Measured Performance of YH90420 Cryogenic Quadrature 4-20 GHz Hybrids

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Technical Report **IT-CDT 2023-3**

Date 25/05/2023

Revision 1

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Change Record

Revision	Date	Affected Paragraphs(s)	Reason/Initiation/Remarks
A	2023-05-09	All	First Issue

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1. Introduction

This report presents the performance of 4-20 GHz quadrature hybrid designed and fabricated in Yebes Observatory, following the same structure used in [3]. It is a 3 dB 90˚ directional coupler specially conceived to operate satisfactorily when cooled down to cryogenic temperatures. It can be used in a broad range of temperature, from 300 K down to 4 K or even lower, considering that its insertion loss decreases with the temperature. The materials and mechanical construction have been carefully selected and the result is a very compact, reliable and low thermal mass device, capable of withstanding extreme thermal cycling. The coupling and reflection characteristics show very low temperature dependence.

The bandwidth of this hybrid is motivated by ALMA development roadmap 2030 [1] which sets "*the top development priority for ALMA should be to expand the bandwidth of the receivers and upgrade the digital system and correlator".* The implementation of this goal has been conducted by the Wideband Sensitivity Upgrade (WSU) initiative [2], which requires "*future receiver upgrades to have at least 16 GHz of instantaneous bandwidth per polarization with 2SB mixers, with a goal of 32 GHz per polarization*", meaning a factor of 2 to 4 increase compared to existing receivers.

In radio astronomy receivers a quadrature hybrid like this may be used for different purposes:

1) As IF hybrid in 2SB sub-mm wave receivers [4], like in several ALMA bands.
2) To build balanced amplifiers combining two hybrids with two LNAs greatly improving the return loss of the single ended units and reducing the sensitivity to the input mismatch [5].
3) To convert linear polarization antenna outputs into circular polarization [6] of cm-wave receivers.

2. Fabrication

Figure 1 shows an outside view of a 4-20 GHz hybrid. Its external dimensions and mechanical interfaces are shown in figure 2. The hybrid chassis is made of aluminum 6082. Eight M2 threaded holes, 3.8 mm depth, are available on the bottom side of the chassis to be used for thermal anchoring. The four ports of the hybrid are female SMA connectors.

Figure 1. External view of a 4-20 GHz hybrid. Dimensions excluding connectors are 40.23 x 13 x 14 mm.

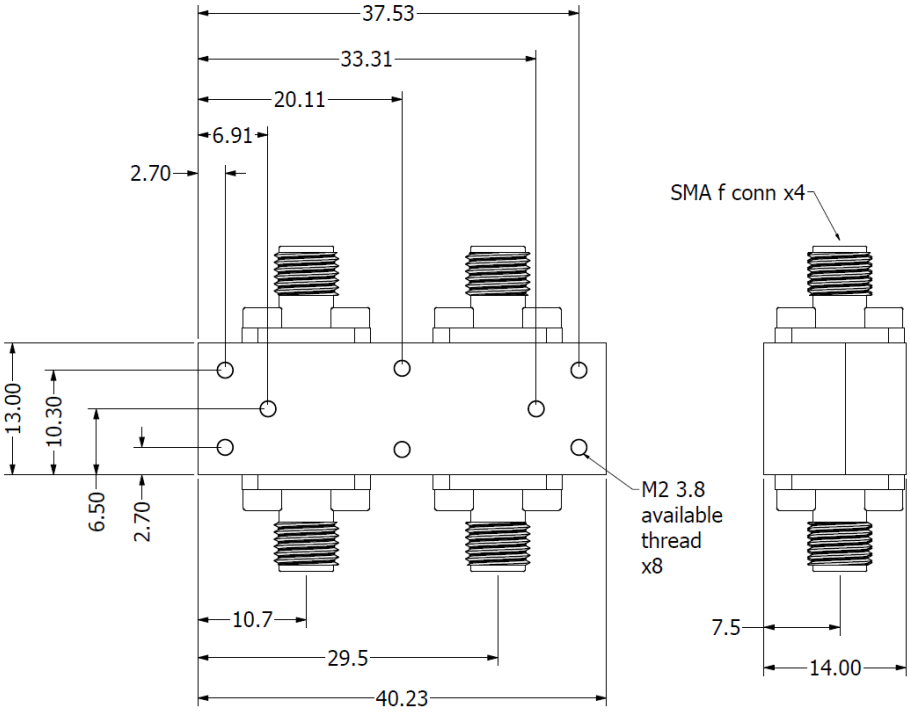

Figure 2. Dimensions of the 4-20 GHz hybrid.

