

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

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Authors: Inmaculada Malo, Juan Daniel Gallego, Javier González, Isaac López-Fernández, Carmen Diez, Ricardo Amils



Observatorio de Yebes
Apartado 148
19080 Guadalajara
SPAIN

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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 the 2-14 GHz receiver of the 13-m Radio Telescope of the *Observatorio de Yebes*.

There are two types of calibration needed for VLBI: amplitude and phase.

Amplitude calibration is performed by injecting a well-known broadband AWG¹ noise signal at the frontend of the system (most of the times right after the feed) that allows the astronomer to have a conversion factor between the arbitrary count detected by the linear power detectors in the backend and the actual power that is being collected by the system. Whereas absolute amplitude information has not been relevant in legacy S/X geodetic observation, this is changing in the VGOS era where source structure and polarization have been identified as limiting factors in the accuracy of the measurements. Nowadays it is required that VGOS stations are capable of giving also amplitude information.

Phase calibration consists in the measurement of the change of the phase response of the receiver across the frequency band of interest. Instrumental variations of phase and delay during a scan or between scans affects the fringe phase coherence leading to noisier geodetic observables or even, in the worst case, the loss of the detection. A correction of the visibility data can be introduced if those changes are known. For this reason, a harmonic comb generator driven by the atomic oscillator of the station is installed in the frontend of VLBI receivers. The variations in the phase response over frequency and time are therefore registered by the phase of these tones.

Amplitude and phase calibration signals are injected to the receiver RF front-end by a directional coupler, right after the horn and before the LNA, inside the cryostat (see Figure 1).

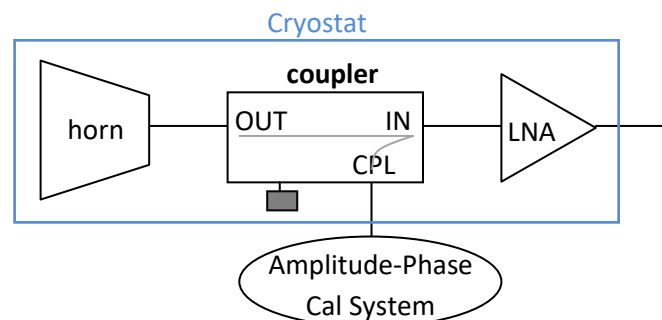


Figure 1: Coupler for the injection of the amplitude and phase calibration system.

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.

¹ AWG: Additive White Gaussian

The reasons are:

1. Low insertion loss and low coupling to minimize the noise added to the receiver:

The coupler increases the noise temperature of the receiver by two reasons: a) the noise introduced by the dissipative loss of the component and b) the noise coupled from the amplitude and phase calibration system.

1.1. The noise introduced by the dissipative loss of the coupler which depends on:

- Its loss in the main RF path (i.e. the S_{12} in this configuration).
- Its physical temperature

Therefore coupler is located in the cold stage of the cryostat at a physical temperature around 20 K reducing its physical temperature and its losses (because losses of a good electrical conductor as Cu or Au are reduced when its physical temperature goes down).

Insertion loss could, in principle, be reduced building the coupler with a superconductor material (see Section 0).

1.2. The thermal noise from the amplitude and phase calibration system coupled to the receiver.

The amplitude and phase calibration system, at room temperature, is connected to the receiver by means of the coupler (see Figure 1). For a 20dB coupler, the 300 K (physical temperature of the calibration system) contributes with approximately 3 K to the noise temperature of the receiver. **In order to reduce this noise, it is proposed to change the 20 dB couplers² by 30 dB couplers³, reducing from 3 K to 0.3 K this contribution.**

2. Constant group delay.

The group delay is a measurement of the linear slope of the phase response over frequency. For an ideal transmission line the group delay is constant.

The phase calibration signal goes through the coupler from the CPL to the IN port. So the group delay of the CPL-IN path must remain constant to avoid adding instrumentation errors to the phase calibration.

The group delay of the CPL-IN path for the 20 and 30 dB couplers has been measured in the 0.1-20.1 GHz band at 300 K and 20 K (see Figure 3). At cryogenic temperature, variation of the group delay is higher for the 30 dB coupler.

The change of the group delay over time has not been measured.

3. Directivity higher than 10 dB.

Directivity is the ratio of the power coupled to the CPL port (S_{13}) to the power coupled to the isolated (ISO) port (S_{14}). Directivity higher than 10 dB assures calibration signals are not disturbed significantly by the echoes reflected from the horn (see Figure 2).

² Pulsar CS20-15-436/13 1820

³ Pulsar CS30-15-436/13 1940

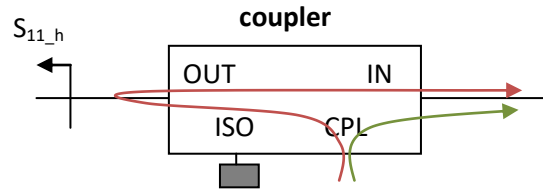


Figure 2. Calibration signals (green color line) vs echoes reflected by the horn (red color line).

