CRYOGENIC
AMPLIFIER REPORT

MMIC 32-38 GHz LNAs
MQ 2001 & MQ 2002

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INDEX OF DOCUMENTS

32-38 GHz IAF MMIC LNA REPORT

1. Introduction

LNA MQ 2001 and MQ 2002 are Q band prototype low noise cryogenic amplifier designed to test a specific type of MMICs from the *Fraunhofer Institut für Angewandte Festkörperphysik* (IAF). These MMICs were designed by Beatriz Aja, from the University of Cantabria at IAF, Freiburg, supported by *Instituto Geográfico Nacional*, *Observatorio de Yebes*.

The chassis supporting the MMIC and the external circuitry of the amplifier is a general design devised to test different types of MMICs. The MMIC is fabricated with IAF's metamorphic GaAs 100 nm technology (R740). It is an early prototype of one of several parallel approaches being carried out at CAY towards a low noise cryogenic amplifier in the 31 to 50 GHz band. The band of interest for the present application is 32-38 GHz.

This document includes a description of the amplifier and how to operate it, details about the tests performed, the measurements techniques utilized and plots with the relevant data collected (an index is provided thereafter).

2. Description and operating conditions of the amplifier

- Figure 1 shows an outside view of the amplifiers. RF input and output connectors are 2.4 mm connectors (input is on the left and output on the right). DC connector is a 9 pin microminiature D-type ITT-Cannon. The pinout is provided in figure 2.
- The external dimensions and mechanical interfaces of the amplifier are shown in figure 4. As shown in this figure, all the wholes on the top and bottom side of the chassis are metric M2. The bottom side holes can be used to attach the amplifiers to a cold plate.
- The unit should be biased by a **servo controlled power supply** (NRAO style) capable of setting the necessary gate voltage for any given drain current.
- The units have four stages of IAF metamorphic GaAs 0.1×60 µm transistors **(stages 3 and 4 are biased together in the MMIC)**. These devices are **ESD sensitive**; cautions must be taken during its manipulation and operation. The bias circuits built in the amplifier include a 10 nF capacitor which acts as a charge divider to prevent damage to the transistors. A ~1:10 voltage divider is also implemented at the gates input lines to improve EMC and protect against ESD: high operating values of the gate voltages are normal. A schematic of these circuits is shown in figure 3.
- One bias condition has been selected for the amplifier, which optimizes the device for noise and gain.