3. Measured and typical performance

S-parameters of the hybrid are measured with an Agilent E8364B Vector Network Analyzer from 0.1 to 26.1 GHz. For cryogenic measurements, the hybrid is cooled in a dewar with a CTI 1020 refrigerator. Two cool-down cycles are needed, one for measuring the direct path (S_{21}) and the other for measuring the coupled path (S_{31}). The isolated path (S_{41}) is not usually measured because it requires a modification of the measurement setup of the dewar and a third cool-down cycle (so it is time-consuming). Also, theoretically, the isolation is very similar to the return loss due to the symmetry of the structure. This has been validated by measurements at ambient and cryogenic temperature in some units, but we cannot provide isolation data of every unit.

The dissipative losses of the hybrid are estimated from the average equivalent insertion loss (A.E.I.L.), calculated as:

$$A.E.I.L. = 10\log\left(S_{11}^2 + S_{12}^2 + S_{13}^2 + S_{14}^2\right)$$

where S_{11}, S_{12}, S_{13} and S_{14} are the S-parameters of the hybrid, and assuming S_{41} equal to S_{11} .

The cryogenic measurements are performed connecting one port of the hybrid to the output stainless steel dewar transition (also connected to the VNA port 2) and the other port of the hybrid to the input transition (also connected to the VNA port 1) through a semi-flexible low-loss Cu cable. A full two port calibration is performed inside the dewar at room temperature using the electronic calibration kit Agilent N4693-60001 (ECAL calibration with unknown thru) in place of the hybrid and

with the same semi-flexible cable. The stainless steel lines are assumed to be invariant with temperature. The semi-flexible Cu cable is measured at cryogenic temperature independently and its loss variation is taken into account to correct the S-parameters. Time domain gating is used to eliminate the residual reflection change of the lines upon cooling. The temperature of the hybrid is carefully monitored using a Lake Shore sensor diode attached to the hybrid chassis.

The typical performance of a 4-20 GHz quadrature hybrid at cryogenic temperature is shown in the Table 1.

Amplitude unbalance (± dB)	**Phase unbalance (± deg)**	**Return loss / 90% BW (dB)**	**A. E. Insertion Loss (dB)**
0.4 dB	4	15 / 18	0.3

Table 1. Typical performance of a 4-20 GHz 90 deg hybrid at cryogenic temperature.

Measurements of some recent units both at ambient (300 K) and cryogenic temperature are presented in Table 2 and Table 3. In order to show the performance in the whole band, measurements of the YH904201008 hybrid are presented in Annex 1 as an example. Note that the performance of the hybrid remains up to 21 GHz.

Yebes Part Number		**Amplitude unbalance (± dB)**	**Phase unbalance (± deg)**	**Return loss / 90% BW (dB)**	**A. E. Insertion Loss (dB)**
YH90420	1007	0.4	3	19 / 20	0.6
YH90420	1008	0.4	3	18 / 19	0.7
YH90420	1009	0.2	2	18 / 20	0.7
YH90420	1010	0.3	3	18 / 20	0.6
YH90420	1011	0.3	2	19 / 21	0.7
YH90420	1012	0.3	5	18 / 19	0.7
YH90420	1013	0.4	2	19 / 21	0.7
YH90420	1014	0.5	3	18 / 20	0.7
YH90420	1015	0.3	2	19 / 20	0.7
YH90420	1016	0.4	1	19 / 20	0.7
YH90420	1017	0.4	3	20 / 21	0.7
Mean (σ)		**0.4 (0.08)**	**3 (1)**	**19 (0.6) / 20 (0.7)**	**0.7 (0.04)**

Table 2. Measurements of some 4-20 GHz 90 deg hybrid at ambient temperature (297 K), including the estimation of the mean and standard deviation ("σ").

