CDT Yebes

Wettzell_2 S/X Bands
Cryogenic Receiver Upgrade

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1. Introduction

This report summarizes the new design and characteristics of the S and X bands cryogenic receiver for the Geodetic Observatory Wettzell developed at Technology Development Center, Yebes Observatory.

The receiver is based on a two stage closed cycle cryocooler (CTI-22), the cold stage below 20 K and the intermediate stage, below 70 K.

Specifications

Frequency bands*	S Band: 2.2-2.37 GHz X Band: 8.15-9.0 GHz
Physical Temperature	< 65 K radiation shield < 19.5 K cold stage
Pressure	< 10^{-6} mbar
Pressure Leaks at room temperature (mainly outgassing)	< 8 · 10^{-6} mbar·l/s
Average Gain	39.3 dB at S band 37.9 dB at X band
Noise Temperature	S band: < 14 K X band: < 18 K
Input	S band: N-N connector X band: waveguide WR-112 S band calibration: SMA X band calibration: SMA
Output	S band: SMA X band: SMA
Output impedance	50 Ω

* IVS Frequency Bands for Geodetic Observations.

2. Enhancements summary

- Design and construction of a new bottom dewar flange keeping connection points and orientations.
    - Flange design adapted to the cold head (easier He pipes connection).
    - Hermetic Fischer connectors for DC signals.
    - New SMA vacuum connectors for RF signals.
    - Polished inner surface.
    - New vacuum valve flange.
    - New vacuum sensor flange.
- Design and construction of a new 70 K radiation shield with multilayer insulation.
    - Polished top flange.
- Design and construction of a new polished aluminum intermediate stage, <70 K.
- Design and construction of a new copper cold stage, <20 K.
- Installation of the directional coupler for the X band inside the receiver and thermal gap adjustment to 0.4 mm.
    - X band transition (waveguide to SMA) and directional coupler measurements.
- New DC wiring and RF cabling.
- Thermal conductivity improvement placing indium foils between the different pieces.
- New housekeeping devices:
    - Two vacuum traps.
    - Two heating resistors and thermostats.
    - Two thermal sensors.
- New cold head CTI22 installation (BKG supplied).
- New viton o-rings.
- Cooling and vacuum tests (leakage rate measurement).
- LNAs measurements: CII1-12#123D (Caltech – X band) and S-2.3-30H 240RL (Berkshire - S band), at cold and room temperature, before installation.
- Receiver performance (noise temperature and gain).
- Complete report (specifications, cryostat geometry, CAD drawings, vacuum and cooling tests results, LNAs specifications, user and maintenance manual, safety instructions, etc.).

3. Cryostat geometry

The cryostat design is based on the previous cryostat updated in Yebes in 2013 and currently installed in the 20 m radio telescope at Wettzell Observatory. This new receiver will be a back up for the first receiver.

This new design has been performed carefully due to the little free space inside the cryostat and also taking into account the space inside radio telescope to place the receiver.

Next figure show the cryostat design overview:

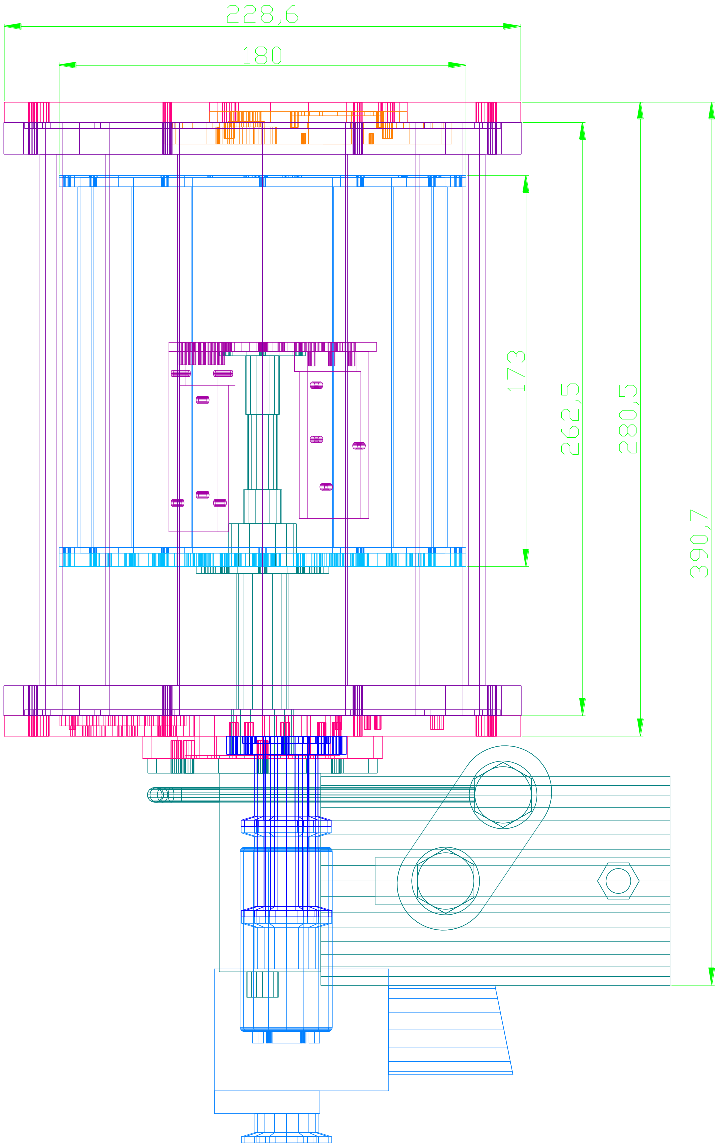


Figure 1. Cryostat overview. Cold head (green), vacuum case (violet), radiation shield (blue) and cold stage (violet).

The cryostat is built over a CTI22 Model cold head in a steel made cylindrical dewar. At the top cover, a vacuum window lets the X band radiation go through, for the S band a hermetic N connector feedthrough is used. At the bottom cover there are the RF connectors for S and X bands outputs and the calibration signals input, the flanges for the pressure sensor and vacuum valve and hermetic Fischer connectors for the DC cabling.

Inside the cryostat, attached to the intermediate stage, there is an aluminum made cylindrical radiation shield covered with multilayer insulation (MLI) in order to decrease the radiation thermal load inside the cryostat. The temperature of this stage is less than 65 K. Removing the radiation shield, the entire receiver can be easily reached. It is the coldest part of the receiver at, approximately, 19.5 K. Both amplifiers are thermally attached to the copper made cold stage to keep them at the lowest temperature.

The RF cables that connect the amplifiers with the room temperature stage (SMA connectors) are coaxial semi-rigid stainless steel cables, UT-085B-SS.

3.1. Vacuum case

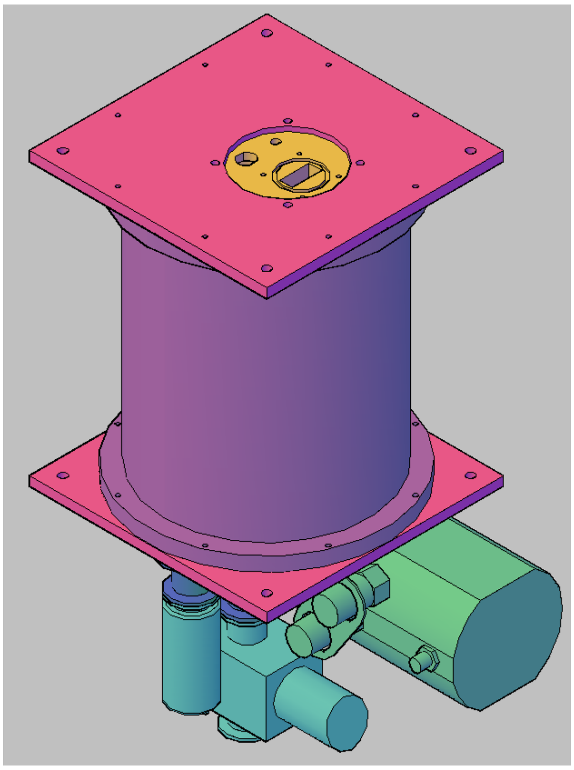


Figure 2. Vacuum case and cold head 3D view.

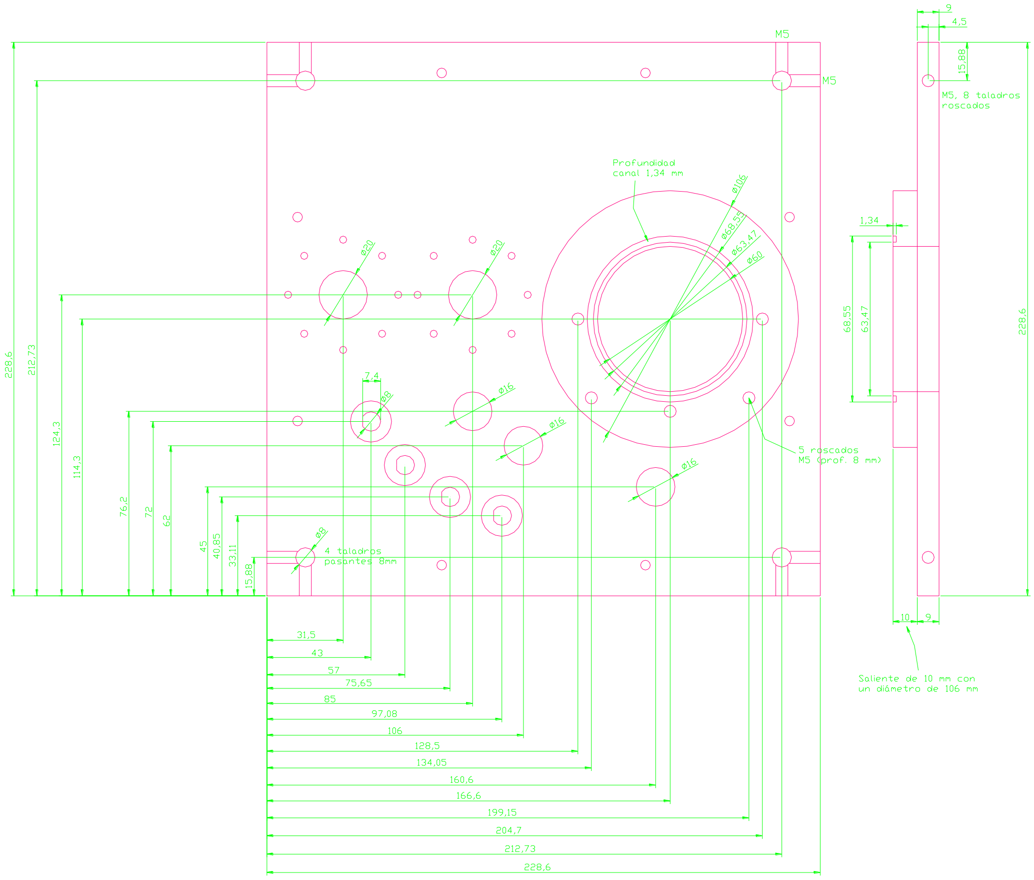
The dewar consists of three main parts: stainless steel cylinder, bottom flange and top flange. At the top cover the inputs for the X and S bands are located (waveguide through a vacuum window for X band and coaxial input through a N-N hermetic transition for S band). Both inputs are located in an independent piece from the top flange which belongs to the original design.

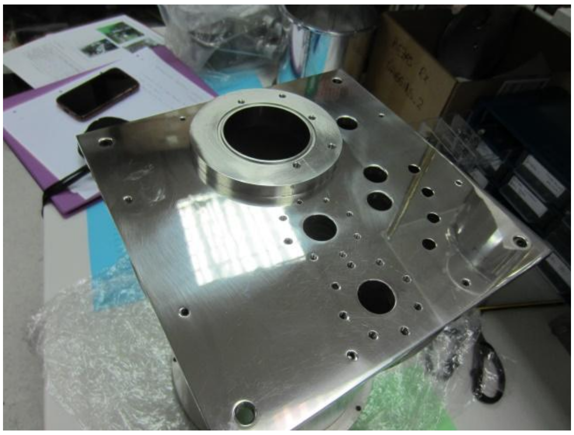
The dewar lower flange has several outputs for different uses:

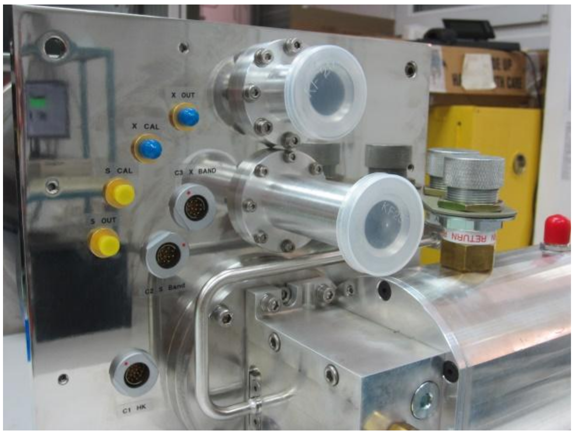
- Cold head connection. This flange has been designed with a salient that allows connecting the helium pipes to the cold head without forcing the cold head aeroquip connectors.
- Two apertures with transitions for the vacuum control (pressure sensor and vacuum valve).
- Three hermetic Fischer connectors for the housekeeping control and monitoring, and amplifiers biasing.
- Four SMA hermetic connectors for the RF output signals coming from the LNAs and the calibration signals input.

Inside the dewar, at the bottom cover, there is an aluminum plate, with DB9 and DB15 connectors, to carry out the transition between room temperature DC wiring coming from the Fischer connectors and the DC wiring which connects the different receiver devices (amplifiers and housekeeping elements).

Dewar and flanges design and setting up







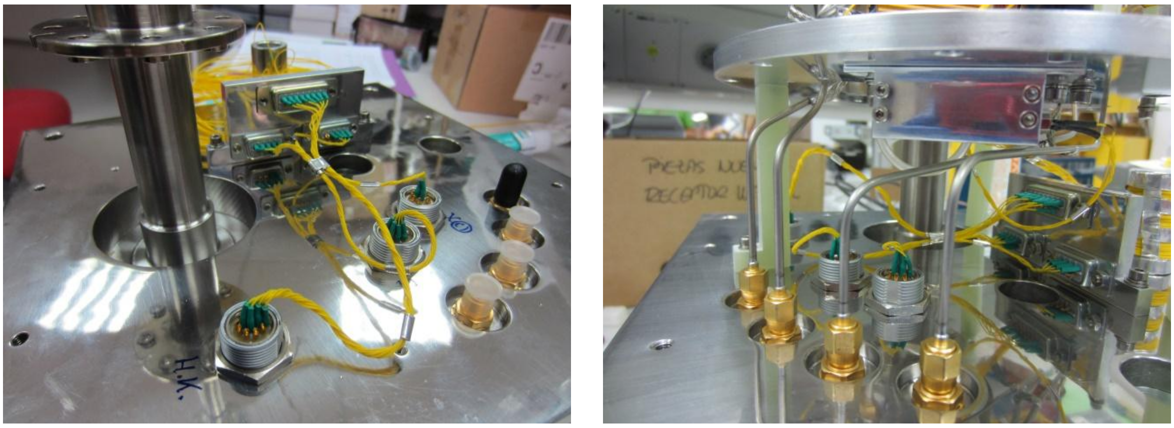
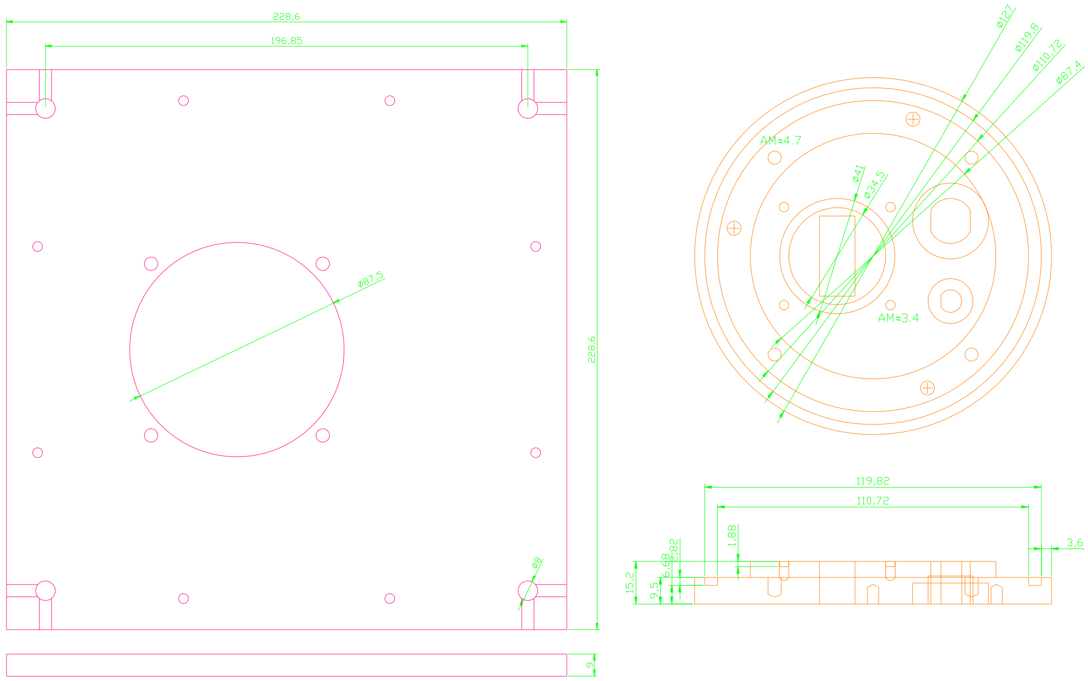


Figure 3. Dewar bottom flange, outside and inside views.