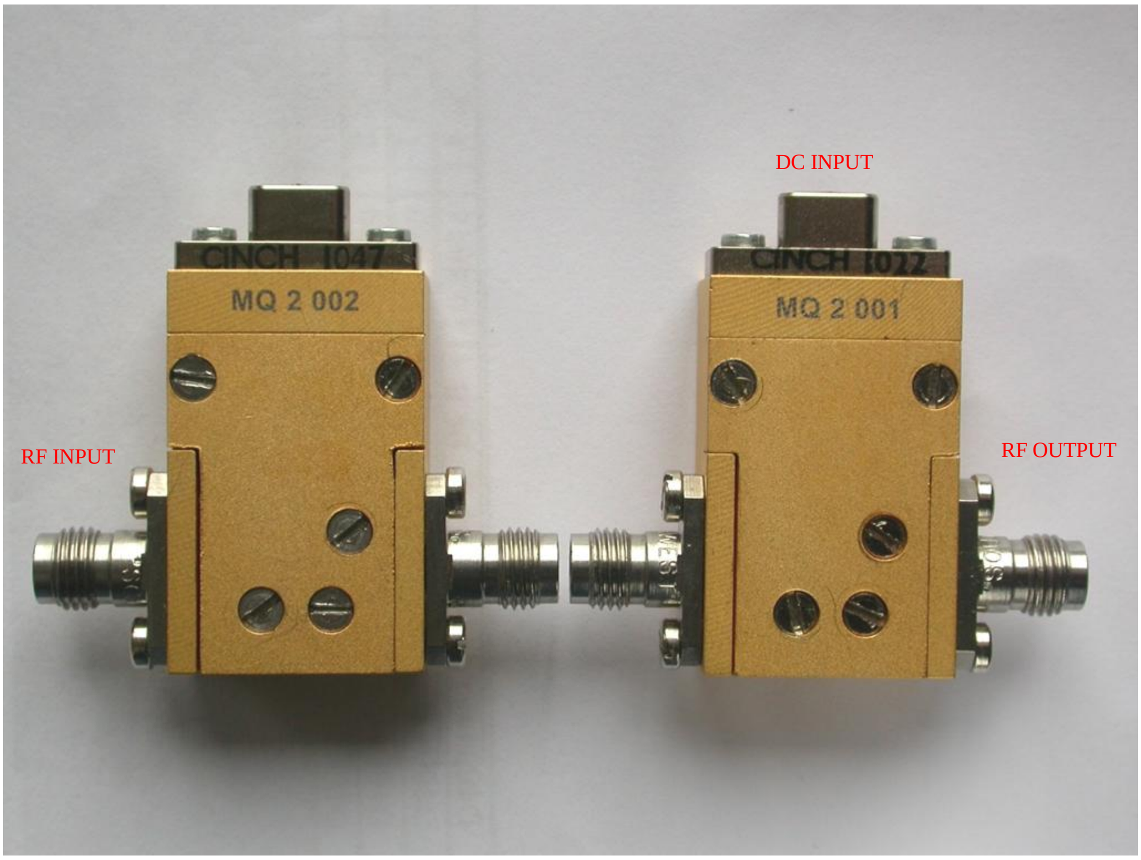

Figure 1: *Amplifiers external view. Box dimensions are 20.6×32.5×12 mm (excluding connectors).This unit has an aluminum chassis. Total weight is 52 g.*

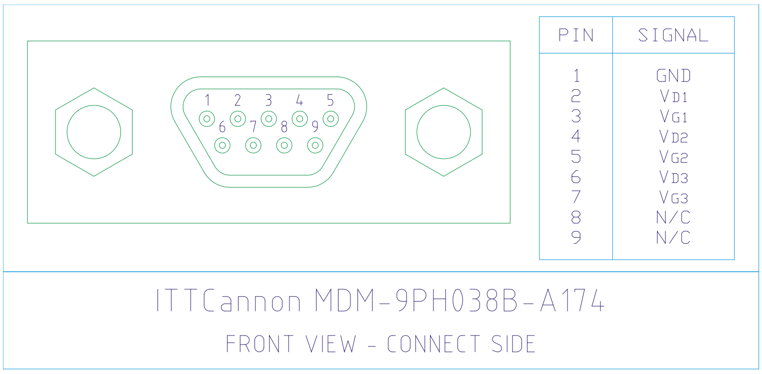

Figure 2: *DC Connector pinout*

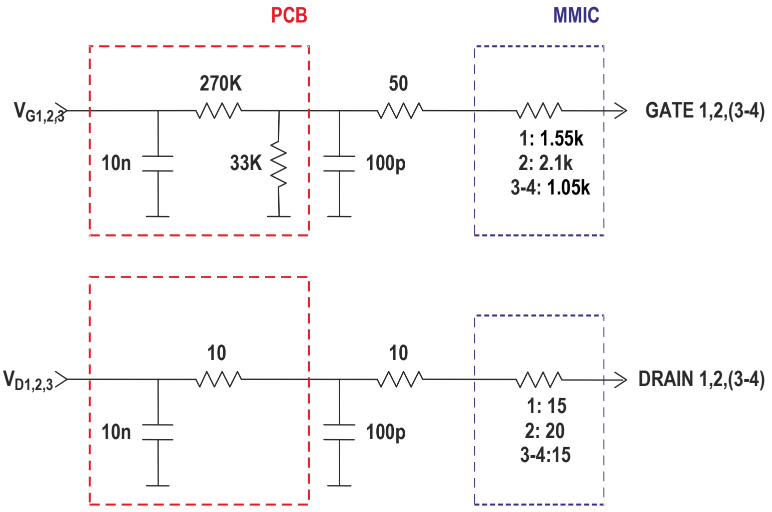

Figure 3: *Schematic of the bias circuits. The components on the PCB (inside the red boxes) and the chassis are identical for all stages. Resistance values in the MMIC (inside the blue boxes) are marked 1:, 2: and (3-4): after each stage number. MMIC capacitors are not shown.*