2. 30 dB Couplers Measurements.

Results of the two 30 dB couplers (named serial number 1 (#SN1) and 2 (#SN2)) are presented in the Table 1 at room and cryogenic temperature for two different frequency bands. Full measurements could be found in the Annex I.

Serial Number	Pulsar CS30-15-436-13 1940 #SN1			
Nominal Coupling	30 dB			
Connector	SMA female			
Frequency Band	2 – 14 GHz		1.5 – 15.5 GHz	
<i>Temperature</i>	297 K	20 K	297 K	20 K
Return Loss (max. any port)	-22	-17	-21	-17
Coupling: mean	30.8	31.1	30.8	31.1
Δ_{pp}	0.9	0.7	1.2	1.7
Group delay IN-CPL (Δ_{pp}) [ps]	33	84	33	84
Insertion Loss dB (max.)	0.30	0.26	0.32	0.31

Serial Number	Pulsar CS30-15-436-13 1940 #SN2			
Nominal Coupling	30 dB			
Connector	SMA female			
Frequency Band	2 – 14 GHz		1.5 – 15.5 GHz	
<i>Temperature</i>	297 K	20 K	297 K	20 K
Return Loss (max. any port)	-21	-18	-21	-18
Coupling: mean	31.3	31.7	31.3	31.8
Δ_{pp} (f > 5GHz)	0.6	0.9	1.6	1.6
Group delay IN-CPL (Δ_{pp}) [ps]	17	69	17	116
Insertion Loss dB (max.)	0.29	0.19	0.33	0.27

Table 1. Yebes measurements of the 30 dB coupler.

3. 20 dB (old) and 30 dB (new) couplers comparison

Pulsar 20 dB couplers are being replaced by Pulsar 30 dB couplers in the 2-14 GHz receiver of the 13-m Yebes Radio telescope. Figure 3 shows a comparison of the characteristics of CS30 #SN2 and CS20 #SN5 couplers in order to understand how the performance of the receiver could be affected by the change of the couplers type. At cryogenic temperature:

- 1) The coupling of CS30 is 10-11 dB lower than CS20 so the noise temperature of the receiver will be reduced around 2.7 K.
- 2) The Average Effective Insertion Loss of the coupler is a measurement of its dissipative loss, directly related to the noise produced by the coupler. It is slightly overestimated in this report because the power coupled to the isolated port (S-par S_{14}) had not taken into account. CS20 A.E. insertion loss is slightly lower than CS30 (approximately 0.05 dB) so the noise temperature of the receiver could be increased by 0.2 K.
- 3) For CS30 the group delay in the calibration path (i.e. coupled path, IN-CPL):
 - a. It changes considerably between 2-5 GHz, in a similar way as in CS20 coupler.
 - b. For frequencies higher than 5 GHz, the average value of the change of the group delay over frequency is about 50 ps higher than in CS20.
 - c. For frequencies higher than 5 GHz, the peak to peak ripple of the change of the group delay over frequency is almost twice for CS30 #SN1 (84 ps) and three times for CS30 #SN2 (116 ps) than in CS20 coupler (44 ps).
 - d. Higher ripples could be related to resonant frequencies produced inside the cavity of the coupler. Indeed almost every sharp change of the group delay for the two CS30 couplers appear at the same frequencies. These frequencies are: 11.2 GHz, 13.5 GHz, 14.8 GHz, 16.3 GHz, 17.8 GHz y 19.3 GHz.
 - e. It is important to remark that:
 1. Group delay variation over frequency could be calibrated (if it remains constant in time).
 2. Resonances present sharp variations of the performance and may cause significant changes with time or aging.