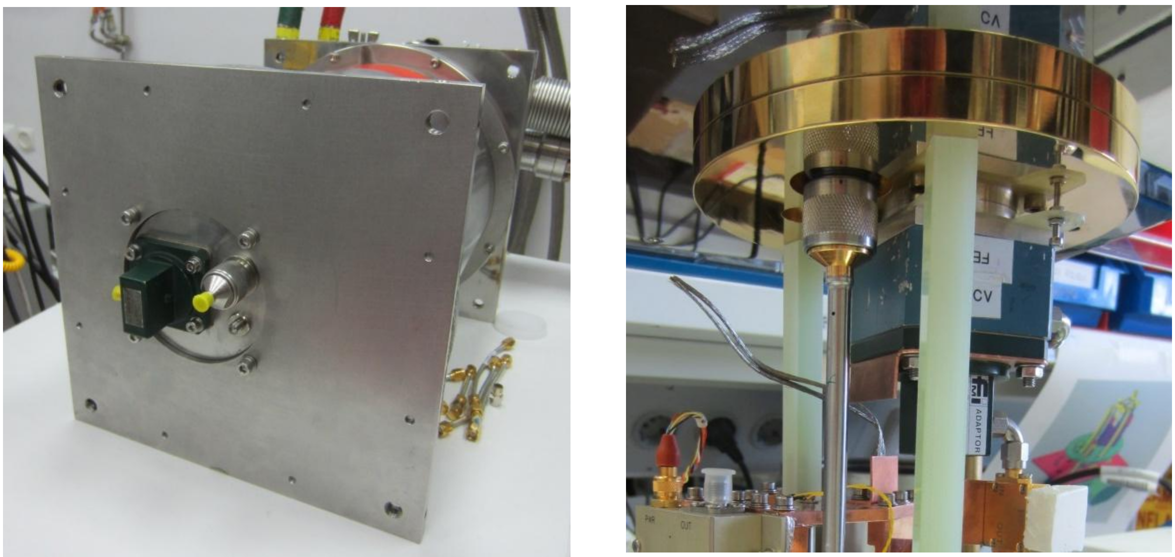
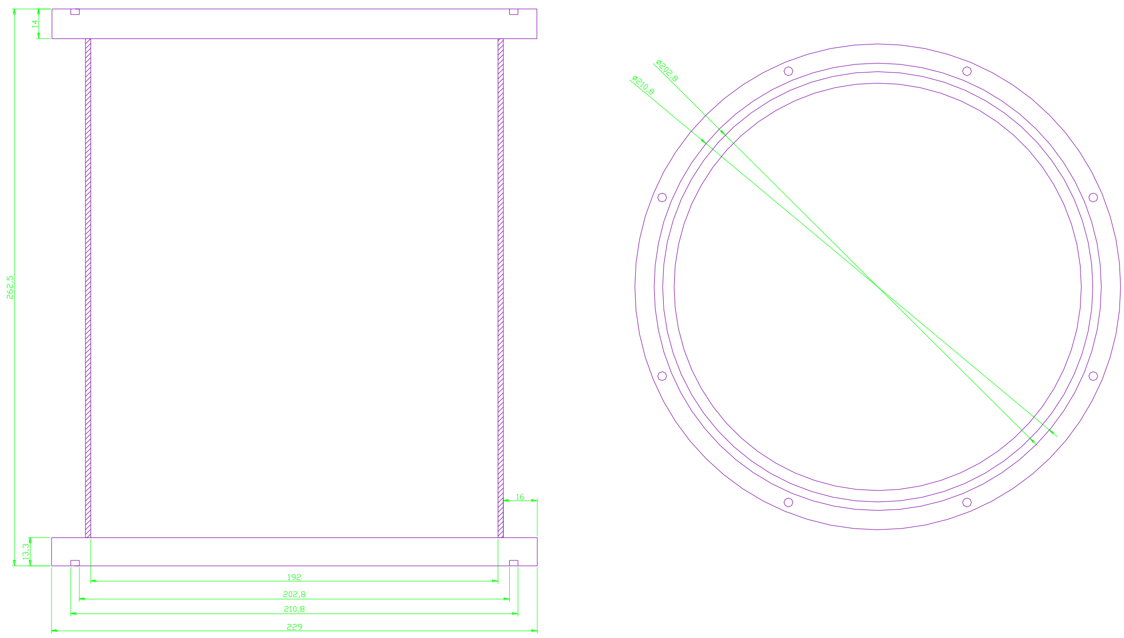


Figure 4. Top flange and S/X bands inputs.



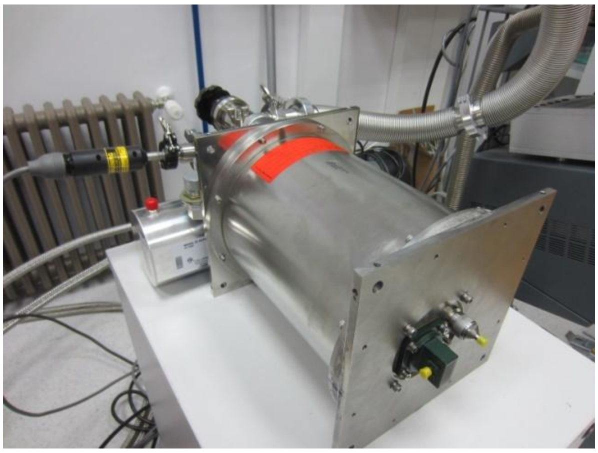


Figure 5. Complete dewar setting up.

3.1.1. Vacuum window

The vacuum window goal is to allow transition (physical, electromagnetic and vacuum) between the signal and the X band branch inside the cryostat. A vacuum window, supplied by Wettzell Observatory, has been used for the laboratory tests carried out at Yebes, along with a waveguide-coaxial transition.

Figure 6. Vacuum window used for the vacuum tests, gain and T_{noise} measurements.

In case this kind of window is not available, it is possible to use vacuum windows made of Halar (Ethylene-Chlorotrifluoroethylene copolymer with a 0.125 mm thickness). Vacuum windows with greater thicknesses can generate resonance picks, for example, several tests carried out with the Mylar window with a thickness of 0.5 mm (see figure below) have shown resonances at several frequencies.

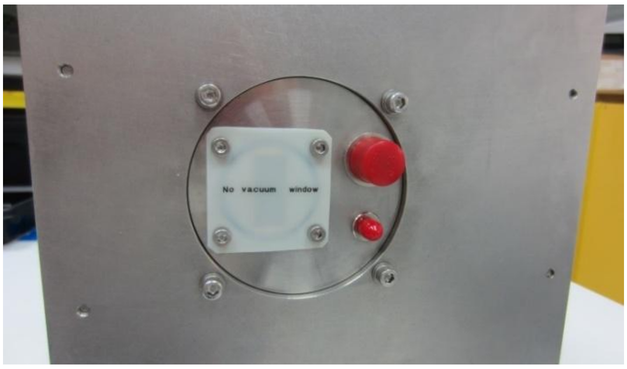


Figure 7. Mylar Windows that could be used for tests.

3.1.2. Vacuum seals

O-rings with their main specifications and locations are presented in the table below:

Seal	Type	d_1 (mm)	d_2 (mm)	Reference	Qty
Vacuum case – top and lower flanges	OR VI	202.8	3.53	571.943	2
Vacuum window – golden transition	OR VI	34	2.5	461.979	1
Golden transition – top flange	OR VI	110.72	3.53	305.643	1
Cold head –lower flange	OR VI	63.22	1.78	435.803	1
Vacuum system transitions – lower flange	OR VI	28	4	670.265	2

Table 1. Vacuum seals Epidor. [5]

3.2. Intermediate stage and radiation shield

The intermediate stage is an aluminum plate of 6 mm thickness and 180 mm diameter (aluminum 1050). This stage is screwed onto the first stage of the cold head, allowing to reach a temperature below 70 K.

Attached to this plate there is an aluminum cylinder to cover the cold stage and reduce the radiation load, the so-called radiation shield. To improve the radiation shield performance, this is covered with multilayer insulation, MLI (8 layers with a total thickness of ~3-4 mm). Over the cylinder, there is another aluminum plate of 1 mm thickness to decrease the radiation load from the top cover.

The Mylar layers used are NRC-2, crinkled aluminized Mylar film 0.006 mm, with a reflectivity of 0.03. The NRC-2 exhibit excellent thermal insulation efficiencies when the pressure inside the receiver is less than 10^{-4} mbar (the pressure reached inside the dewar is usually below 10^{-6} mbar).

On the intermediate stage, there are placed several housekeeping devices: temperature sensor, heating resistor, thermostat and zeolites based vacuum trap. These devices have the following characteristics:

- Heating resistor: 100 Ω, 25 W.
- Zeolites regeneration resistor: the vacuum trap includes a 100 Ω and 2.5 W regeneration resistor.
- Temperature sensor: DT-470 Lakeshore Si-diode.
- Thermostat: 70° ± 3°.

The housekeeping devices allow to achieve a better vacuum inside the cryostat and help to warm up faster the receiver in case it is necessary. Both in the intermediate stage and the bottom flange it´s possible to find two aluminum cylinders that permit to give more length to the DC cables, reducing the conduction load from the room temperature stage to the cold stage.

To reduce the RF cables conduction load between the cold stage and the bottom flange of the dewar, a copper mesh is placed from the intermediate stage to every cable. The position of the mesh in the cable is calculated and optimized taking into account the length of the cables and the load generated in each of the stages according to the expected final temperature.

Between the intermediate stage and the bottom flange are placed three fasteners made of G10 (fiber glass pieces with very low thermal conductivity), which permit to hold the stage and avoiding all the weight load of the stage over the cold head screws. Besides, in case it is necessary to change the cold head, these fasteners will let change it without disassemble completely the receiver. These kinds of fasteners are also located between the intermediate stage and the golden piece, to hold this piece during the receiver assembly.

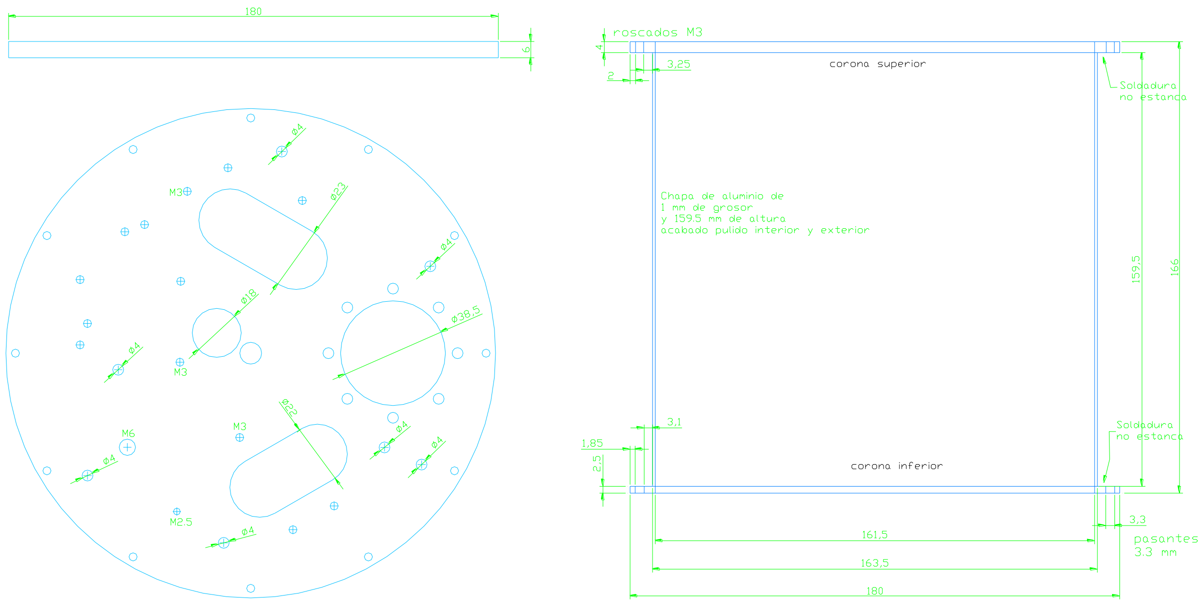


Figure 8. Intermediate stage and radiation shield design.

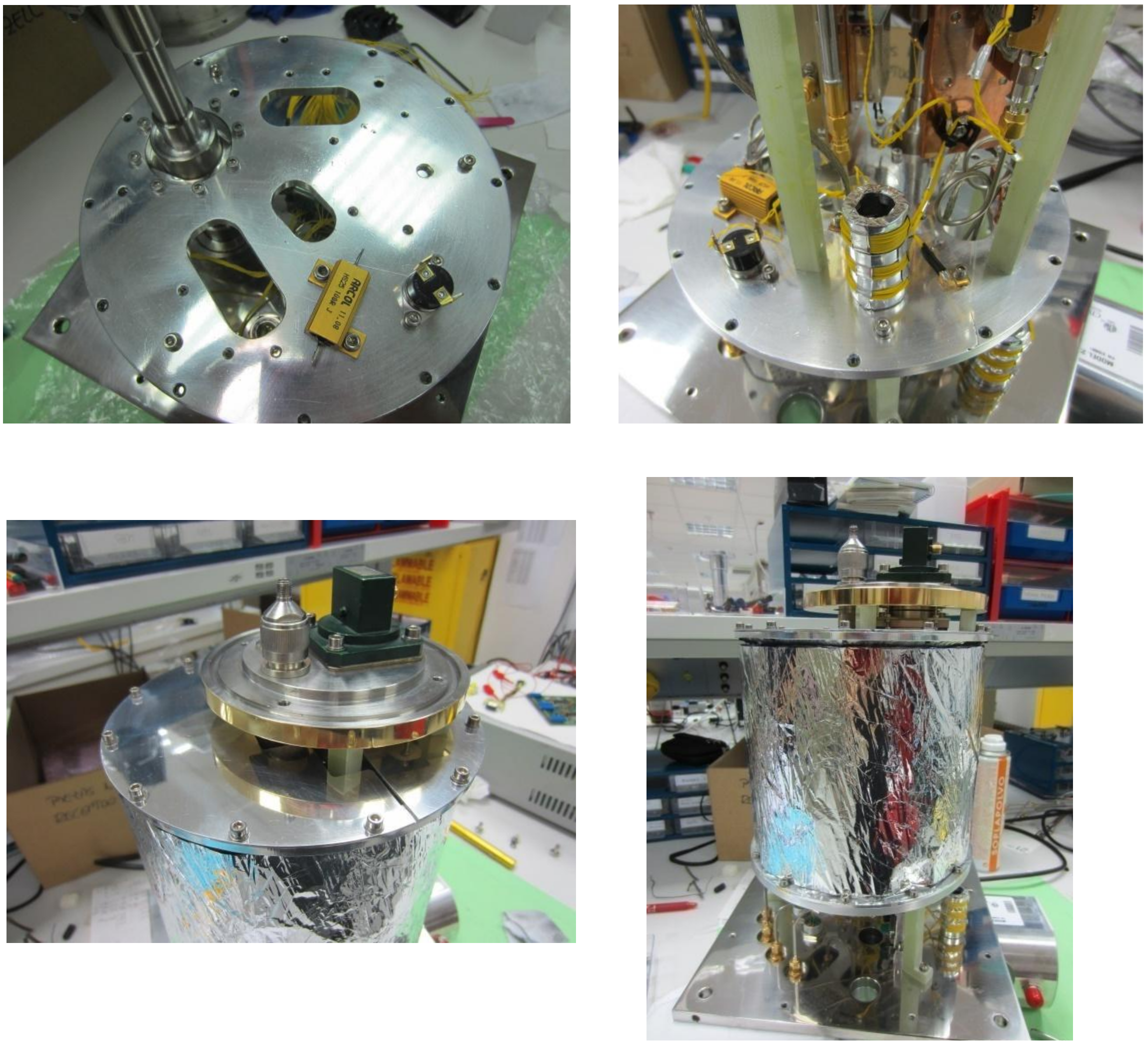


Figure 9. Intermediate stage and radiation shield with multilayer insulation.