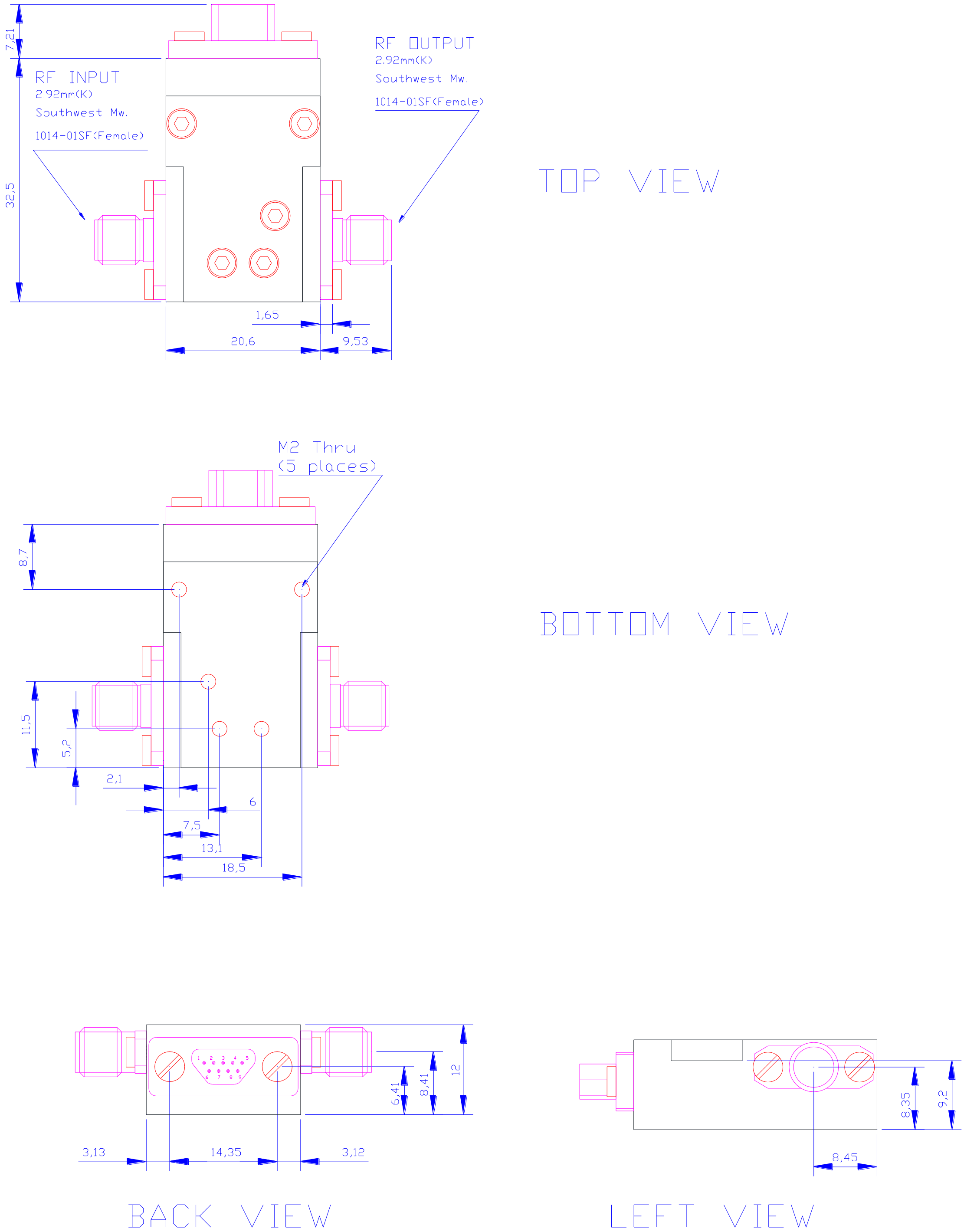

Figure 4: *LNAs external dimensions*.

3. Measurements

3.1 Description

Noise temperature (and gain) was measured with a system based on a computer controlled HP 8970 B Noise Figure Meter, using an external mixer (Marki). Room temperature data were obtained with an Agilent 346CK01 noise source followed by a 10 dB attenuator. The DUT is cooled in a Dewar with a CTI 1020 refrigerator. Cryogenic measurements were taken with the “cold attenuator” method, using the same Agilent 346CK01 noise source plus a special 15 dB quartz attenuator cooled at cryogenic temperature. The attenuator design allows an efficient cooling of the resistive elements and an accurate reading of its temperature by a Lakeshore sensor diode, minimizing the effect of the stray heating produced by the inner conductor of the input coaxial cable. An absolute accuracy (@ 3σ) of ~3 K and 0.9 dB at T_{amb}=14 K for an amplifier of 25 dB of gain and 20 K of noise can be estimated with methods presented in [1]. Repeatability is better than these values by an order of magnitude.

