

Yebes 30 dB cryogenic directional coupler for the injection of the calibration signal to the 2-14 GHz wideband VGOS receiver

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1. Introduction

Radio Astronomy receivers, specifically those to be used in the VLBI observations, incorporate subsystems for calibration. This is particularly the case of VGOS 2-14 GHz receivers.

There are two types of calibration needed for VLBI: amplitude and phase [1]. Amplitude and phase calibration signals are injected to the receiver RF front-end by a 30 dB directional coupler, right after the horn and before the LNA, inside the cryostat (see Figure 1).

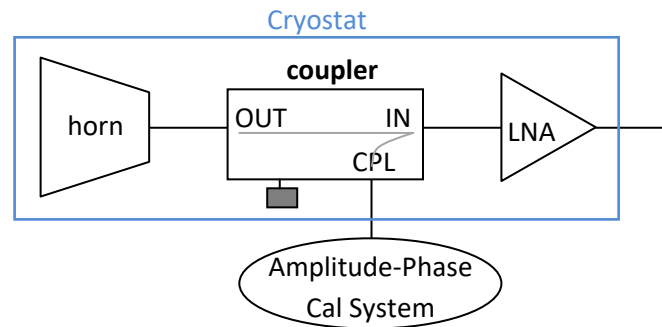


Figure 1: Coupler for the injection of the amplitude and phase calibration system.

The characteristics of a good coupler for the injection of the amplitude and phase calibration signals are:

1. Low insertion loss and coupling to minimize the noise added to the receiver.
2. Constant group delay.
3. Directivity higher than 10 dB.

There are commercial devices available for ambient temperature but they are not specially conceived neither to operate at cryogenic temperatures (around 20 K) nor survive thermal cycles from ambient to cryogenic temperature. Some of them have been measured at Yebes at cryogenic temperature [1][2] showing degradation of their cryogenic performance and a high infant mortality rate due to the thermal stress on the contact stripline to connector produced by thermal cycles.

Due to these limitations, it was decided to design and manufacture at Yebes a 30 dB directional coupler in the 3-14 GHz band specially suited for cryogenic operation, improving the performance and reliability of commercial units at cryogenic temperatures.

2. Yebes 30 dB directional coupler.

The 30dB Yebes coupler works in the 2-14 GHz frequency band although its best performance has been focused in the 3-14 GHz band. The reason is that the 2-3 GHz band of VGOS receivers is usually filtered (i.e. eliminated) because of the high RF interferences present in it.

The directional coupler is based on stripline technology. It is a symmetric structure formed by three uniformly coupled stages, with even / odd impedances of 50.45 / 49.55 Ω (for the first and third stage) and 52.45 / 47.66 Ω (for the central stage). The materials and mechanical construction have

been carefully selected following the structure in [3]. The result is a very compact, reliable and low thermal mass device, capable to withstand extreme thermal cycling and operation temperatures of at least 4 K. The coupling and reflection characteristics show very low temperature dependence.

Results of a representative Yebes 30 dB directional coupler (serial number 1004) are presented in Table 1 at room and cryogenic temperature for two different frequency bands. Full measurements could be found in the Annex I.

Serial Number	Yebes YC30214-1004			
Nominal Coupling	30 dB			
Connector	SMA female			
Frequency Band	3 – 14 GHz		2 – 14 GHz	
<i>Temperature</i>	<i>297 K</i>	<i>18 K</i>	<i>297 K</i>	<i>18 K</i>
Return Loss [dB] (min / 90% band)				
Direct path	23 / 24	20 / 22	23 / 24	20 / 22
Coupled path	20 / 22	18 / 19	20 / 22	18 / 20
Coupling [dB]	-28.9 ± 1	-28.7 ± 0.9	-28.9 ± 1.8	-28.8 ± 1.9
Group delay IN-CPL (Δ_{pp}) [ps]	12	21	12	21
Insertion Loss [dB] (max.)	0.34	0.05	0.34	0.05
Directivity [dB]	23 (*)		23 (*)	

(*) Some units show lower directivity but it is always higher than 15 dB.

Table 1. Yebes measurements of the YC30214-1004 coupler.

Comparing to the commercial couplers tested from Pulsar [1] and Krytar [2], Yebes coupler performance has some advantages for VGOS receivers:

- Yebes coupler does not present sharp variations of the group delay performance (see Figure 2) so significant changes with time or aging are not expected, avoiding adding instrumentation errors to the phase calibration.