3.3. Cold stage

The cold stage consists of three copper plates. The main one is directly attached to the cold head cold stage, where it is possible to reach a temperature below 20 K; the others are screwed to both sides of the first one, placing indium foils between them to get better thermal conductivity.

The S band amplifier is attached to one of these plates. In this receiver the X band amplifier is joined to the cold stage through a copper mesh. The waveguide transition and the X band directional coupler are also connected to the cold stage through copper meshes.

Attached to these plates are also placed a vacuum trap, thermostat, heating resistor and the temperature sensor (same specifications than the used for the intermediate stage).

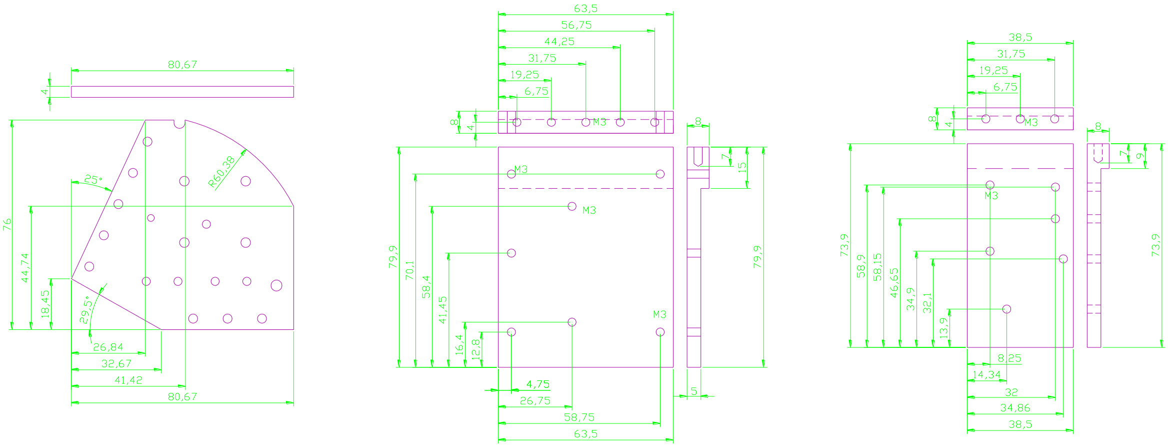


Figure 10. Cold stage design.

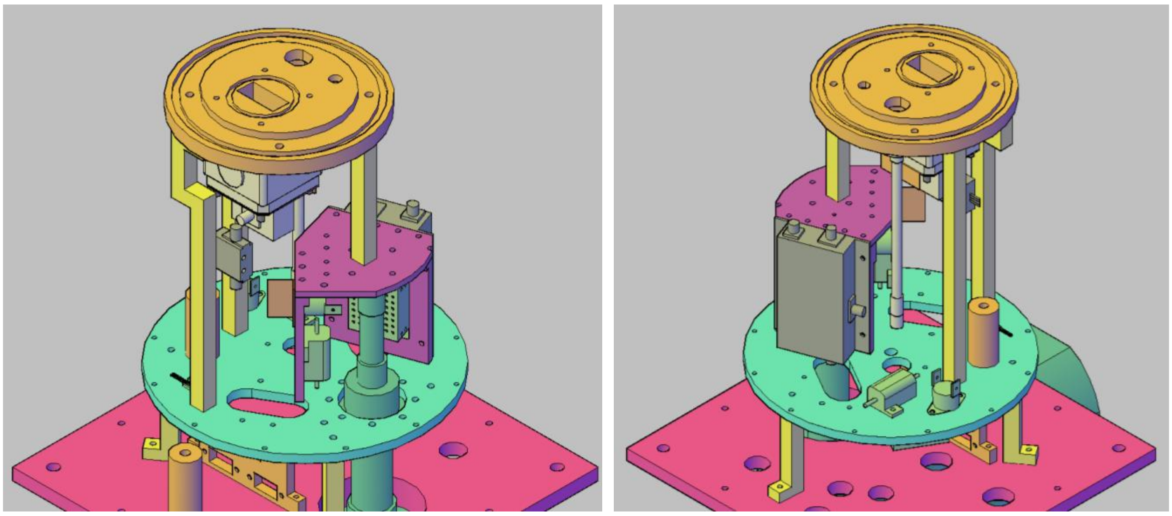


Figure 11. Receiver stages, 3D View.

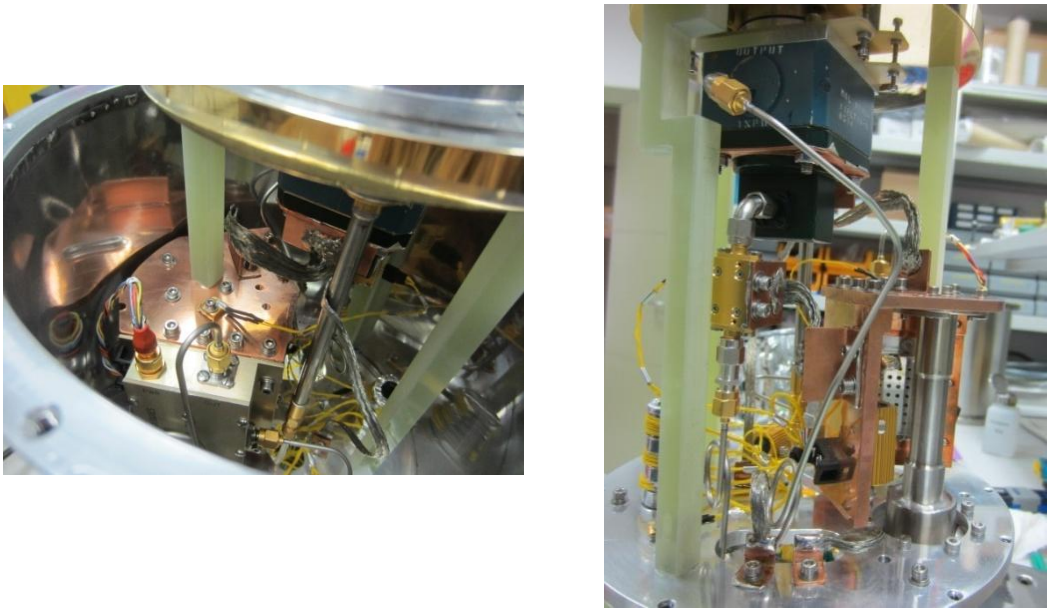


Figure 12. Cold stage with LNAs and housekeeping devices.

4. Amplifiers setting-up

The cryostat contains two low noise amplifiers:

LNA/Band	Berkshire S-2.3-30H 240RL S Band	Caltech CII1-12#123D X Band
Optimized between	2.1 – 2.4 GHz	8.0 – 9.0 GHz
Average noise temperature @13.5 K	5.3 K	4 K
Average gain @13.5 K	40.6 dB	40 dB
ΔG(f)	3 dB	1.3 dB
Dissipated power	63.8 mW	24 mW
Stages	3	2

Table 2. LNAs main specifications measured at Yebes Observatory.

4.1. LNAs biasing

S Band - Berkshire S-2.3-30H 240RL								
T=13.5 K (optimum)								
V_{d1}	**I_{d1}**	**V_{g1}**	**V_{d2}**	**I_{d2}**	**V_{g2}**	**V_{d3}**	**I_{d3}**	**V_{g3}**
2.3 V	**6.0 mA**	**-0.54 V**	**2.5 V**	**8.0 mA**	**-0.42 V**	**3.0 mA**	**10.0 V**	**-0.6 mA**
T=19.5 K (measured)								
V_{d1}	I_{d1}	V_{g1}	V_{d2}	I_{d2}	V_{g2}	V_{d3}	I_{d3}	V_{g3}
2.3	6.0	-0.53	2.5	8	-0.42	3	10	-0.59
T=293.4 K (optimum)								
V_{d1}	I_{d1}	V_{g1}	V_{d2}	I_{d2}	V_{g2}	V_{d3}	I_{d3}	V_{g3}
2.5	10	-0.55	2.5	10	-0.5	2.5	10	-0.72
T=297 K (measured)								
V_{d1}	I_{d1}	V_{g1}	V_{d2}	I_{d2}	V_{g2}	V_{d3}	I_{d3}	V_{g3}
2.5	10	-0.54	2.5	10	-0.49	2.5	10	-0.7

Table 3. LNA S Band Biasing.

X Band - Caltech CII1-12#123D		
T=13.2 K (optimum)		
V_d	**I_d**	**$V_{g1}=V_{g2}$**
1.2 V	**20.0 mA**	**2.34 V**
T=19.5 K (measured)		
V_d	I_d	$V_{g1}=V_{g2}$
1.2	20	2.62
T=295 K (optimum)		
V_d	I_d	$V_{g1}=V_{g2}$
1.8	50.5	2.39
T=297 K (measured)		
V_d	I_d	$V_{g1}=V_{g2}$
1.8	50.5	2.39

Table 4. LNA X Band Biasing.

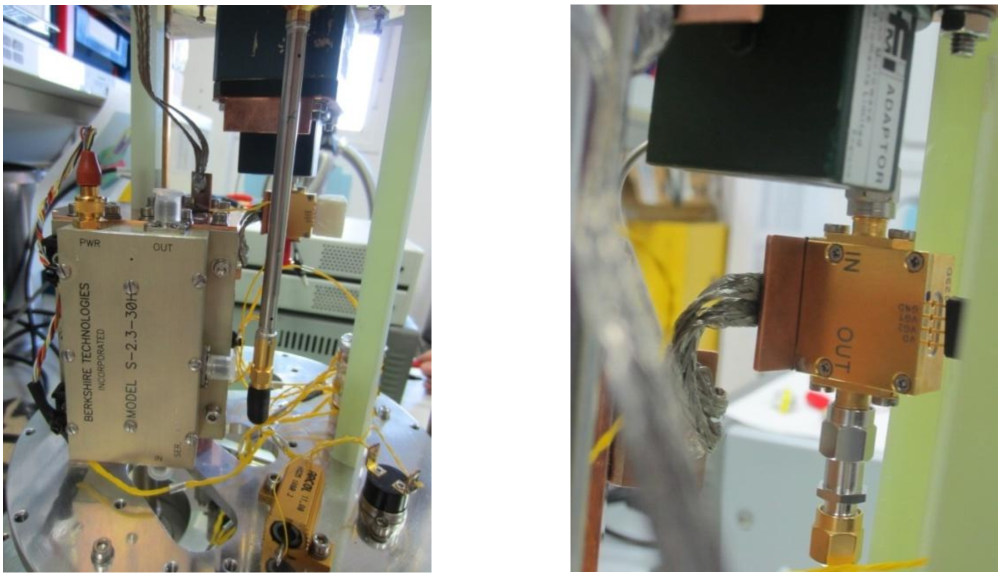


Figure 13. Berkshire and Caltech LNAs.

4.2. LNAs biasing module

A new LNAs biasing module was developed at Yebes Observatory for the first Wettzell S/X bands receiver. In any case, a second module has been made and delivered to Wettzell to carry out different tests at Wettzell laboratories and also as a spare unit.

Warning! In case changing the receiver, it is very important to adjust the biasing values in the modules for the new amplifiers. To make this adjustment, the back cover of the biasing module can be removed for accessing to the biasing power supplied card (the schematics of this card is shown in the next figure). The card allows to adjust four stages (three for the S band LNA and one for the X band LNA). V_d and I_d can be adjusted for each stage by means of the corresponding potentiometer.

The biasing values can be monitored through a DB25 female connector placed at the module front panel. Read values could be slightly different to the real ones due to cable ohmic losses. When adjusting (only if necessary), read the values directly through the pins in the card.

Low Noise Amplifiers biasing procedure:

- Connect Fischer connectors to the corresponding connectors (S and X) on the dewar.
- Connect DB9 connectors to the S and X inputs.
- Connect a power supply to the +15 V and -15 V inputs.
- Turn on power supply and verify electric current values.

Power consumption (with Wettzell_2 Rx amplifiers, biasing card adjusted for T_{cold} biasing values):

- +15 V ⇒ 55 mA
- -15 V ⇒ 35 mA

Biasing monitor DB25 connector verification (DB25 pin-out):

Pin	Signal	Value	Pin	Signal	Value
1	GND		8	V_{d2_S}	2.5
2	V_{d_X}	1.2	9	I_{d2_S}	0.8
3	I_{d_X}	2.0	10	V_{g2_S}	
4	V_{g_X}		11	V_{d1_S}	2.3
5	V_{d3_S}	3	12	I_{d1_S}	0.6
6	I_{d3_S}	1	13	V_{g1_S}	
7	V_{g3_S}				

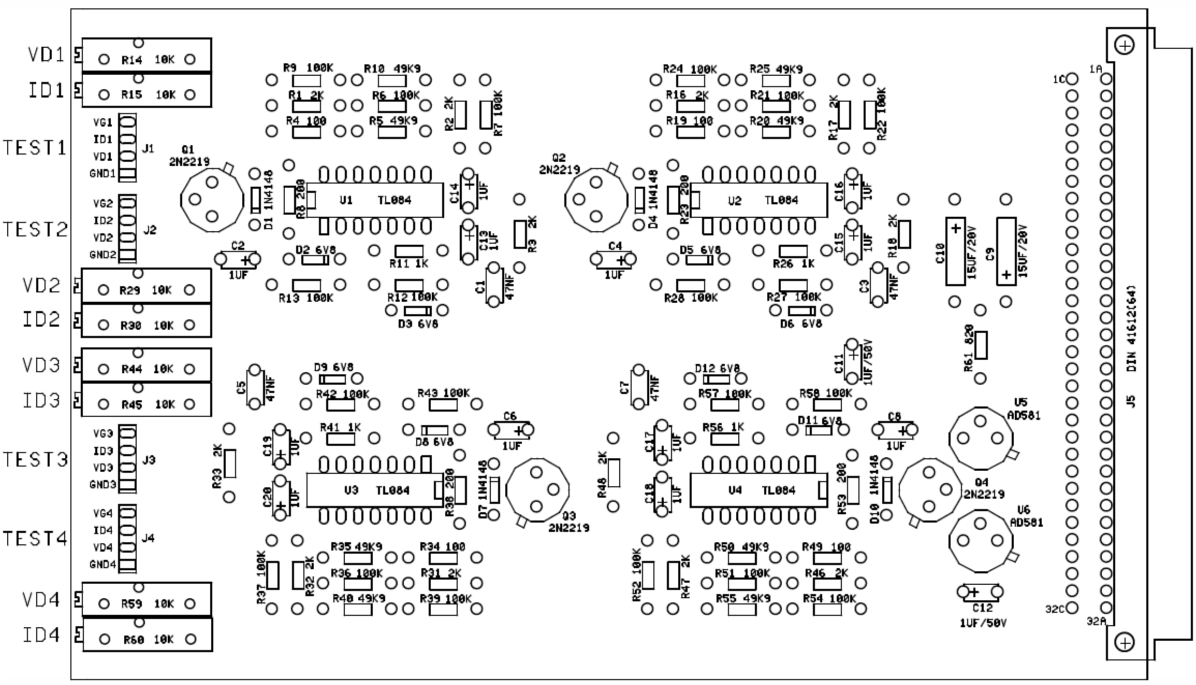


Figure 14. PC Board components.

LNAs Biasing Monitor DB25 Connector Pin-out

DB25 pin	Signal	Wire color
1	GND	Black
2	V_{d4} -X	Red
3	I_{d4} -X	White
4	V_{g4} -X	Gray
5	V_{d3} -S	Pink
6	I_{d3} -S	Purple
7	V_{g3} -S	Yellow
8	V_{d2}-S	Brown
9	I_{d2}-S	Blue
10	V_{g2}-S	Green
11	V_{d1}-S	White, green dots
12	I_{d1}-S	Brown, green dots
13	V_{g1}-S	White, yellow dots
14	No connection	--
…	…	…
25	No connection	--

Table 5. LNAs Biasing Monitor DB25 Connector pin-out, Wettzell_2 module.

Figure 15. Biasing module.

5. Internal and external DC wiring

There are 3 hermetic Fischer connectors at the dewar bottom flange:

- One of them, with 16 pin, for housekeeping signals and monitoring.
- Two of them, with 11 pin, for the amplifiers biasing signals.