S parameters were measured in the same Dewar, using an HP 8510 C Vector Network Analyzer. The effect of the hermetic transitions and stainless steel access lines is de-embedded in real time using custom software. The change with temperature of the cryogenic cable at the DUT output is also taken into account in the de-embedding. The small variations of the transitions upon cooling are corrected by using time domain gating.

Simultaneously, the amplifier was checked for signs of possible out of band instability. Rollet constant was greater than 1 at all frequencies. The amplifiers were also tested with a spectrum analyzer Agilent 9565 EC (0-50 GHz) and wide band detector from a HP 8757 A Scalar Network Analyzer in DC (non-modulated) mode, sensitive to higher frequency oscillations. Stability tests were carried out with a wide range of bias settings, and oscillations were not detected.

3.2 Index of plots

We provide plots of the vector network analyzer measurements and noise figure meter measurements at ambient and cryogenic temperatures, for the optimum bias points. A picture of each amplifier is provided for reference purposes.

1. Summary of performance, characteristics and bias
2. Noise and gain measurements
    a. Noise temperature & gain at room temperature
    b. Noise temperature & gain at cryogenic temperature
3. Return loss measurements
    a. Input & output reflection loss at room temperature
    b. Input & output reflection loss at cryogenic temperature

References

[1] J. D. Gallego, J. L. Cano, "*Estimation of Uncertainty in Noise Measurements Using Monte Carlo Analysis*", 1st Radionet Engineering Forum Workshop, 23-24/06/2009, Gothenburg (available at http://www.radionet-eu.org/fp7wiki/lib/exe/fetch.php?media=na:engineering:ew:gallego_final.pdf)

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CRYOGENIC LNA DATA SHEET

DATE: 15/02/17

BAND:	32-38 GHz	S/N:	MQ 2001
MMIC: IAF	Run: 740a	Wafer: 11	Cell: 30

ROOM TEMPERATURE DATA T = 288.2

NOMINAL BIAS			
	V_{d1} = 1.1	I_{d1} = 14.0	V_{g1} = 0.62
	V_{d2} = 1.1	I_{d2} = 14.0	V_{g2} = 1.1
	$V_{d3,4}$ = 1.5	I_{d3} = 28.0	V_{g3} = 1.28

COAXIAL MEASUREMENTS	31.0-50.0	**32-38**	33.5-34.5
FREQUENCY BAND:	31.0-50.0	**32-38**	33.5-34.5
AVERAGE NOISE TEMP:	191.3	**176.7**	178.2
AVERAGE GAIN:	26.9	**28.9**	28.9
MIN. INPUT RETURN LOSS:	-8.9	**-13.3**	-13.5
MIN. OUTPUT RETURN LOSS:	-8.8	**-10.4**	-12.5

CRYOGENIC TEMPERATURE DATA T = 14.6

NOMINAL BIAS			
	V_{d1} = 0.60	I_{d1} = 3.0	V_{g1} = 0.24
	V_{d2} = 0.60	I_{d2} = 3.0	V_{g2} = 0.61
(P_{diss} = 11.6 mW)	V_{d3} = 1.00	I_{d2} = 8.0	V_{g2} = 0.50

COAXIAL MEASUREMENTS			
FREQUENCY BAND:	31.0-50.0	**32-38**	33.5-34.5
AVERAGE NOISE TEMP:	19.9	**17.1**	17.0
MIN./MAX. NOISE TEMP:	15.7/27.8	**15.7/19.2**	16.7/17.3
AVERAGE GAIN:	27.5	**28.9**	28.9
GAIN FLATNESS:	4.7	**0.9**	0.2
MIN. INPUT RETURN LOSS:	-6.3	**-12.5**	-13.3
MIN. OUTPUT RETURN LOSS:	-9.4	**-12.1**	-18.5

REMARKS:
Gain data from VNA measurements
Coaxial noise measurements according to cold att. method

V_d in Volts, I_d in mA, Noise temperature in K, Gain and Return loss in dB, Frequency band in GHz

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CRYOGENIC LNA DATA SHEET

DATE: 15/02/17

BAND:	32-38 GHz		S/N:	**MQ 2002**	
MMIC:	IAF	Run: 740a	Wafer: 11	Cell: 23	

ROOM TEMPERATURE DATA T = 288.2

NOMINAL BIAS	V_{d1} = 1.1	I_{d1} = 14.0	V_{g1} = 0.95
	V_{d2} = 1.1	I_{d2} = 14.0	V_{g2} = 0.60
	$V_{d3,4}$ = 1.5	I_{d3} = 28.0	V_{g3} = 1.22

