.

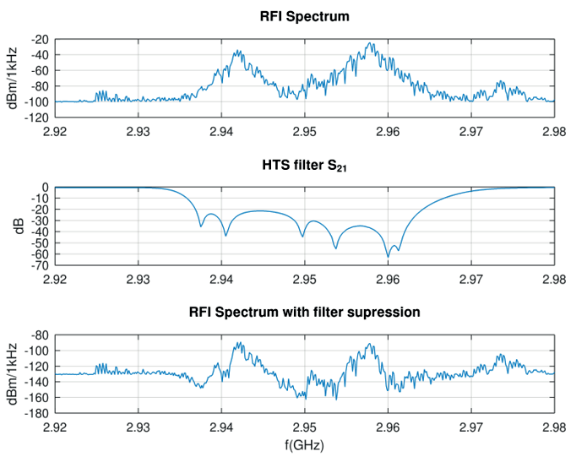

Fig. 5 Estimation of total power.

The expected total attenuation of the filters is 33.49 dB, which results in a total power at the input of the LNAs of −30.15 dBm.

4.2 Measurements

After the installation and cooling-down process, initial measurements were taken, and the receiver power pointing to the radar direction was lower than expected. There could be several reasons for this, but the most probable one is the blocking effect of a hill that is in the line of sight. Figure 6 shows the estimated and measured values.

Additional continuum measurements were done to see the total power between 2 and 6 GHz. These measurements were carried out with the radar ON and OFF.

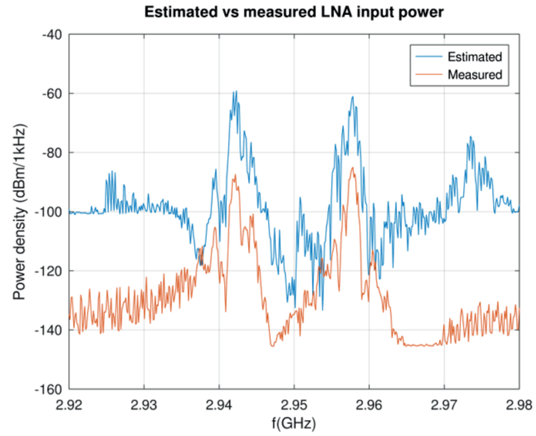

Fig. 6 Estimated and measured total power at LNA input.

Table 1 Power levels from the radar at different elevations.

Antenna position		Power	
Az	El	HPOL	VPOL
325	0	−47.19	−54.98
325	5	−65.33	−75.02
325	10	−69.13	−82.35
325	20	−87.42	−82.25
325	45	−95.59	−90.18

The main goal of these tests was to see the difference in the total power when the radar is ON or OFF, and how significant this RFI is now with the filters installed in comparison with other RFI signals, such as 5G. Results are presented in Figures 7 and 8.

The measurements were done at different positions, doing azimuth drifts at a fixed elevation. The elevation in the example presented was 5 degrees, which is the minimal elevation that the antenna observes. The azimuth step was 5 degrees, and during measurements the antenna was two minutes at every position.

The main difference when the radar is ON is the presence of peaks around its direction (325°). In some particular directions, the power is even higher than pointing to the radar. The origin of these levels is due to 5G base stations that are placed in the directions 95°, 210°, and 310° in azimuth. Figure 9 shows the spectrum of 5G RFI, whose total integrated power reaches around −34 dBm at the input of the LNAs, 20 dB above the radar signal after the HTS filters installation. Nevertheless, these levels were obtained with the option MAX HOLD in the spectrum analyzer, so the total power is not received at the same time, and continuum measurements might be more realistic.