Hermetic Fischer Connector		Description	
C1	Housekeeping	16 pin	Pol2=
C2	S-LNA-Bias	11 pin	Pol2=
C3	X-LNA-Bias	11 pin	Pol1=

Next figures show the Fischer connectors pin-out (11 and 16 pin):

Figure 16. 11 pin Fischer ("wire" connector view (female), red point up).

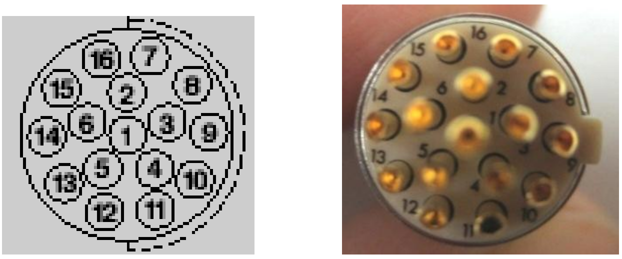


Figure 17. 16 pin Fischer ("wire" connector view (female), red point up).

The DC wiring has been done using small section long cables (Kynar 30 awg.) to reduce the conduction thermal load.

5.1. Low Noise Amplifiers biasing wiring

Next figures show the **amplifier biasing connectors pin-out**:

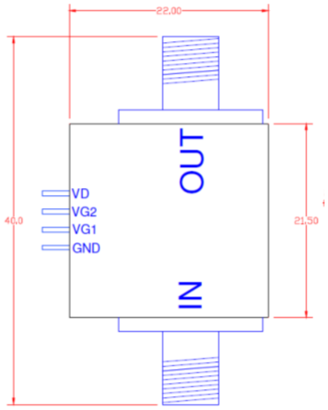


Figure 18. X band amplifier biasing Connector pin-out.

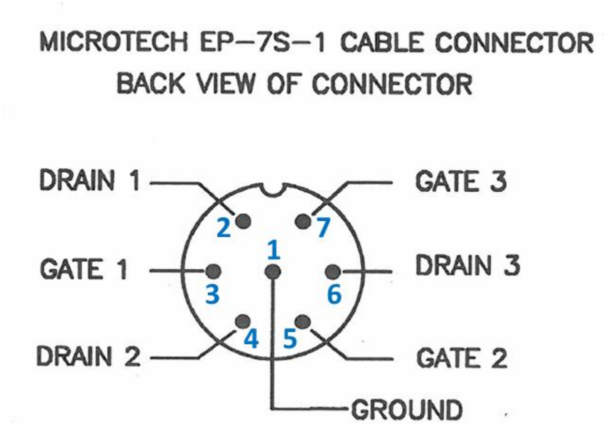


Figure 19. S band amplifier biasing connector pin-out.

Biasing cables pin-out

Internal wiring				External wiring		Pol2=
Signal	**Microtech**	**DB9**	**Fischer (panel) Pin**	**Fischer (cable) Pin**	**Wire Color**	**DB9**
GND	1	1	1	1	*Black*	1
V_{d1}	2	2	2	2	*Brown*	2
V_{g1}	3	3	3	3	*Red*	3
V_{d2}	4	4	4	4	*White*	4
V_{g2}	5	5	5	5	*Orange*	5
V_{d3}	6	6	6	6	*Yellow*	6
V_{g3}	7	7	7	7	*Green*	7

Table 3. **S band LNA** biasing cable (from the LNA to the external cable).

Internal wiring				External wiring		Pol1=
Signal	**LNA pin**	**DB9**	**Fischer (panel) Pin**	**Fischer (panel) Pin**	**Wire Color**	**DB9**
GND	GND	1	1	1	*Black*	1
V_d	V_d	2	2	2	*Red*	2
V_{g1}	V_{g1}	3	3	3	*Brown*	3
V_{g2}	V_{g2}	4	4	4	*Violet*	

Table 4. **X band LNA** biasing cable (from the LNA to the external cable).

5.2. Housekeeping wiring

At the room temperature stage (300 K), there is a 16 pin Fischer connector placed for the cryostat internal monitoring signals: heating resistors, zeolites regeneration resistors, temperature sensors and thermostats.

Signal	Description
Ti_+	Intermediate stage temperature sensor (+)
Ti_-	Intermediate stage temperature sensor (-)
Tc_+	Cold stage temperature sensor (+)
Tc_-	Cold stage temperature sensor (-)
Calef_on	Signal to activate the heaters after passing through the thermostat
Regen_on	Signal to activate the zeolites regeneration resistor
GND_res	Ground
Calef_mon	Heaters monitor
Regen_mon	Regenerators monitor

Table 5. Housekeeping signals description.

A 2-meters-lenght cable connects the receiver with the different housekeeping signals. At one end there is the 16 pin Fischer connector to be plugged to the receiver. The other end contains the following elements:

Internal wiring			External wiring		
Signal	**DB15**	**Fischer (panel) Pin**	**Fischer (cable) Pin**	**DB25**	**Banana connectors**
Tc_+	1	1	1	3-4	
Tc_-	2	2	2	15-16	
Ti_+	3	3	3	6-7	
Ti_-	4	4	4	18-19	
Calef_on	5	5	5		Red
Regen_on	6	6	6		Yellow
GND_res	7	7	7		Black
Calef_mon	8	8	8		Red (test point)
Regen_mon	9	9	9		Black (test point)

Table 6. Housekeeping cable pin-out.

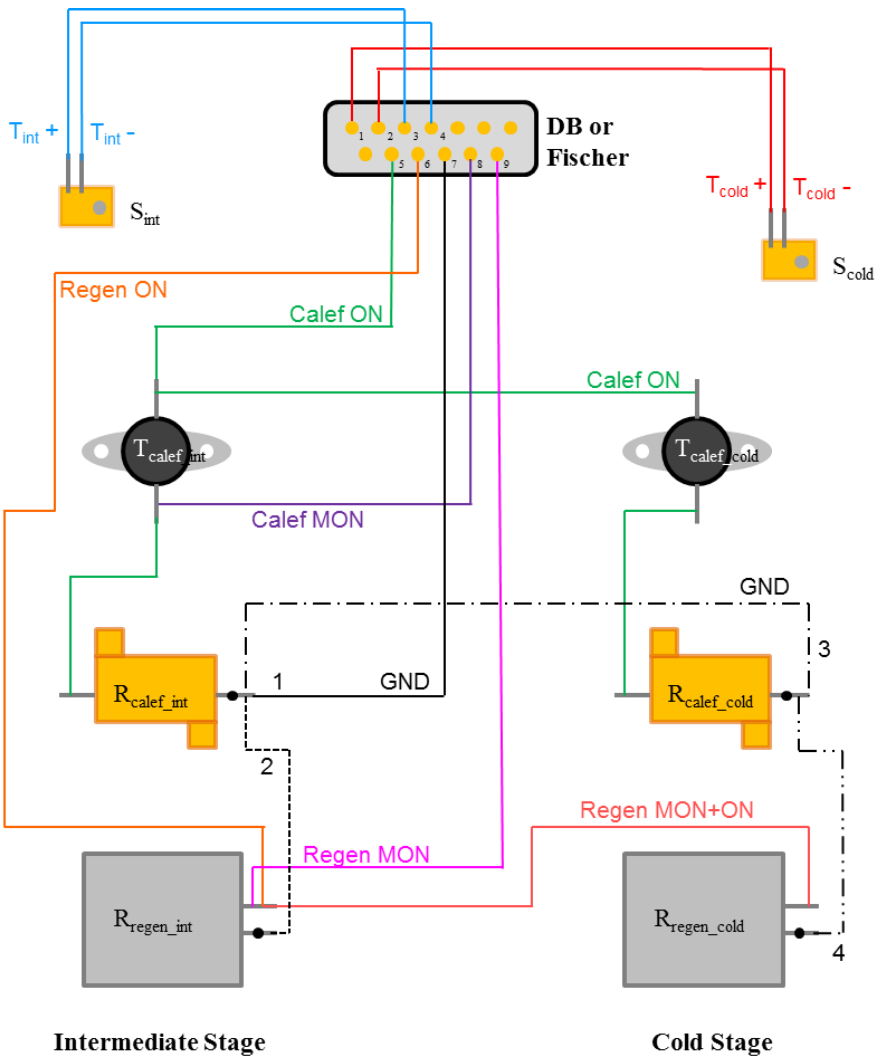


Figure 20. Housekeeping circuit scheme.

6. Cryogenic system

This receiver uses a Model 22 CTI-Cryogenics Cold Head, with the following characteristics:

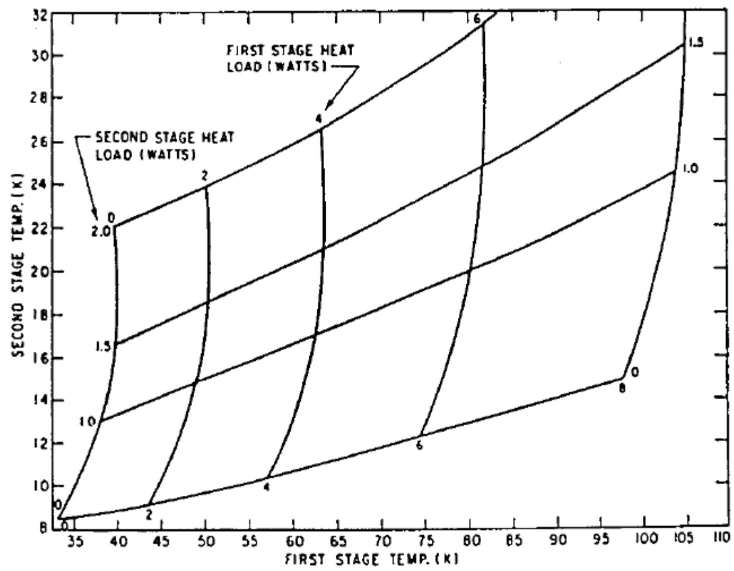


Figure 21. 22C cryodyne cryocooler typical refrigeration capacity (50 Hz).

7. Cryostat thermal and vacuum behavior

Several tests have been performed to determine the cryostat thermal and vacuum behavior. Cooling and pumping systems used for tests:

- Cold head: CTI22.
- Compressor: CTI 8200, 220 V - 50 Hz.
- Vacuum system:
  - Rotary pump and turbomolecular pump (Alcatel).
  - Vacuum sensors (MKS): Pirani sensor (pressure from atmospheric to 10^{-4} mbar) and cold cathode (pressure from 10^{-4} mbar to 10^{-8} mbar).
- Temperatures monitoring: Lakeshore system.

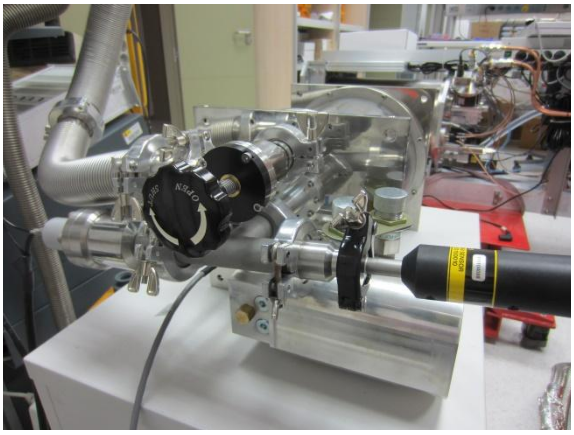


Figure 22. Vacuum sensors and valve.

Measurement, **final results**:

- **Intermediate stage temperature**: **< 65 K** (at 24°C room temperature, for a higher room temperature, around 30°C, the intermediate stage can reach a temperature of 72 K ⇒ keep refrigerated the receivers room if it is possible).
- **Cold stage temperature**: **< 19.5 K** (at 24°C room temperature, for a higher room temperature, around 30°C, the intermediate stage can reach a temperature of 23 K).
- **Vacuum < 10^{-6} mbar** (cryogenic vacuum).
  - Leakage rate < $8 \cdot 10^{-6}$ mbar·l/s (dewar volume 7.6 l).
- **Cooling down time**: **≈ 12 h** (room temperature dependent).
  - Dynamic compressor pressure: 280 psi.
- **Warming up time**: **≈ 15 h** (or < 3 h with zeolites regeneration and heating resistors turned on).
- **Warming cycles**:
  - Power consumption:
    - Heaters: 25.75 V ⇒ 0.5 A
    - Vacuum traps: 6.178 V ⇒ 0.117 A
  - From room temperature, the intermediate stage needs 4 hours to reach the maximum temperature, ≈ 340 K (67 °C).

- The cold stage has a first cycle of one hour to reach 68 °C, after that, the maximum temperature reached is around 60 °C.

In this kind of receiver, with a small size, the stages final temperatures have a high dependence with the room temperature. It is convenient to control the temperature at the receivers cabin and keep it as low and stable as possible.

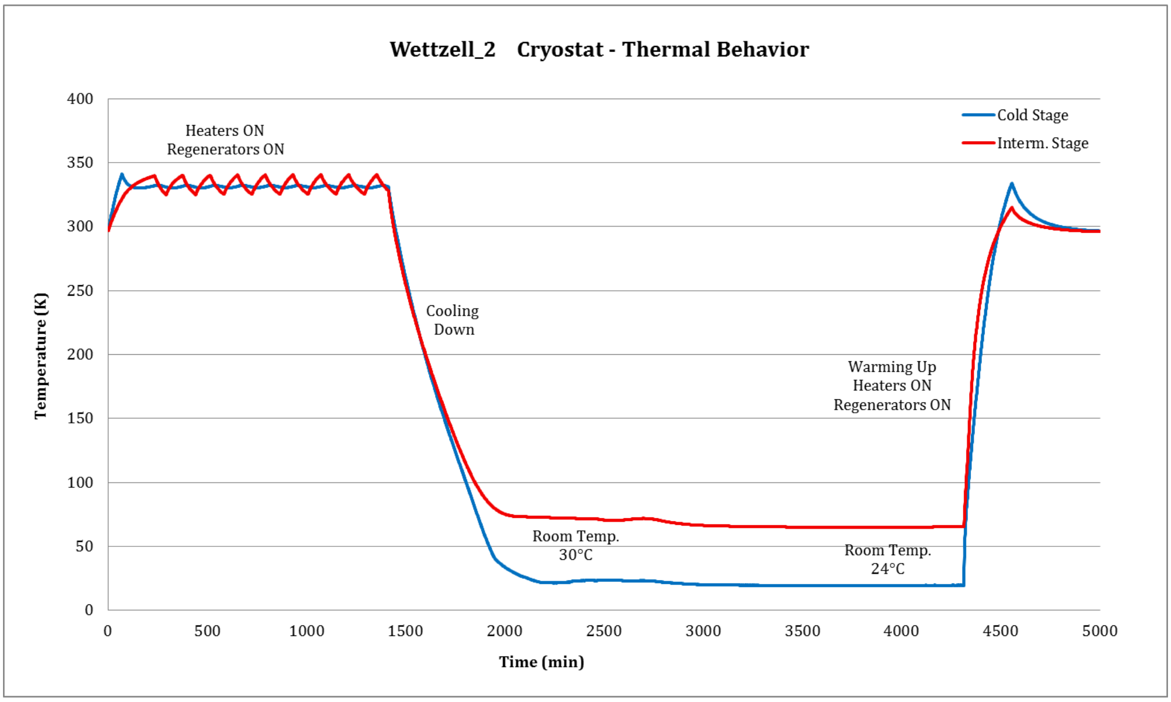
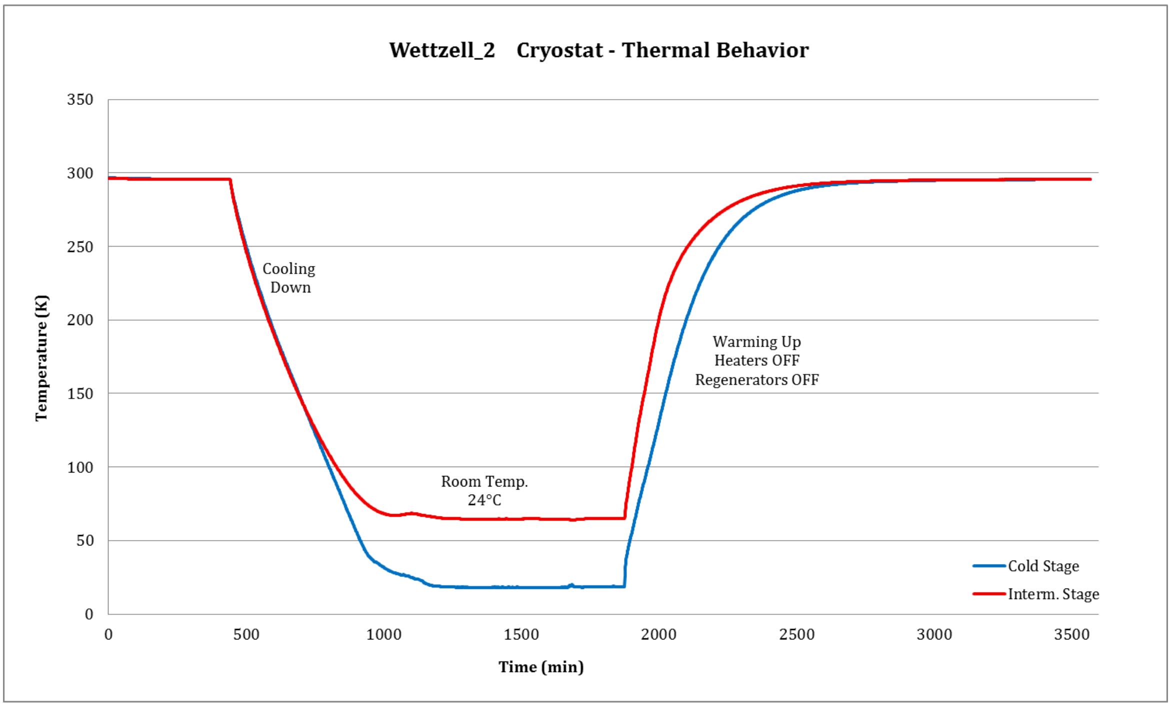


Figure 23. First vacuum and cooling test. Temperatures **19.5/65 K @ 24°C**.
Warming with resistors on.