	FREQUENCY BAND:	31.0-50.0	**32-38**	33.5-34.5
COAXIAL MEASUREMENTS	AVERAGE NOISE TEMP:	176.7	**172.9**	181.1
	AVERAGE GAIN:	26.6	**28.7**	28.8
	MIN. INPUT RETURN LOSS:	-8.6	**-10.7**	-10.7
	MIN. OUTPUT RETURN LOSS:	-9.0	**-10.1**	-13.4

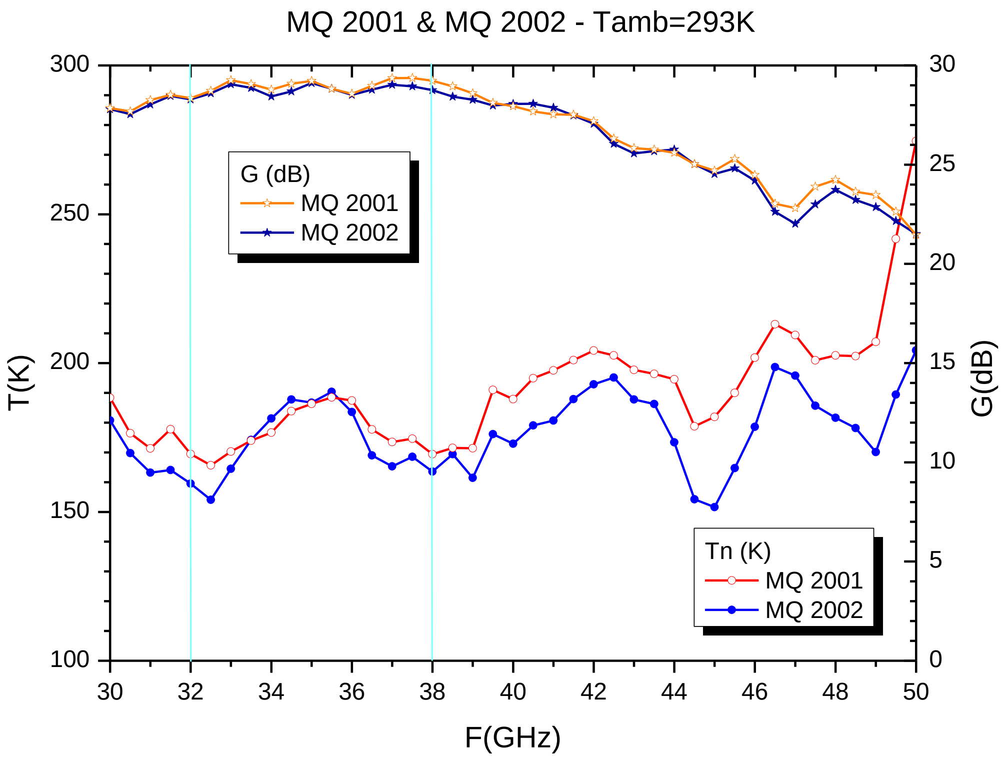
CRYOGENIC TEMPERATURE DATA T = 14.6

NOMINAL BIAS	V_{d1} = 0.60	I_{d1} = 3.0	V_{g1} = 0.56
	V_{d2} = 0.60	I_{d2} = 3.0	V_{g2} = 0.19
(P_{diss} = 11.6 mW)	V_{d3} = 1.00	I_{d2} = 8.0	V_{g2} = 0.33