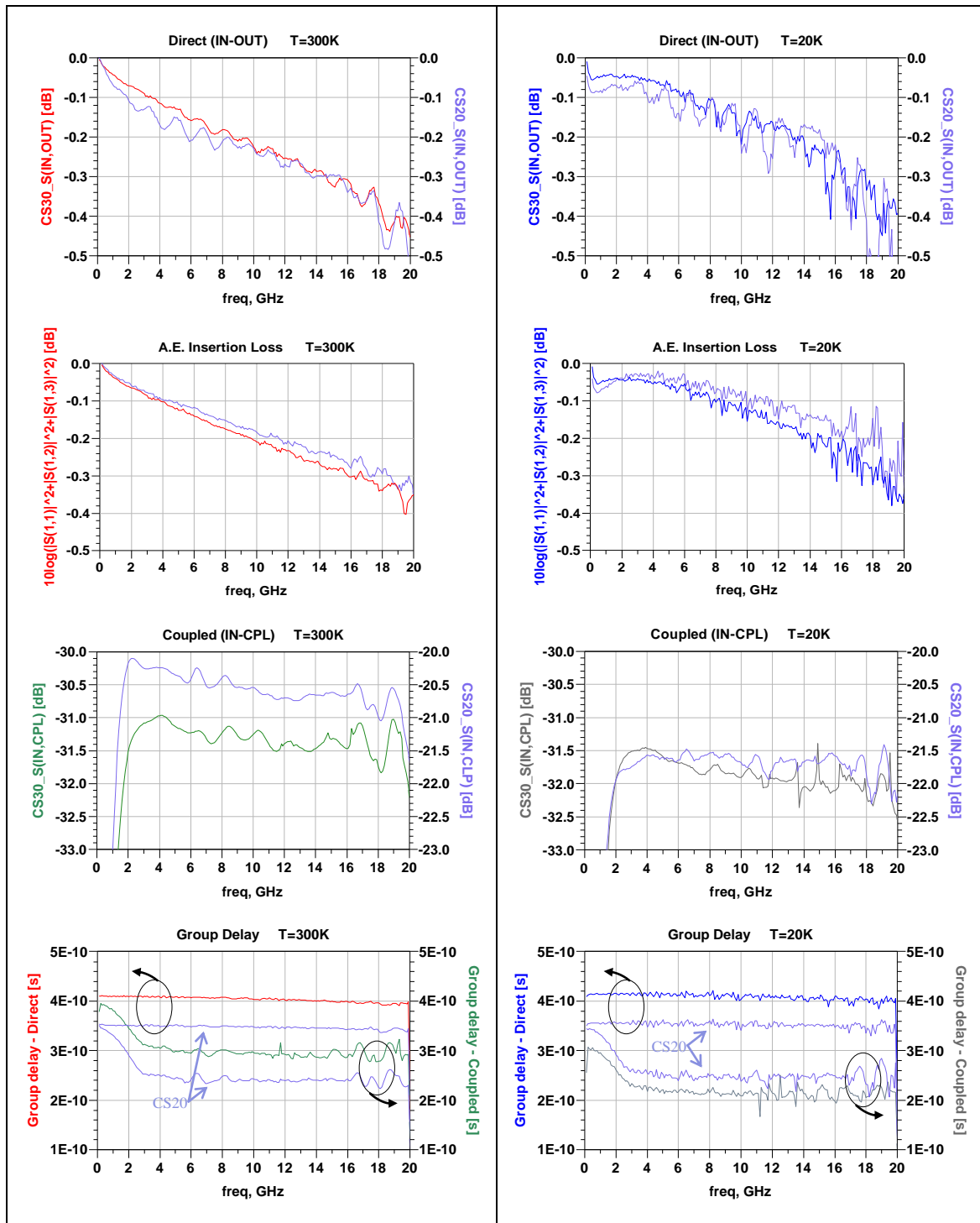


Figure 3. CS30 vs CS20 (purple color lines)

4. Superconductor 30 dB coupler.

A superconductor 30 dB coupler with a high temperature superconductor material has been tried to design without success.

The design requirements are:

- A “*high temperature*” superconductor (i.e. YBCO), because the cold stage temperature of the receiver cryostat is higher than the critical temperature (T_c) of the usual superconductors (i.e. Pb has a T_c of 7 K).
- *Microstrip line technology*: YBCO is a very fragile material so a stripline technology was ruled out because of the difficulty for finding a metal for the box with the same thermal expansion coefficient as the YBCO so the stripline structure withstand the cryogenic operation thermal cycles.
- *Wide band operation (1.5-15.5 GHz)*: The coupler must consist of different stages of symmetrical and uniformly coupled lines, taking into account the end-to-end symmetry of the structure in order to maintain a constant group delay over the complete frequency band.
- *Directivity higher than 10 dB*: It was not possible to achieve. Phase velocity of the even and odd modes is considerably different for the microstrip quasi-TEM modes because of the high permittivity of YBCO material even using a “backward wave” type couplers.

Therefore, under these conditions, it was not possible to obtain an usable superconductor 30dB coupler.

5. Conclusions and future work

20 dB couplers (Pulsar CS20-15-436/13 1820) for the injection of the amplitude and phase calibration system in the 2-14 GHz receiver for the 13-m Yebes Radio Telescope will be changed by 30 dB couplers (Pulsar CS30-15-436/13 1940). As a result the noise temperature of the receiver will be improved by 2.7 - 3 K.

It must be taken into account that the frequency behavior of the group delay is different both mean and peak to peak value in CS20 than in CS30 couplers. There are higher sharp changes of the group delay of the CS30 couplers at some frequencies probably related to resonant modes in the coupler cavity. It would be interesting to know how much this sharp changes impacts phase calibration.

6. Annex I: Ambient and cold measurements.