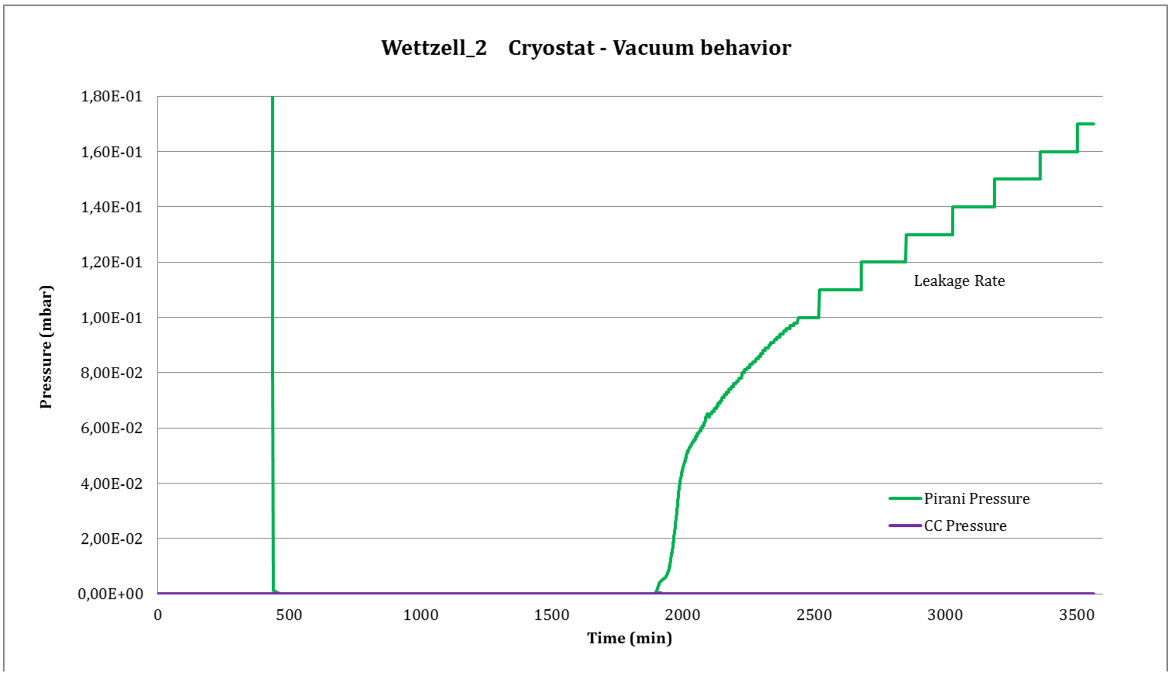


Figure 24. Second vacuum and cooling test. Warming with resistors off.
Leakage rate measured at room temperature.

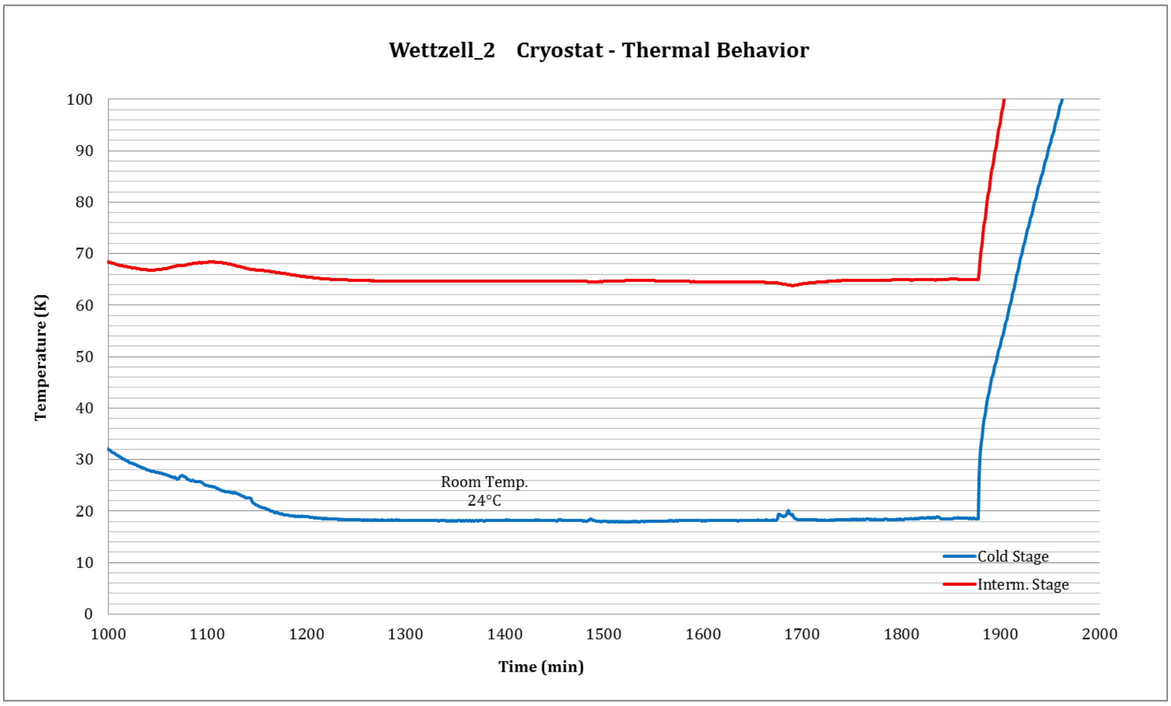


Figure 25. Second vacuum and cooling test. Temperatures **18.5/64.6 K @ 24°C**.

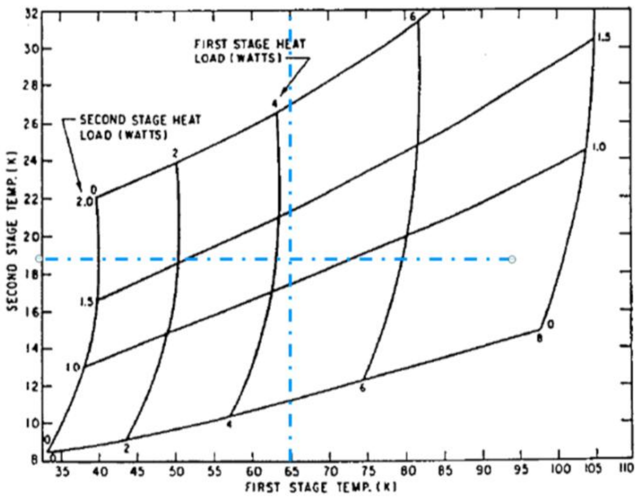


Figure 26. Estimated load at 24 °C room temperature. **Intermediate stage load ≈ 4.3 W, cold stage load ≈ 1.2 W.**

8. Receiver calibration: noise temperature, gain and coupling

The Y factor method has been used to calibrate the receiver (measure the noise temperature). The noise temperature measurement is carried out connecting the receiver input to different adapted loads with known temperatures.

When the load at the input has a temperature, T_H, the power at the output is P_H, hot load. If a second measure is done with a load with a different temperature, T_C, the power will be different, P_C, cold load. Then, the receiver noise temperature can be calculated by the following expressions:

$$T_{RX} = \frac{T_H - Y \cdot T_C}{Y - 1} \quad \text{where} \quad Y = \frac{P_H}{P_C}$$

This method is based on the hypothesis that the receiver behavior is linear between P_H and P_C.

The thermal loads used, for these measurements, are:

- Hot load: coaxial cable with SMA 50 Ω load at room temperature, ≈ 297 K.
- Cold load: coaxial cable with SMA 50 Ω load submerged in liquid nitrogen, ≈ 77 K.

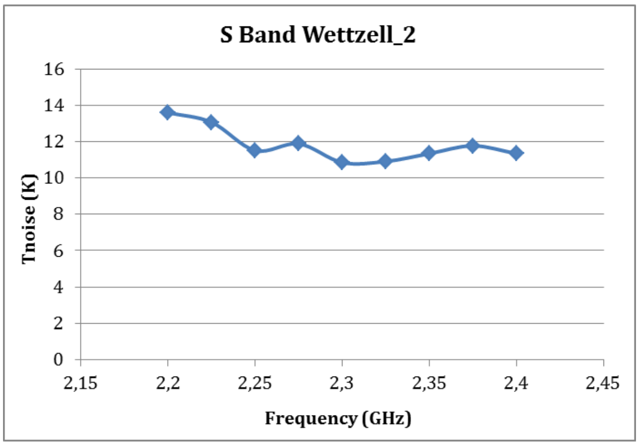
The following results show the receiver noise temperature without taking into account the losses due to the cables, SMA connectors, waveguide to coaxial transitions, couplers, etc.

Receiver Noise Temperature measured at cold temperature

S band Rx, T_{cold}~19.5 K	
T_H = 297 K	T_C = 77.3 K
Freq. (GHz)	**Noise Temp. (K)***
2.2	**13.59**
2.225	**13.06**
2.25	**11.51**
2.275	**11.88**
2.3	**10.85**
2.325	**10.91**
2.35	**11.34**
2.375	**11.77**
2.4	**11.34**
*T_{rx} affected by RFI	

X band Rx, T_{cold}~19.5 K	
T_H = 297 K	T_C = 77.3 K
Freq. (GHz)	**Noise Temp.(K)***
8	**9.02**
8.1	**10.08**
8.2	**11.7**
8.3	**13.41**
8.4	**10.94**
8.5	**9.92**
8.6	**11.27**
8.7	**15.52**
8.8	**17.17**
8.9	**12.98**
9	**12.35**
*T_{rx} affected by waveguide to coaxial transition placed outside, before the vacuum window.	

Table 7. T_{RX} at cold temperature (**LNAs at ≈ 19.5 K**).



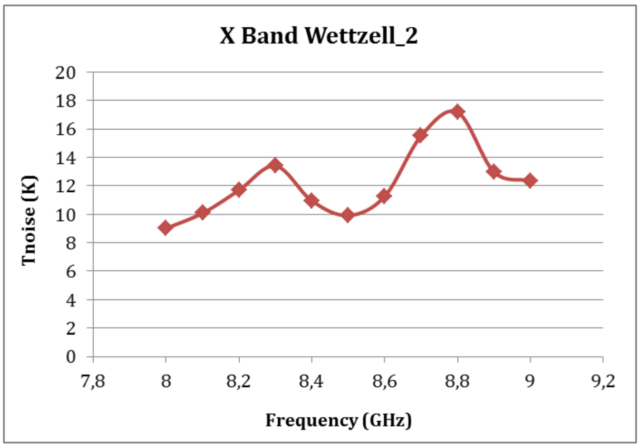


Figure 27. T_{RX} at cold temperature (**LNAs at ≈ 19.5 K**).

Receiver Gain and Coupling measured at cold temperature

S band		
Freq. (GHz)	**Gain (dB)**	**Coupling (dB)**
2	39.3	-29.7
2.1	40.5	-30.3
2.2	40.9	-29.9
2.3	40.2	-30.2
2.4	38.7	-29.5
2.5	36.2	-30.2

X band		
Freq. (GHz)	**Gain (dB)**	**Coupling (dB)**
8	38	-29.3
8.2	38	-28.9
8.4	38.1	-28.3
8.6	37.8	-28.6
8.8	37.7	-27.4
9	38	-27.7

Table 8. Gain and coupling at cold temperature (LNAs at ≈ 19.5 K).

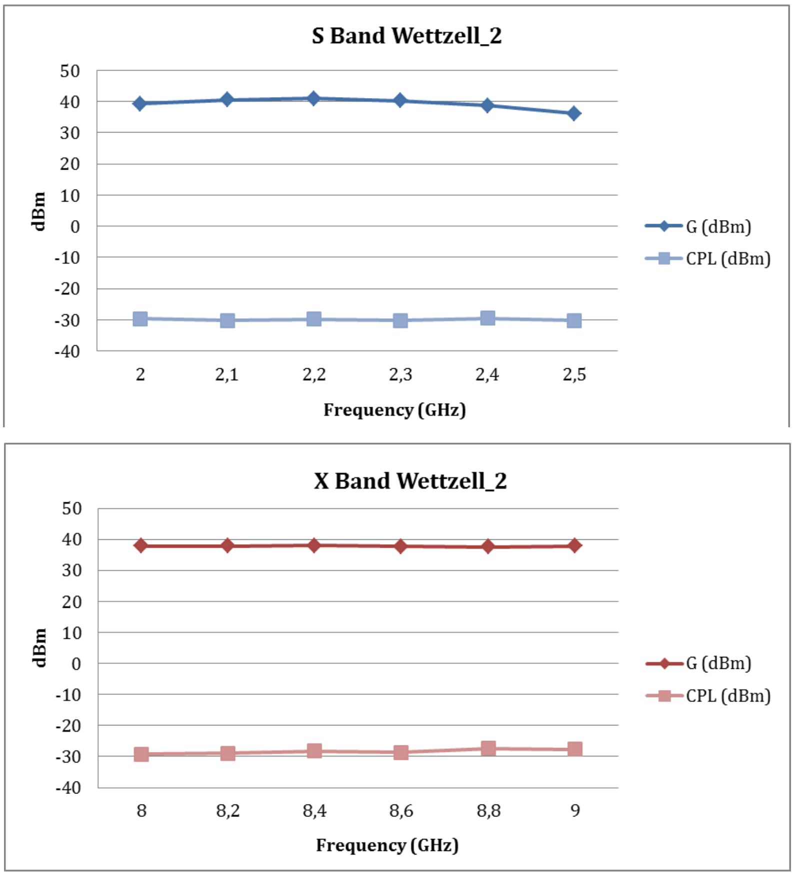


Figure 28. Gain and coupling at cold temperature (**LNAs at ≈ 19.5 K**).

Noise temperature and receiver gain measured at room temperature

The measurements at room temperature have been carried out with a signal analyzer Keysight (PXA Signal Analyzer N9030A, frequency range from 3 Hz to 50 GHz), to check the correct receiver performance before closing it.

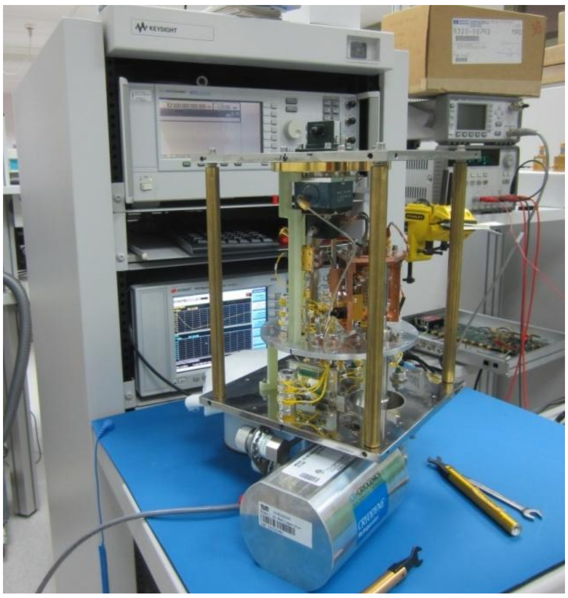


Figure 29. Wettzell_2 receiver measured at room temperature.