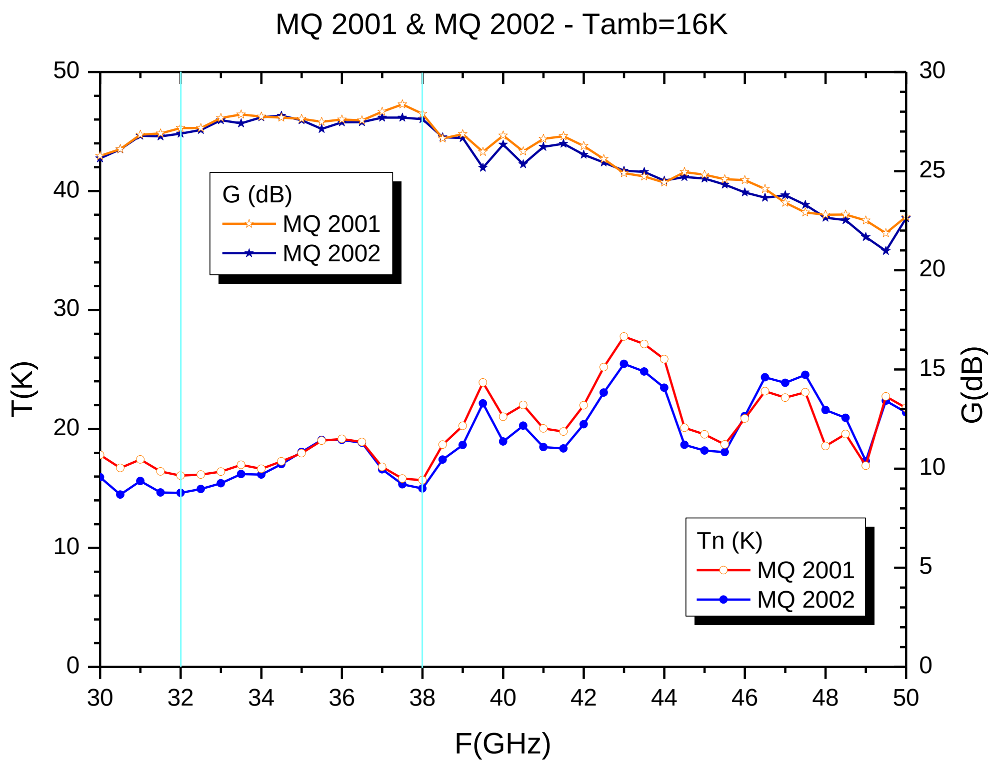
	FREQUENCY BAND:	31.0-50.0	**32-38**	33.5-34.5
COAXIAL MEASUREMENTS	AVERAGE NOISE TEMP:	19.2	**16.6**	16.5
	MIN./MAX. NOISE TEMP:	14.6/25.5	**14.6/19.1**	16.2/17.0
	AVERAGE GAIN:	27.3	**28.5**	28.5
	GAIN FLATNESS:	4.6	**0.9**	0.2
	MIN. INPUT RETURN LOSS:	-6.3	**-11.3**	-11.5
	MIN. OUTPUT RETURN LOSS:	-9.0	**-12.4**	-17.6

REMARKS: Gain data from VNA measurements
Coaxial noise measurements according to cold att. method

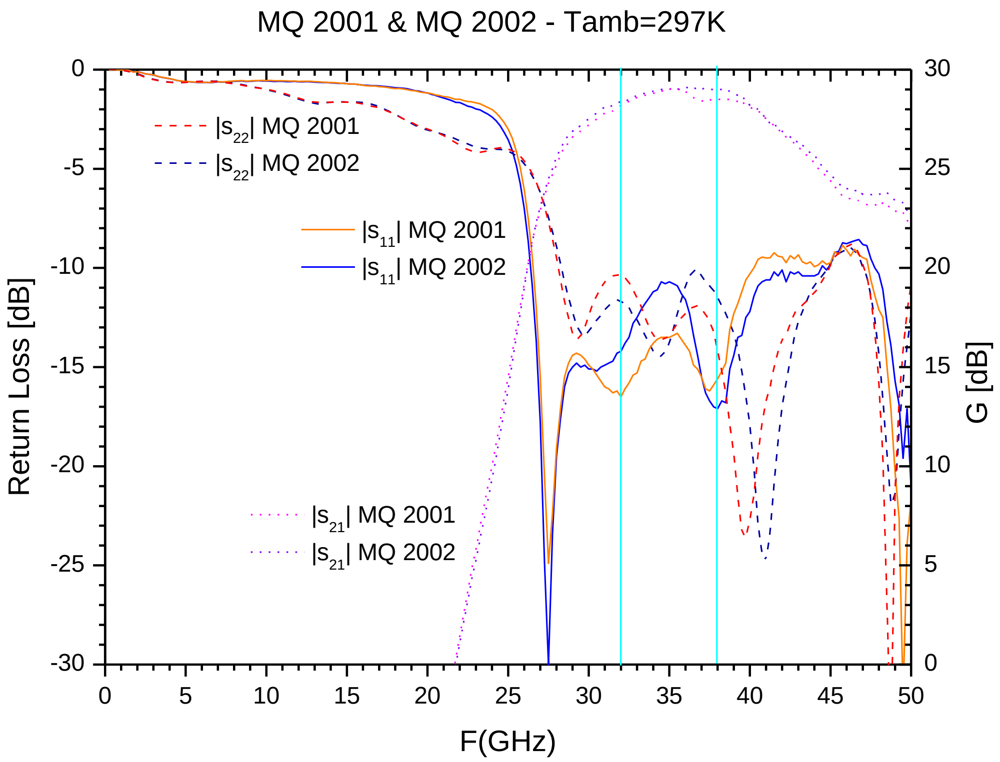
V_d in Volts, I_d in mA, Noise temperature in K, Gain and Return loss in dB, Frequency band in GHz