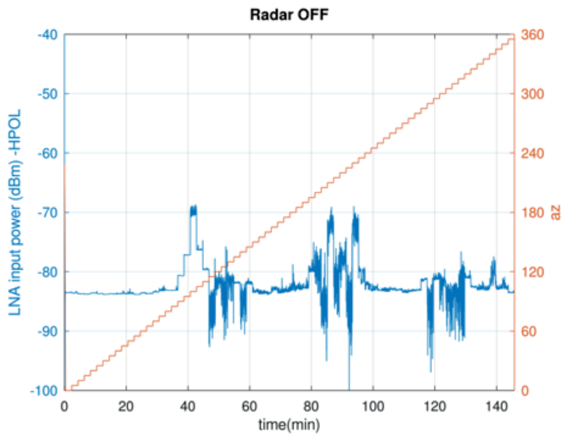

Fig. 7 Continuum measurements with radar OFF.

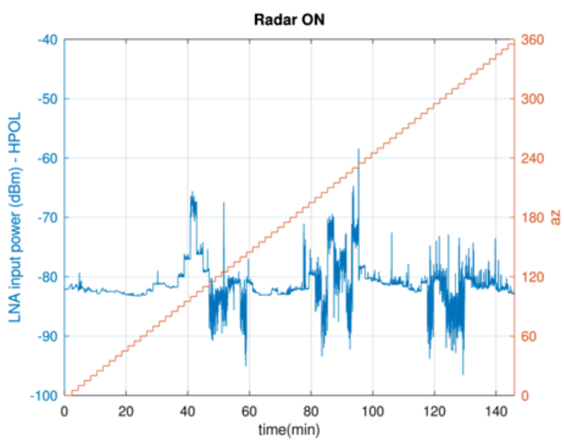

Fig. 8 Continuum measurements with radar ON.

5 Conclusions

RAEGE Santa Maria station operations were compromised due to a strong RFI from a nearby radar at 2.95 GHz. Operation could be resumed initially by installing commercial filters, although this resulted in the loss of VGOS Band A, inhibiting the station from entering the VGOS core network. Normal operation was able to start after the installation of two HTS filters, designed and constructed at Yebes Observatory, with an attenuation above 33 dB in the radar signal.

Due to the radar RFI signal, RAEGSMAR was only able to enter as an official VGOS station and begin regular operations in VGOS sessions around one year later than the predicted time.

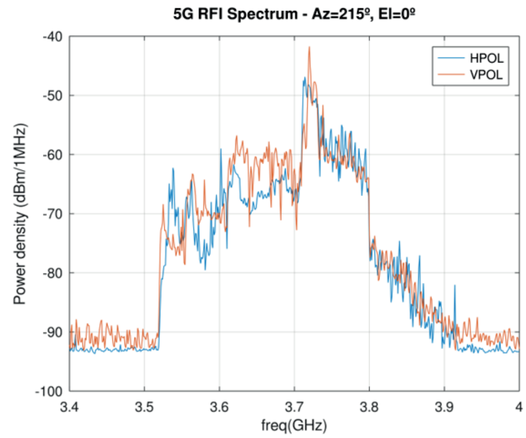

Fig. 9 Spectrum of RFI from 5G.

Currently, with the HTS filters, other RFI signals, such as those from 5G base stations, can be more problematic than the radar signal. Future tasks include installing filters to attenuate the 5G signal and possibly designing new HTS filters to further improve attenuation of the radar signal.

References

1. https://www.raege.eu
2. J. A. López-Pérez et al., "The Atlantic Network of Geodynamic and Space Stations (RAEGE)" in International Association of Geodesy Symposia, Berlin: Springer, doi:10.1007/1345_2022_152, 1–5, 2022
3. https://raege-az.pt
4. J. A. López-Pérez et al., "Description of RAEGE Yebes VGOS Receiver Upgrades," in Proceedings of the 12th General Meeting of the International VLBI Service for Geodesy and Astrometry, Greenbelt, MD: NASA, Jan. 2023, pp. 47–51. Accessed: Jan. 13, 2023. [Online]. Available: https://ivscc.gsfc.nasa.gov/publications/gm2022/09_lopezperez_etal.pdf
5. I. Malo et al., "Cryogenic Measurement of two LTCC Commercial Filters for Interferences Reduction in Radio Astronomy Receivers", Yebes CDT Technical Report 2022-14