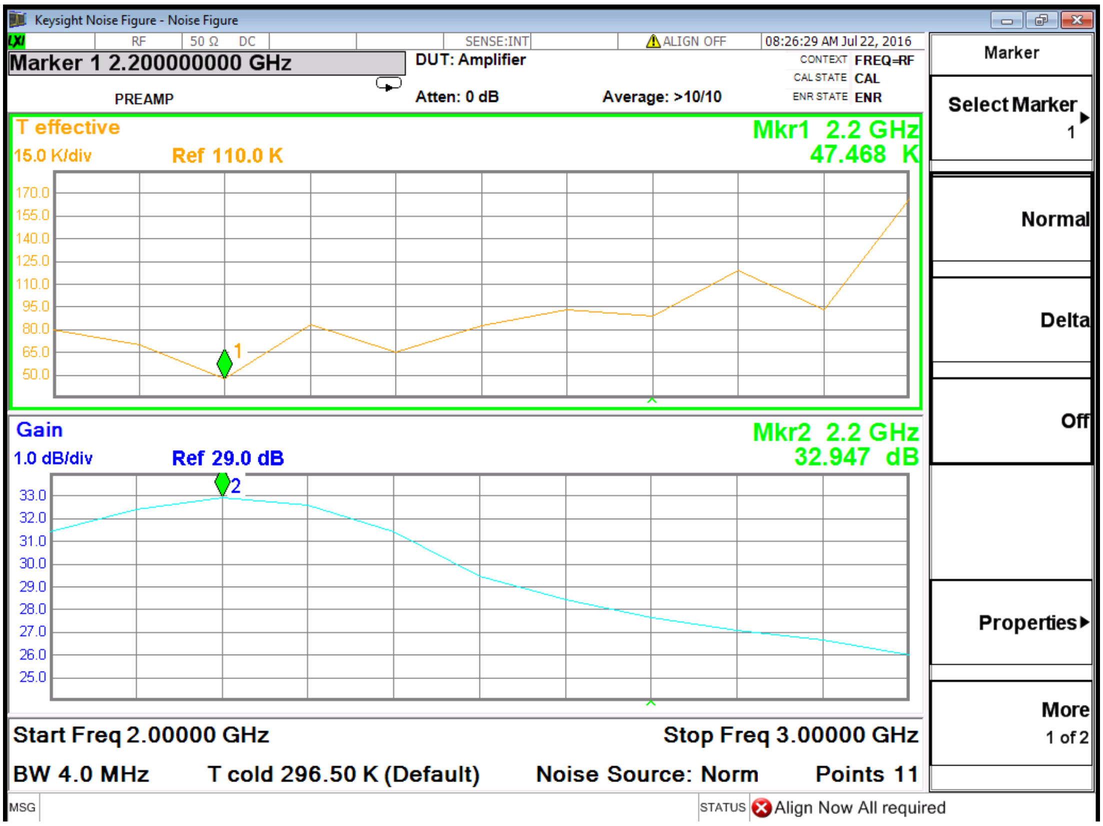


Figure 30. S band noise temperature and gain measured at room temperature.

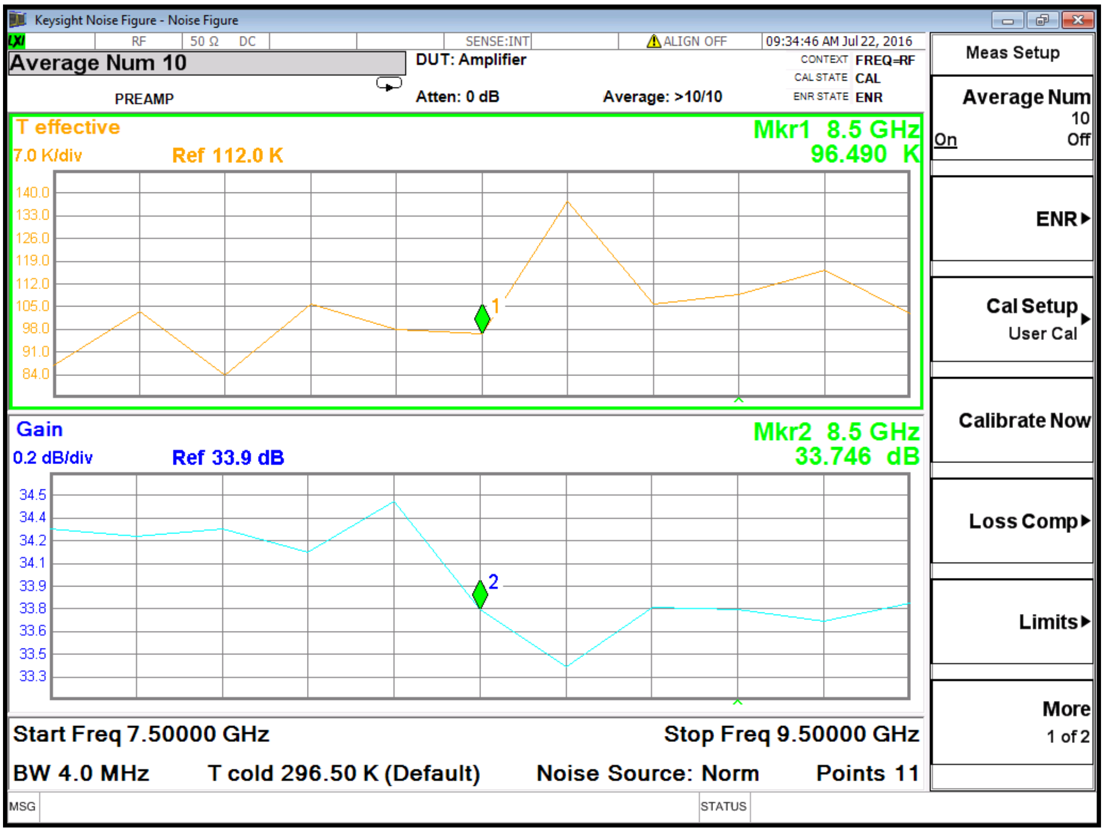


Figure 31. X band noise temperature and gain measured at room temperature.

9. Installation, first use and switch off

For receiver installation proceed as follows:

- Vacuum controller, temperature monitor system, LNA bias module and RF module must be switched off.

- **Pumping**
  - Connect housekeeping cable to the Fischer connector at cryostat rear side (Housekeeping).
  - Connect the vacuum controller to the vacuum sensor Quadmag.
  - Connect the vacuum valve to the corresponding vacuum flange (the valve must be closed).
  - Switch on the vacuum controller. The vacuum sensor will start the set up and a green led will light continuously when ready. The vacuum controller will show atmospheric pressure.
  - Switch on the temperature monitor (housekeeping cable has a (temporary) DB25 connector for a Lakeshore connector input). The temperature of the first 2 channels will be around room temperature.
  - Connect the vacuum system (rotary pump and turbomolecular) to the vacuum valve.
  - Start running the rotary pump for a few minutes.
  - Slowly, open the valve. The vacuum level will start to decrease. During this procedure avoid any abrupt opening of the valve. When the vacuum is about 10^{-1} mbar, start turbomolecular operation.
  - Connect the regeneration resistor banana connector to a power supply.
    - Black: GND
    - Yellow: +6 V, ≈ 117 mA (Wettzell_2 receiver)
  - Connect the heating resistor banana connector to a power supply.
    - Black: GND
    - Red: +25 V, ≈ 5 mA (Wettzell_2 receiver)
  - Leave the system running in the above conditions for 12 hours. Then, the resistors can be turned off. The vacuum system should be pumping at least for 12 more hours.

- **Connecting the helium compressor**

  Warning! Be sure the helium pipes and compressor pressure is correct (as indicated in the user's manual) and they are not contaminated.
  - Remove all dust plugs and caps from the helium supply and return lines, compressor and cold head. Check all fittings.
  - Connect the helium return line between the compressor and the cold head.
  - Connect the helium supply line between the compressor and the cold head.
  - Verify proper helium supply static pressure (245 psi for CTI 8200 compressor). If the indicated pressure is not the specified by the compressor manufacturer, follow the instructions supplied by the manufacturer.
  - Connect the cold head cable between the compressor and the cold head.

- **Connecting the LNAs biasing module**
  - Connect the LNAs biasing module to a power supply (+15 V, -15 V, GND). Power supply off.

- Plug the S and X bands LNAs biasing cables between the LNA Bias Module and the cryostat (Fischer connectors).
- The LNAs biasing points are already set up. In case a verification or change is needed, go to chapter 4.
- Turn on the power supply (verify correct electric current values).

- **First use**

After 24 hours pumping the system is ready to start the cooling down process.

Warning! Be sure your vacuum system can be used during cooling process. For carrying out this process, (usually) it is necessary to have a rotary and a turbomolecular pump. Just using a rotary pump, at low temperatures, can cause vacuum inversion. It is important to verify the turbomolecular pump behavior during the process.

- The pressure inside the receiver should be at $5 \cdot 10^{-3}$ mbar or lower.
- Switch on the compressor. The temperatures will start decreasing.
- The vacuum valve has to be opened until the intermediate stage reaches, at least, 120 K. If it is allowed by the pumping system, the valve can be opened until the system achieves the final temperatures.
- After 10-11 hours the cryostat will reach its operational cryogenic temperature and pressure.

Temperature radiation shield	< 70 K
Temperature cold stage	< 20 K
Pressure	< 10^{-5} mbar

- **Switch off**

For switching off the system proceed as follows:

- Be sure that the pumping valve is closed.
- Switch off the compressor.
- Switch off the LNAs biasing module.
- Leave the cryostat warming to room temperature. This can be verified at the temperature monitor. This process can be accelerated by turning on the heating resistors (+25 V) and the zeolites regeneration resistors (+6 V).
- Once the system is at room temperature, open slowly the vacuum valve to achieve atmospheric pressure inside the cryostat.

Warning! Be careful with the temperature values when using zeolites regeneration and heating resistors to warm the cryostat. Once the final room temperature is achieved, do not to open the dewar immediately. It is necessary to wait for a few minutes for the temperature system to be stabilized with the resistors turned off. If the dewar is opened too soon, water vapor can appear inside the cryostat and it could cause damages.

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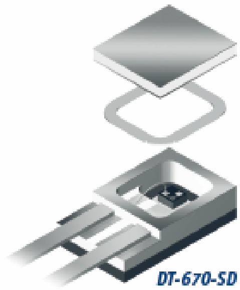
[14] Vaquero, B., Serna Puente, J. M., López Fernández, J. A., Almendros, C., Abad, J.A.. *Reparación cabeza refrigeradora: CTI 350*. Informe Técnico CDT 2013-2.

Appendix

Temperature sensors specifications

Silicon Diodes

DT-670 Silicon Diodes



DT-670-SD

DT-670-SD Features

- Best accuracy across the widest useful temperature range—1.4 K to 500 K—of any silicon diode in the industry
- Tightest tolerances for 30 K to 500 K applications of any silicon diode to date
- Rugged, reliable Lake Shore SD package designed to withstand repeated thermal cycling and minimize sensor self-heating
- Conformance to standard DT-670 temperature response curve
- Variety of packaging options

DT-670E-BR Features

- Temperature range: 1.4 K to 500 K
- Bare die sensors with the smallest size and fastest thermal response time of any silicon diode on the market today
- Non-magnetic sensor

DT-621-HR Features

- Temperature range: 1.4 K to 325 K*
- Non-magnetic package
- Exposed flat substrate for surface mounting

** Calibrated down to 1.4 K, uncalibrated (Curve DT-670) to 20 K*

CAUTION: These sensors are sensitive to electrostatic discharge (ESD). Use ESD precautionary procedures when handling, or making mechanical or electrical connections to these devices in order to avoid performance degradation or loss of functionality.

DT-670 Series Silicon Diodes offer better accuracy over a wider temperature range than any previously marketed silicon diodes. Conforming to the Curve DT-670 standard voltage versus temperature response curve, sensors within the DT-670 series are interchangeable, and for many applications do not require individual calibration. DT-670 sensors in the SD package are available in four tolerance bands – three for general cryogenic use across the 1.4 K to 500 K temperature range, and one that offers superior accuracy for applications from 30 K to room temperature. DT-670 sensors also come in a seventh tolerance band, Band E, which are available only as bare die. For applications requiring greater accuracy, DT-670-SD diodes are available with calibration across the full 1.4 K to 500 K temperature range.

The bare die sensor, the DT-670E, provides the smallest physical size and fastest thermal response time of any silicon diode on the market today. This is an important advantage for applications where size and thermal response time are critical, including focal plane arrays and high temperature superconducting filters for cellular communication.

PACKAGING OPTIONS BO, BR, CO, CU, CY, ET, LR, MT

The Lake Shore SD Package – The Most Rugged, Versatile Package in the Industry

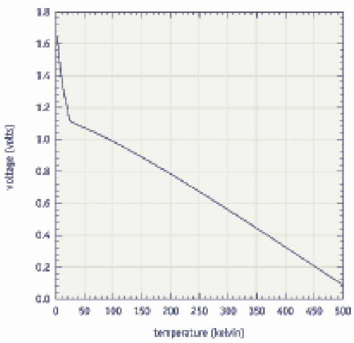
The SD package, with direct sensor-to-sapphire base mounting, hermetic seal, and brazed Kovar leads, provides the industry's most rugged, versatile sensors with the best sample to chip connection. Designed so heat coming down the leads bypasses the chip, it can survive several thousand hours at 500 K (depending on model) and is compatible with most ultra high vacuum applications. It can be indium soldered to samples without shift in sensor calibration. If desired, the SD package is also available without Kovar leads.

DT-621-HR Miniature Silicon Diode

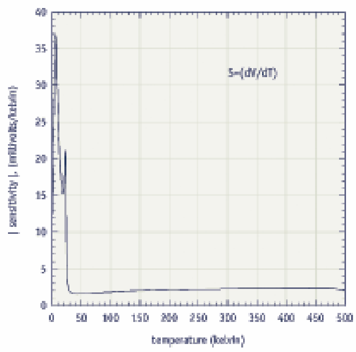
The DT-621 miniature silicon diode temperature sensor is configured for installation on flat surfaces. The DT-621 sensor package exhibits precise, monotonic temperature response over its useful range. The sensor chip is in direct contact with the epoxy dome, which causes increased voltage below 20 K and prevents full range Curve DT-670 conformity. For use below 20 K, calibration is required.

DT-621-HR

Typical DT-670 Diode Voltage Values



Typical DT-670 Diode Sensitivity Values



DC wiring

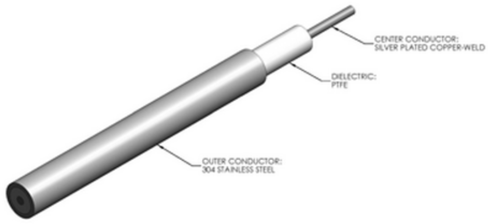
Small section wire Kynar 30 awg. specifications:

Color de la Funda	Amarillo
Corriente Nominal	0,4 A
Diámetro Externo	0.5mm
Filamentos del Núcleo	1 / 0,25 mm
Forma del Cable	Unipolar
Longitud	50m
Material Conductor	Cobre Chapado en Plata
Material de Aislamiento	Kynar
Máxima Temperatura de funcionamiento	+130°C
Número de Hilos	1
Tamaño de los Hilos	0,25 mm
Temperatura de Funcionamiento Mínima	-20°C
Tensión Nominal	300 V
Tipo	Cable envolvente Kynar
Área Transversal	0,05 mm²

RF Cables

UT-085B-SS

Stainless steel 50 ohm semi-rigid cables are designed for applications where low thermal heat transfer is required such as cryogenic feed cables. Because these cables also utilize a solid PTFE dielectric, they are often the first choice for highly corrosive environments.



DIMENSIONS

DIMENSIONS	UNITS	UT-085B-SS
Outer Conductor Diameter	In	0.0865 ± 0.0010
	mm	2.1971 ± 0.0254
Dielectric Diameter	In	0.066 ± 0.001
	mm	1.676 ± 0.025
Center Conductor Diameter	In	0.0201
	mm	0.5105
length (maximum)	Feet	20
	Meter	6.10

MATERIALS

Outer Conductor		304 SS
Outer Conductor Plating		None
Dielectric		PTFE
Center Conductor		SP BeCu
Rohs Compliant		YES

MECHANICAL CHARACTERISTICS

Outer Conductor Integrity Temp.	°C	225
Operating Temperature (Max)	°C	200
Inside Bend Radius (Minimum)	In	0.250
	mm	6.350
Weight	lbs / 100ft	1.31
	kg / 100m	1.97

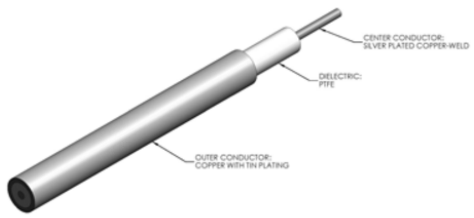
ELECTRICAL CHARACTERISTICS

Characteristic Impedance	ohm	50
Capacitance	pF / ft	29.0
	pF / m	95.2
Corona Extinction Voltage	VRMS @ 60 Hz	1800
Voltage Withstanding	VRMS @ 60 Hz	5400
Higher Order Mode Frequency	GHz	61.0
Attenuation (Db / 100 Ft Typical)	0.5 GHz	31.2
	1.0 GHz	44.4
	5.0 GHz	101.5
	10.0 GHz	146
	18.0 GHz	199.7
	26.5 GHz	246.2
	40.0 GHz	308.7
	50.0 GHz	349.5
	65.0 GHz	N/A
	90.0 GHz	N/A
Power (Watts Cw @ 20 °C, Maximum)	0.5 GHz	142.7
	1.0 GHz	100.5
	5.0 GHz	44.2
	10.0 GHz	30.9
	18.0 GHz	22.7
	26.5 GHz	18.5
	40.0 GHz	14.8
	50.0 GHz	13.1
	65.0 GHz	N/A
	90.0 GHz	N/A

Micro-coax semi-rigid cable UT-085B-SS.