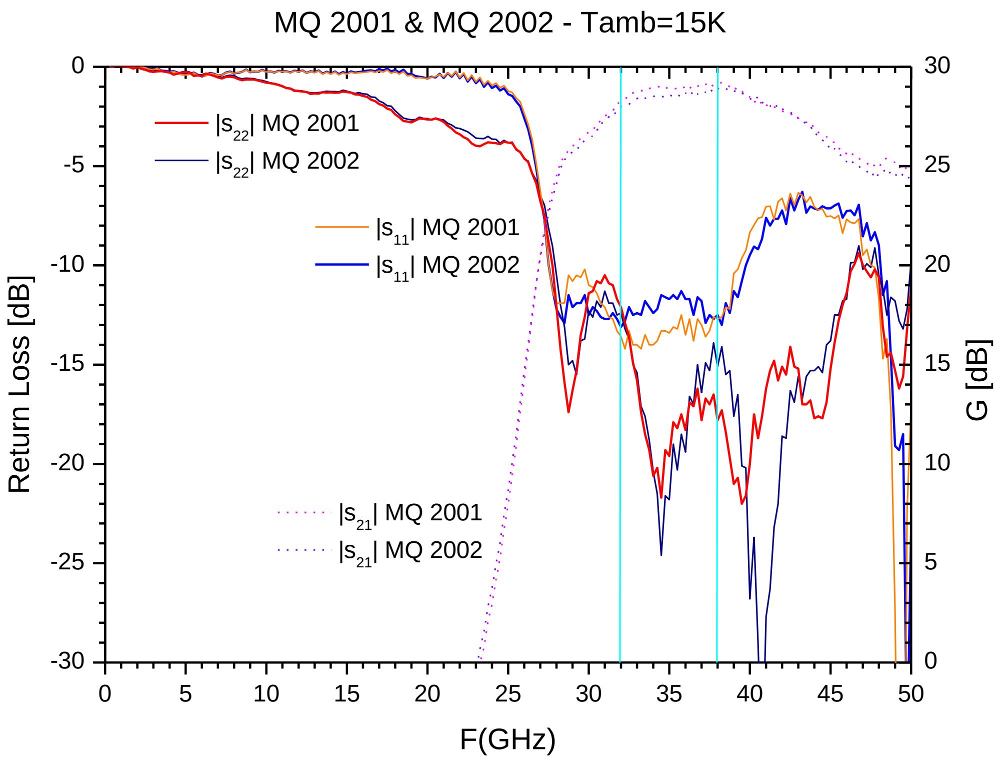


MQ 2001 & MQ 2002 - Tamb=293K
G (dB)
MQ 2001
MQ 2002
Tn (K)
MQ 2001
MQ 2002
T(K)
G(dB)
F(GHz)



MQ 2001 & MQ 2002 - Tamb=16K
G (dB)
MQ 2001
MQ 2002
Tn (K)
MQ 2001
MQ 2002
T(K)
G(dB)
F(GHz)


MQ 2001 & MQ 2002 - Tamb=297K
Return Loss [dB]
G [dB]
F(GHz)
|s22| MQ 2001
|s22| MQ 2002
|s11| MQ 2001
|s11| MQ 2002
|s21| MQ 2001
|s21| MQ 2002


MQ 2001 & MQ 2002 - Tamb=15K
Return Loss [dB]
G [dB]
F(GHz)
|s22| MQ 2001
|s22| MQ 2002
|s11| MQ 2001
|s11| MQ 2002
|s21| MQ 2001
|s21| MQ 2002

ESD AND POWER SUPPLY LEAKAGE PROTECTION OF CRYOGENIC HEMT AMPLIFIERS

Introduction

Cryogenic amplifiers made with InP HEMTs or GaAs metamorphic HEMTs have been found very sensitive to ESD (electrostatic discharges) and leakage from the power supplies. The handling of these devices requires especial precautions beyond the normal care taken with cryogenic amplifiers made with commercial GaAs HEMTs. Especial procedures should be followed during assembly of the amplifiers as well as during tests and operation to avoid permanent damage to the devices. The most common mode of failure is the total or partial destruction of the gate of the transistors. Partially damaged devices may loose one or more gate fingers and show poor or no pinch off, even if the gate junction still show diode characteristics. Totally damaged devices may appear as a short circuit (or low resistance) from drain to source. Sometimes, but not often, the device may appear as an open circuit.