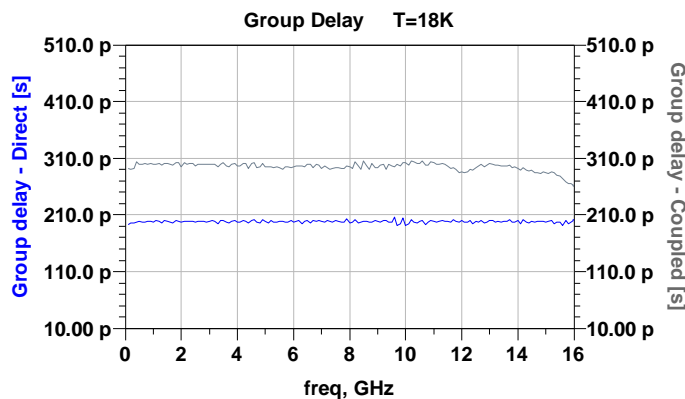


Figure 2: Group delay of the YC30214-1004 Yebes 30 dB directional coupler at cryogenic temperature. It is almost constant in the band (2-14 GHz) and does not show sharp variations (which are usually related to resonant modes).

- Improved return loss at ambient and cryogenic temperatures.
- Improved directivity, reducing the effect on the calibration signal from the echoes reflected by the horn.

Eight 30 dB cryogenic directional couplers have been built up to now for the VGOS receivers (one per polarization, two for each receiver) for Yebes, Sta. María (Azores), HartRAO (South Africa) and Matera (Italy) stations.

The outline drawing is shown in Figure 3.

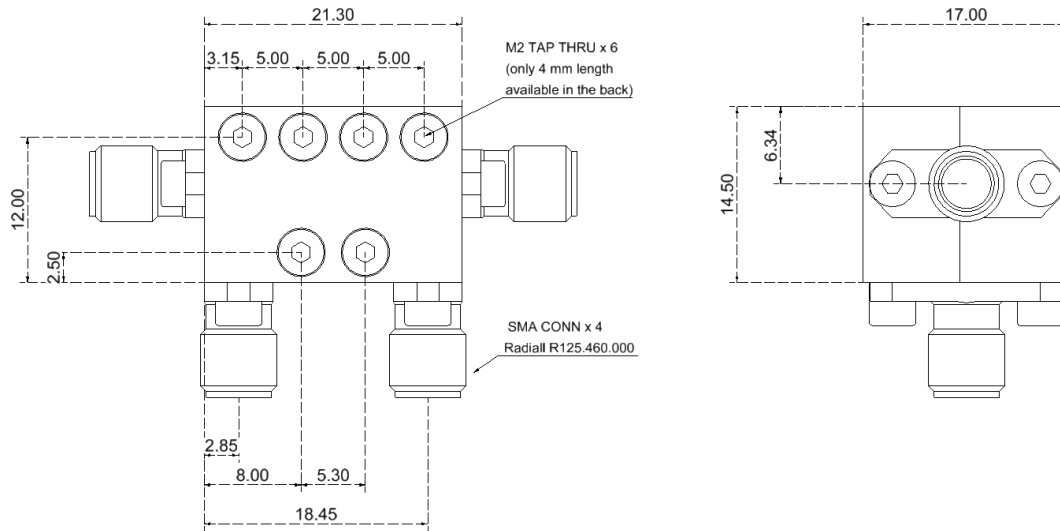


Figure 3. Outline drawing of the Yebes 30 dB cryogenic directional coupler. External dimensions are 21.3 x 12 x 14.5 mm. SMA female connectors. 6 M2 thread 4 mm maximum length available in the back side to fix the coupler.

The electrical schematic of the coupler is presented in Figure 4. There is a direct line connecting 1-2 ports and another line directly connecting 3 - 4 ports. The direct path is between 1- 2 ports. The coupled path is between 1-3 ports and isolated path is between 1-4 ports.. Due to its symmetric inner structure, it could be also used in reversed way: coupled path between ports 2-4 and isolated path between 2-3 ports, .

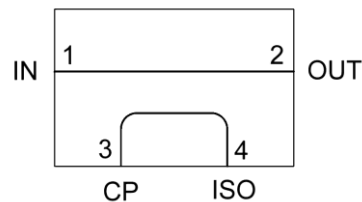


Figure 4. Outline drawing of the Yebes 30 dB cryogenic directional coupler.

The photo of Yebes 30 dB cryogenic directional coupler is shown in Figure 5.



Figure 5. Photograph of the 30 dB directional coupler from Yebes.

3. References.

- [1]. I. Malo, J.D. Gallego, J. González, I. López-Fernández, C. Díez, R. Amils, “New 30 dB coupler for the injection of the calibration signal to the 2-14 GHz wideband VGOS receiver”, CDT Technical Report 2019-16.
- [2]. I. Malo, J.D. Gallego, I. López-Fernández, C. Díez, R. Amils, “Krytar 30 dB coupler for the injection of the calibration signal to the 2-14 GHz wideband VGOS receiver”, CDT Technical Report 2020-16.
- [3]. I. Malo, J.D. Gallego, C. Díez, C. Cortés, C. Briso, “Cryogenic hybrid coupler for ultra low noise Radio Astronomy receiver”, 2009 IEEE MTT-S International Microwave Symposium Digest, Jun. 7-12, Boston (USA), 2009.

Annex I: YC30214-1004 measurements.