UT-141A-TP

Standard copper 50 ohm semi-rigid cables feature low attenuation and VSWR covering the entire microwave spectrum. With numerous connector options available off-the-shelf, this family of cables is one of the most versatile available today. They meet the demands of package density and provide total shielding for eleimination of signal loss and noise.



DIMENSIONS

DIMENSIONS	UNITS	UT-141A-TP
Outer Conductor Diameter	In	0.141 +0.002/-0.001
	mm	3.581 +0.051/-0.025
Center Conductor Diameter	In	0.0362
	mm	0.9195
length (maximum)	Feet	20
	Meter	6.10

MATERIALS

Outer Conductor		Copper
Outer Conductor Plating		Tin
Dielectric		PTFE
Center Conductor		SPCW
Rohs Compliant		YES

MECHANICAL CHARACTERISTICS*

Outer Conductor Integrity Temp.	°C	175
Operating Temperature (Max)	°C	125
Inside Bend Radius (Minimum)	In	0.075
	mm	1.905
Weight	lbs / 100ft	3.29
	kg / 100m	4.94

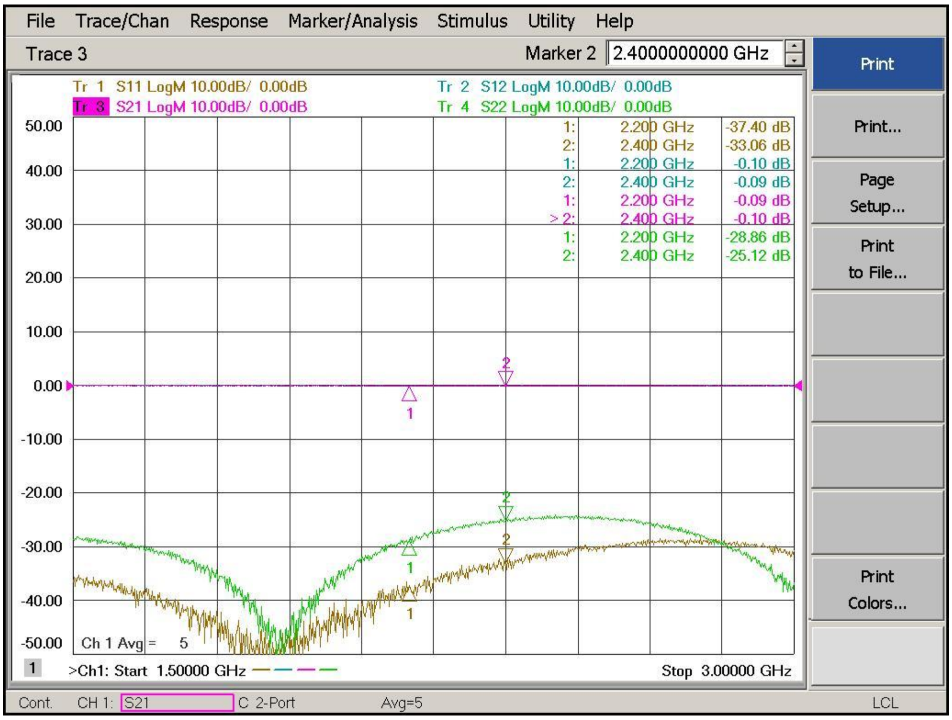
ELECTRICAL CHARACTERISTICS*

Characteristic Impedance	ohm	50
Capacitance	pF / ft	29.0
	pF / m	95.2
Corona Extinction Voltage	VRMS @ 60 Hz	1900
Voltage Withstanding	VRMS @ 60 Hz	9600
Higher Order Mode Frequency	GHz	34.0
Attenuation (Db / 100 Ft Typical)	0.5 GHz	7.6
	1.0 GHz	11.3
	5.0 GHz	27.6
	10.0 GHz	41.6
	18.0 GHz	59.6
	26.5 GHz	76.2
	40.0 GHz	N/A
	50.0 GHz	N/A
	65.0 GHz	N/A
	90.0 GHz	N/A
Power (Watts Cw @ 20 °C, Maximum)	0.5 GHz	483.5
	1.0 GHz	336.2
	5.0 GHz	140.4
	10.0 GHz	94.6
	18.0 GHz	66.8
	26.5 GHz	52.7
	40.0 GHz	N/A
	50.0 GHz	N/A
	65.0 GHz	N/A
	90.0 GHz	N/A

Micro-coax semi-rigid cable UT-141A-TP.

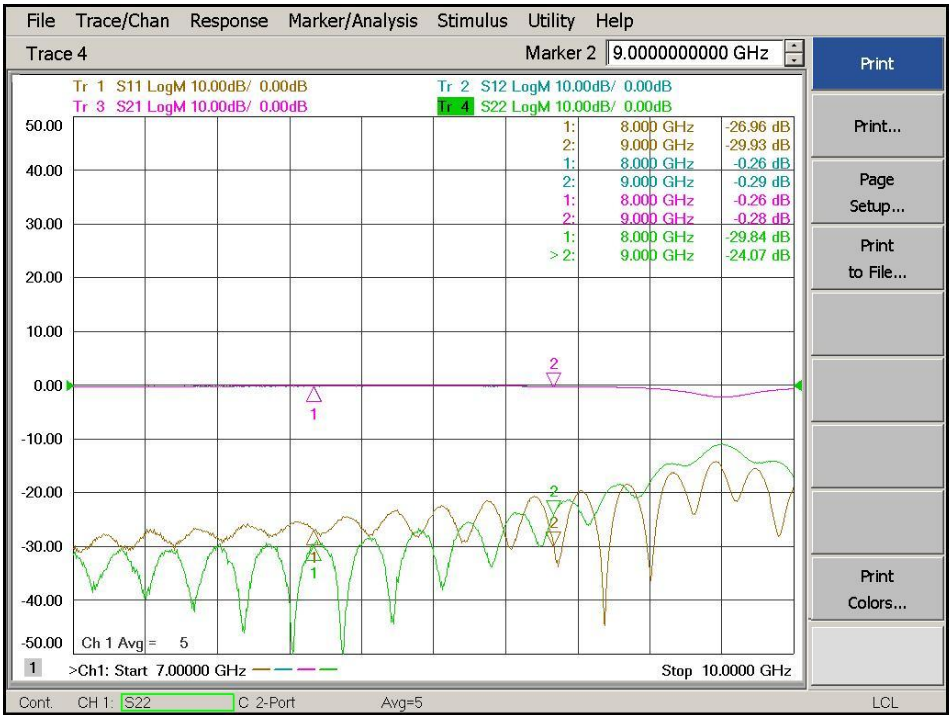
RF Measurements

Air line measurements



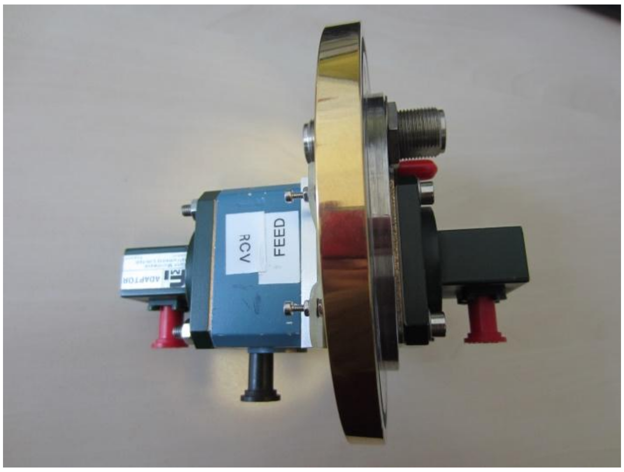
Air line S parameters (input for the S band).

DC block measurements

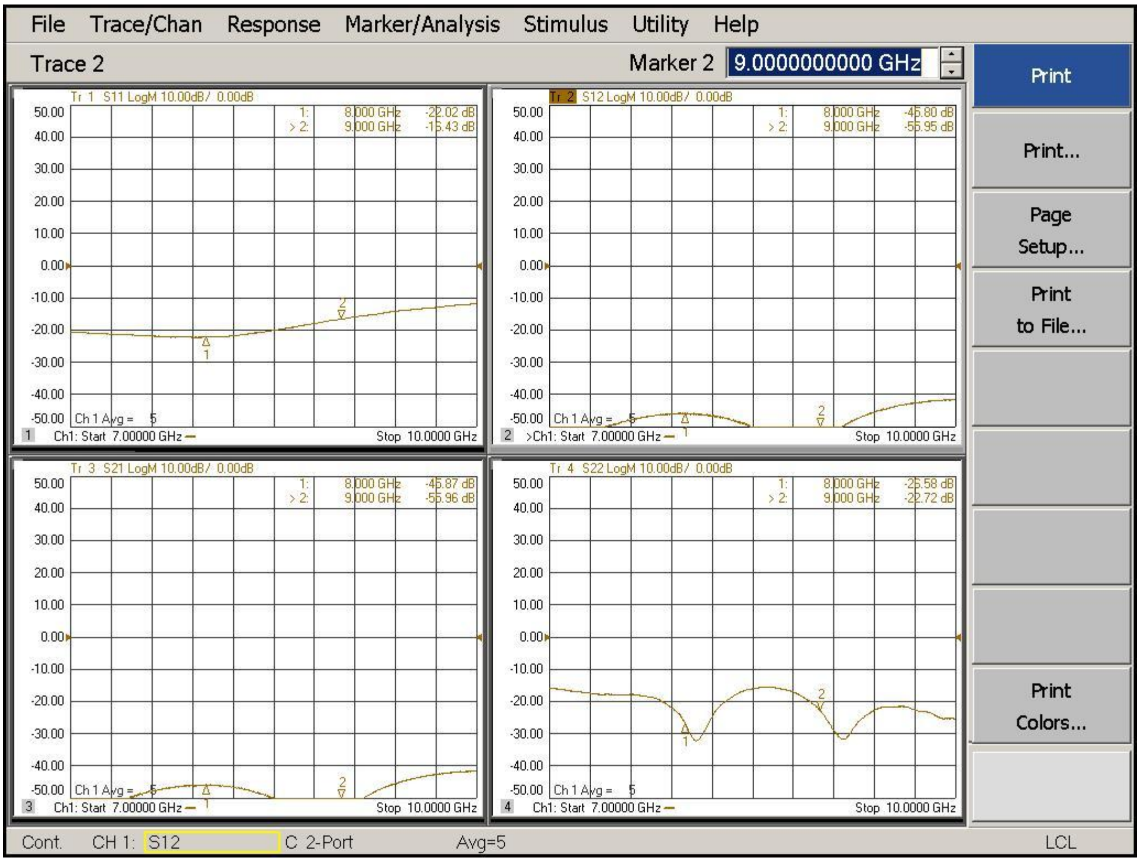


DC block S parameters (placed at the X LNA output).

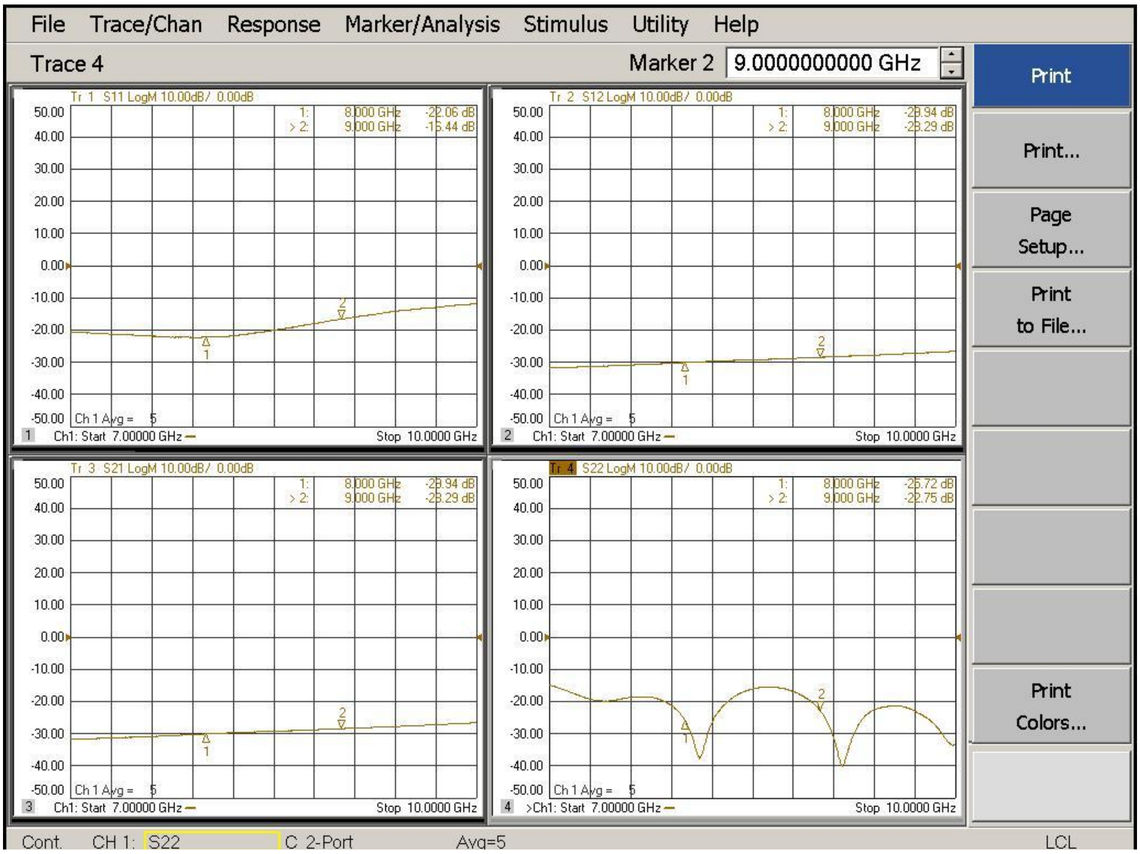
Waveguide to coaxial transition + coupler measurements



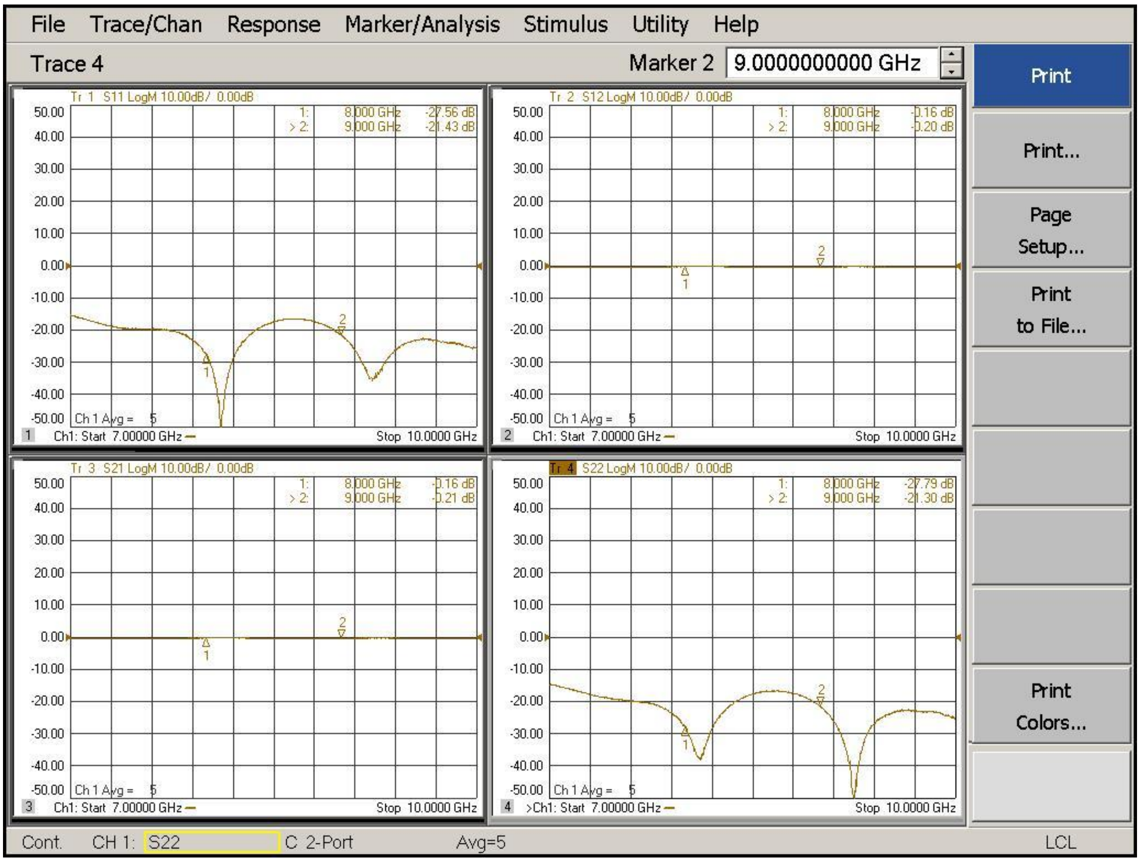
Waveguide to coaxial transition + directional coupler assembly (located inside the cryostat and attached to the cold stage using copper meshes). There is a 0.4 mm gap between the golden piece and coupler. The outer transition has been used for tests and measurements.