ESD is not the only problem. Leakage of soldering irons, bonding machines and even power supplies of the amplifiers has produced many failures. All the equipment used in the assembly test and operation of the amplifiers should be checked for leakage. Most of the field problems detected have been caused by 50 Hz current leakage of input transformers of floating DC power supplies. This leakage is due to the capacitive coupling between primary and secondary of the transformers and it is always present unless there is a grounded faraday shield between the two windings or other especial precautions are taken

Procedure for assembly of the amplifiers

1. Technicians manipulating amplifiers should wear grounded wrist straps.
2. The bench for the assembly of the amplifiers should have a dissipative map connected to ground.
3. A short circuit should be put in the power connector of the amplifier at all times during assembly (the short circuit should short all pins together to the case). The short circuit will only be removed for testing the amplifier or when connected for operation.
4. Coaxial SMA short circuits should be connected to input and output RF connectors at all times during assembly. The short circuits will only be removed for testing the amplifier or when connected for operation.
5. The soldering irons used for assembly should be adequately grounded. It should be checked that no voltage respect to ground is measured on the tip with the soldering iron on and off. The maximum voltage allowed will be 0.020 Vrms respect to ground measured with a high input impedance (> 10 MΩ) voltmeter in AC mode.
6. The tip of the bonding and welding machines used for assembly of the amplifier should be adequately grounded. It should be checked that no voltage respect to ground is measured with machines on or off. The maximum voltage allowed will be 0.020 Vrms respect to ground measured with a high input impedance (> 10 MΩ) voltmeter in AC mode.
7. Be very careful with any measurement instrument used during assembly. If ohmmeters are used for verification of internal cabling, battery operated units are preferred. Make all necessary verifications before the assembly of the transistors when possible. The assembly of the transistors should be the last operation to avoid unnecessary risks.

Procedure for test and operation of the amplifiers

1. Keep the amplifier in an anti-static bag at all times. When it is outside the protective bag, do not touch the contacts of the power connector with bare fingers or with any tool. If possible, the amplifier should be kept with a short circuit in the power connector when not in use. The short circuit should short all pins together and to the case. The short circuit should only be removed if adequate ESD and leakage protection precautions have been taken.
2. Most failures in cryogenic amplifiers are produced when connecting or disconnecting the amplifier to/from the power supply. **A very careful procedure should be followed**.
3. Make sure that the power supply is **off** before connecting or disconnecting the power supply cable to/from the amplifier.
4. Make sure that the power supply and the amplifier are connected to the same protective ground before connecting or disconnecting the power supply cable to/from the amplifier.
5. Very especial care should be taken in case of a DC power supply floating respect to the protective ground. This produces most failures. It is safer to connect the **return** terminal at the output of the DC power supply to the protective **ground** permanently on the power supply side. If this is not possible (for example to avoid ground loops with long cables), a provisional connection from the return of the power supply to the amplifier case should be **made prior to any connection or disconnection** of the power supply cable. Always make sure that there is no voltage between the return of the power supply and the protective ground (case of the amplifier) before connecting the power supply cable. The maximum allowed voltage will be 0.020 Vrms measured with a high input impedance (> 10 MΩ) voltmeter in AC mode.
6. The power supply should have adequate built in protection to avoid excessive voltage and currents in the transistors in case of power supply failure and during the transients produced when the power supply is switched on or off. Adequate Zenner diodes can be used in parallel with the outputs, and adequate series resistors in series. If the protections are designed adequately, the amplifier will survive even in case of errors in the connections of the cables.

Storage of the amplifiers

1. The amplifiers should be stored in a clean dry anti-static environment.
2. The amplifier should be stored with short circuits in the power and RF connectors.
3. For permanent storage desiccators with less than 20% relative humidity should be used. The preferred method of storage is in dry nitrogen containers.
4. For transportation, and for short-term storage, anti-static plastic bags with silica gel bags to keep low relative humidity should be used.