Yebes Part Number		Amplitude unbalance (± dB)	Phase unbalance (± deg)	Return loss / 90% BW (dB)	A. E. Insertion Loss (dB)	T (K)
YH90420	1007	0.4	4	18 / 19	0.2	16
YH90420	1008	0.4	3	17 / 21	0.3	15
YH90420	1009	0.2	3	16 / 19	0.2	19
YH90420	1010	0.3	3	16 / 19	0.3	15.5
YH90420	1011	0.3	3	16 / 20	0.3	15
YH90420	1012	0.3	5	19 / 20	0.3	15
YH90420	1013	0.4	2	16 / 19	0.3	14
YH90420	1014	0.5	4	16 / 18	0.2	15
YH90420	1015	0.4	3	15 / 19	0.3	15
YH90420	1016	0.4	1	15 / 18	0.3	15
YH90420	1017	0.4	3	17 / 21	0.4	15
Mean (σ)		**0.4 (0.08)**	**3 (0.08)**	**16 (1.2) / 19 (1)**	**0.3 (0.06)**	

Table 3. Measurements of some 4-20 GHz 90 deg hybrid at cryogenic temperature, including the estimation of the mean and standard deviation ("σ").

4. References

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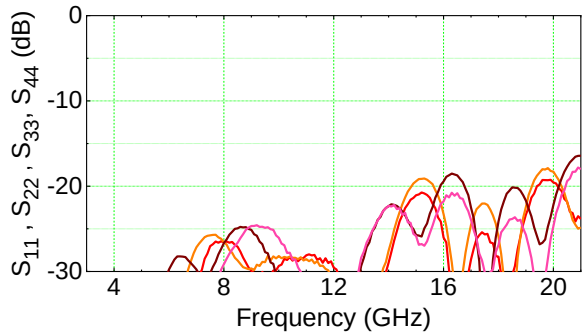
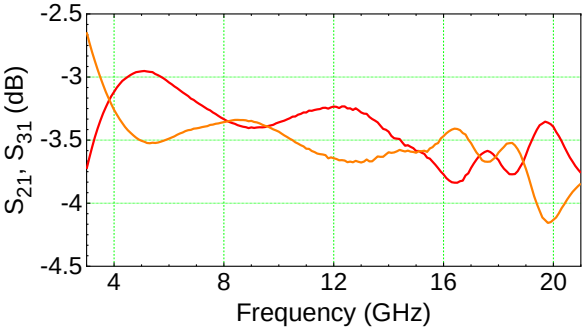
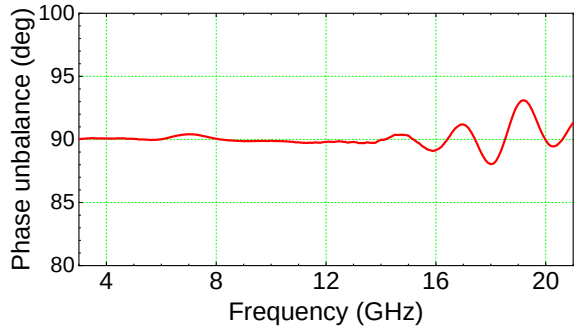
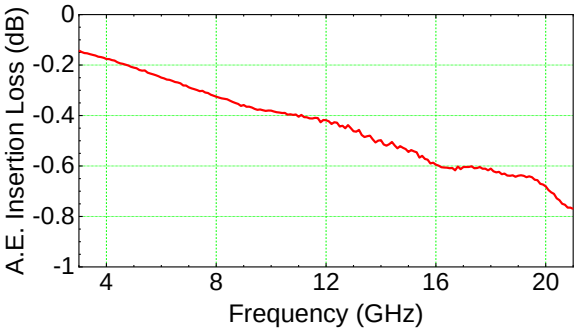
Annex 1. Measurements of YH90420 1008 hybrid

Temperature 297 K









Temperature 15 K