Transition measurements. Input through the coupled port.

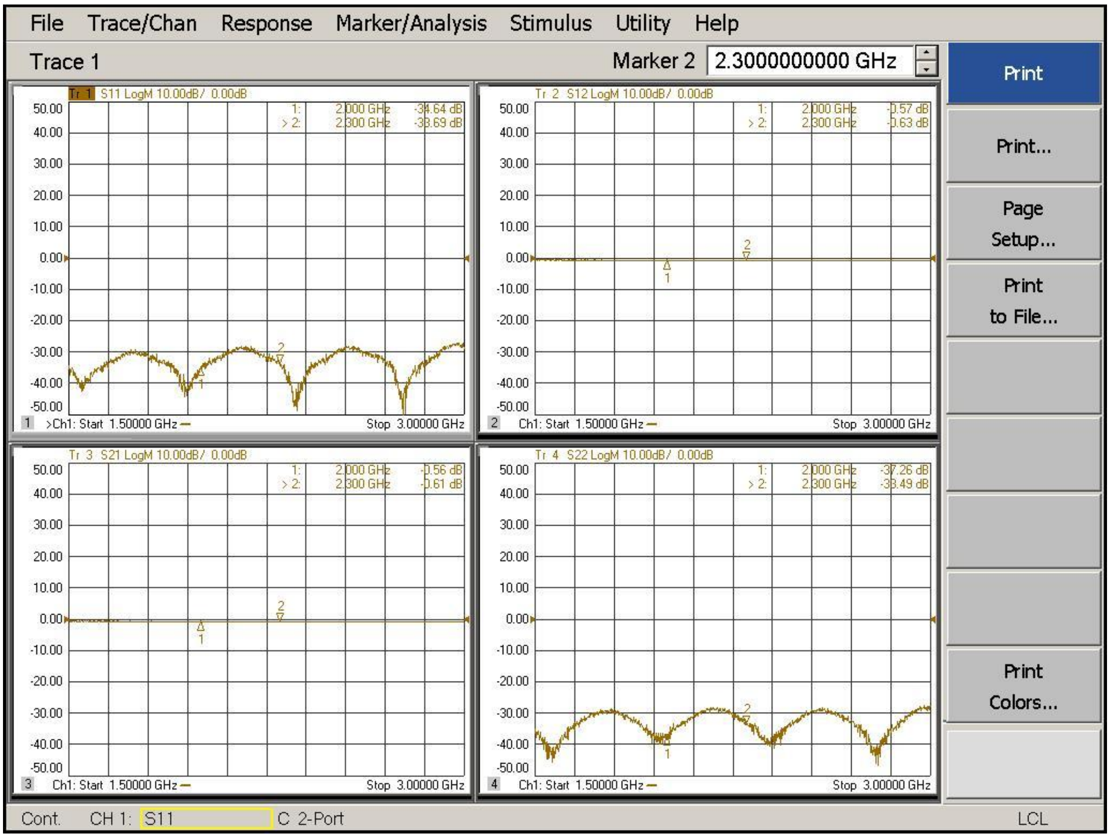


Transition measurements. Output through the coupled port.

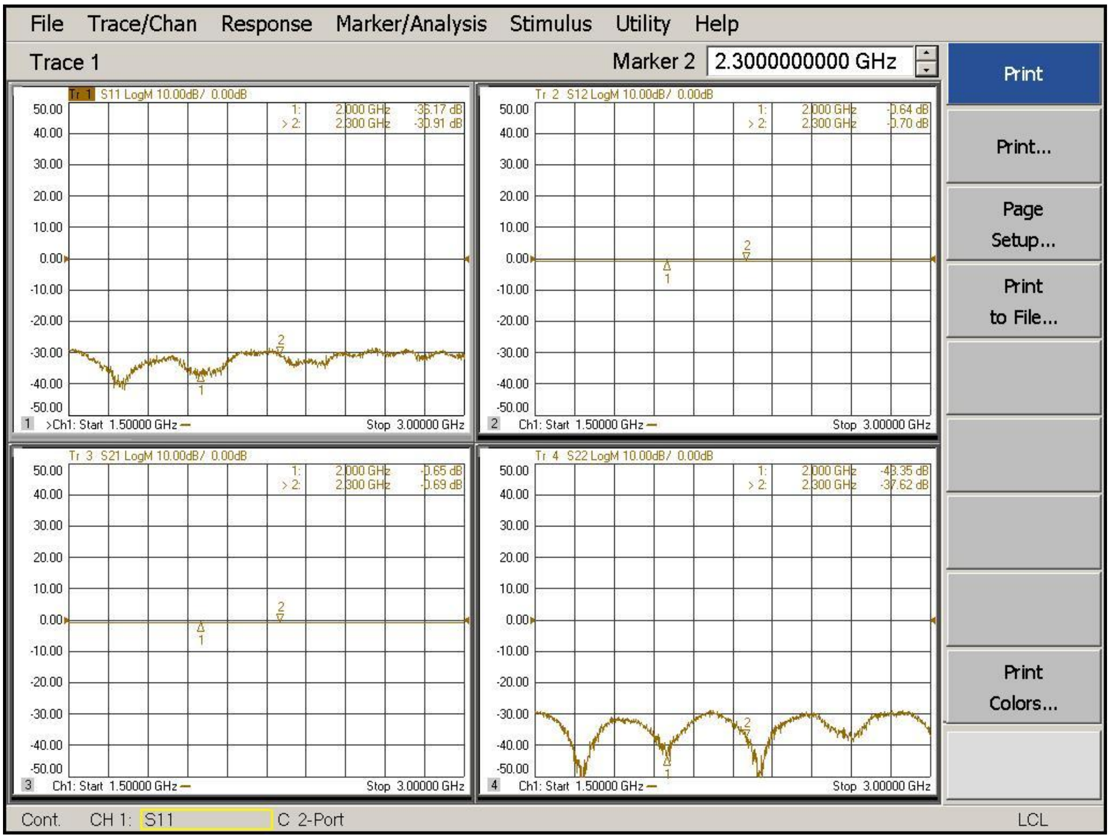


Transition measurements. Input and output.

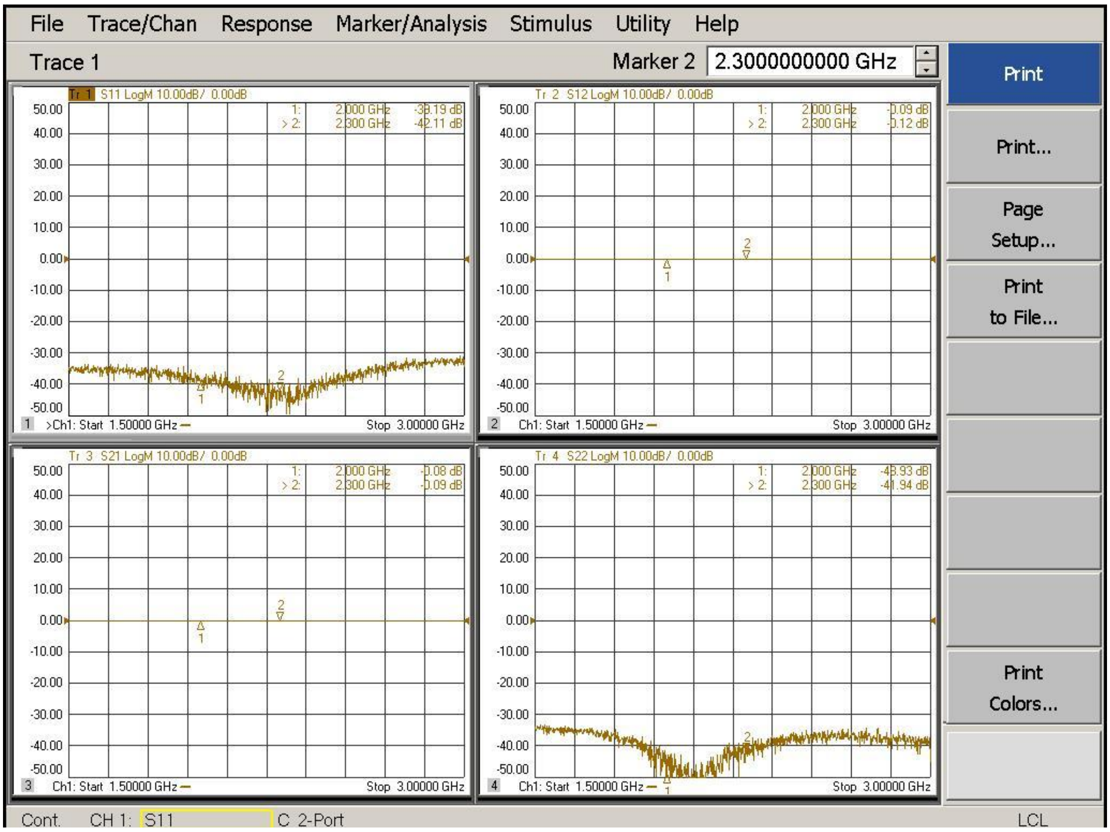
RF cables measurements



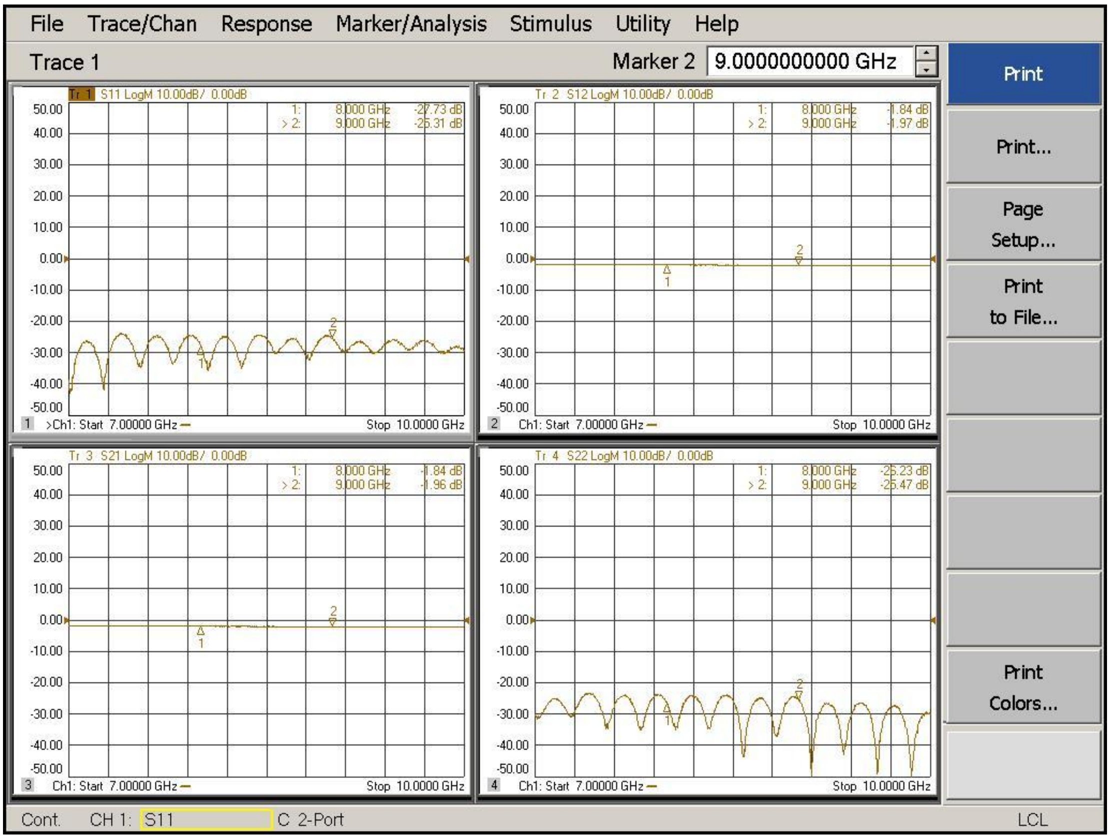
S band calibration signal input S, UT-85B-SS.



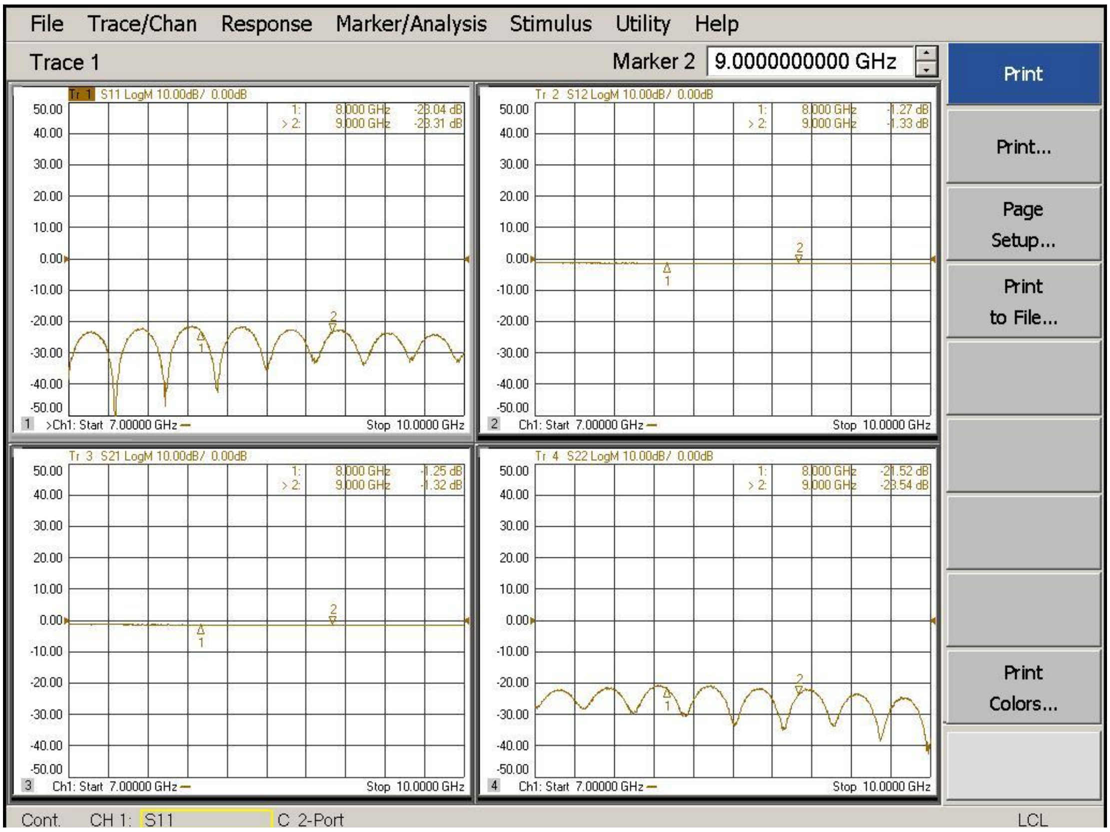
S band output, UT-85B-SS.



Cable from the air line to the S band LNA, UT-141A-TP.



X band calibration input, UT-85B-SS.



X band output, UT-85B-SS.