APPLICATION OF THE TRL CALIBRATION TECHNIQUE FOR HEMT'S MICROWAVE CHARACTERIZATION AT TEMPERATURES DOWN TO 77 K.

F.Séjalon*, M.Chaubet**, L.Escotte***, J.Graffeuil***.

* Université Paul Sabatier, 118 Route de Narbonne, 31400 Toulouse, France.
** Centre National d'Etudes Spatiales, 18 Avenue Edouard Belin, 31055 Toulouse, France.
*** Laboratoire d'Automatique et d'Analyse des Systèmes du CNRS and Université Paul Sabatier, 7 Avenue du Colonel Roche, 31077 Toulouse, France.

ABSTRACT

For the possible application to the cryogenically cooled low noise HEMT amplifier, this paper presents scattering parameter measurements of a HEMT chip at room and liquid nitrogen temperatures and in the 1-20 GHz frequency range. The measurement method which uses the well known TRL calibration technique will be fully discussed. S parameters and noise parameters measured at room temperature by means of this technique have been used to design a single stage low noise amplifier for the K band. Without any tuning this amplifier has an overall noise figure value of 1.6 dB with a 7 dB associated gain at 18 GHz which is in good agreements with predictions.

Keywords : TRL calibration, Low noise cooled amplifiers, HEMT's, Microwave characterization, Noise parameter measurements.

1. INTRODUCTION

In radioastronomy and some space communication systems, amplification of very low level signals often requires the use of cooled devices to reduce thermal noise. This is the case for example of some parametric amplifiers and masers which are somewhat complex and expensive systems. Gallium arsenide field effect transistor offers very interesting characteristics as cooled low noise amplifier at frequencies up to twenty gigahertz (Ref. 1, 2). But since the more recent invention of the High Electron Mobility Transistor (HEMT), as a result of its internal structure, it is allowed to obtain considerably low noise figure in the millimeter-wave frequency range when used at low temperatures (Ref. 3, 4).
As far we know, cryogenically cooled low noise amplifiers already designed nowadays are either optimized for room temperature and their performances evaluated when they are cooled (Ref. 5). Or either they are made with adjustable elements which allow to optimize their performances at cryogenic temperatures but that prohibit their boarding satellites (Ref. 6).
Accurate design (to avoid tuning) of a cryogenically cooled low noise HEMT amplifier requires a complete characterization (DC parameters, small signal parameters and noise parameters) of the HEMT chip at low temperatures. We propose to describe in this paper the method used to measure scattering parameters of a commercially available HEMT chip at 77 K. This technique which has already been used at room temperature for noise parameter measurements of the same device should be very promising at cryogenic temperatures.

2. DESIGN OF A MICROSTRIP TEST FIXTURE FOR CRYOGENIC APPLICATIONS

To the best of our knowledge, well-suited probes for size and pattern of commercially available 0.25 µm gate HEMT chips do not exist yet. Moreover, microwave measurements with RF probe station appear to be very complex at cryogenic temperatures (Ref. 7).
For these reasons, the alternative we choose to characterize RF performances of chip devices consists in mounting the samples in a rigid microstrip test fixture. The test fixture we used is a Thomson BMH 60-type and is represented figure 1.

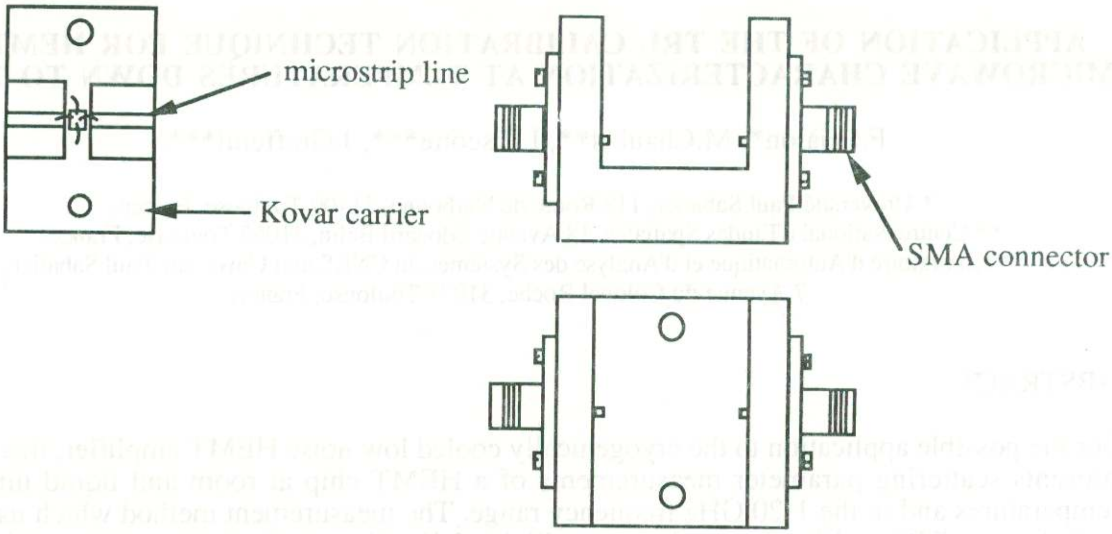

Figure 1 : *Chip carrier and test fixture.*

The chip is mounted on a Kovar carrier and its metallization pads are bonded to the microstrip lines and ground support. The whole is inserted in the test fixture where SMA connectors are adapted. The fixture is fixed to a continuous flow cryostat and cooled by a convection process.It is connected to the equipment through Cu-semi rigid coaxial cables.

A TRL calibration (Ref. 8, 9) allows to establish the reference planes near the chip and to calibrate directly the automatic network analyser removing from the measurements the effects of the cables and test fixture both at room and liquid nitrogen temperatures. Due to the longer temperature cycle and to the tedious operations, this calibration technique which does not require to de-embed the test fixture is particularly interesting compared to the others calibration techniques.

The microstrip TRL standards are made on alumina (ε_r=9.9, h=0.635 mm). They are mounted, like chips, on Kovar carriers and inserted for each one in different fixtures. Thus, we do not have to remove the microstrip standards from the fixtures during the calibration and measurement process. Operations at cryogenic temperatures are then easier but repeatability for connectors and transitions must be good for accurate measurements. The "THRU" and "LINE" lengths (4 and 5.9 mm respectively) permit the calibrations and the measurements to be performed in the 1 to 20 GHz band. The "REFLECTS" are open-ended microstrip lines of 2 mm length each (mounted on a chip carrier where no chip has been die-attached).

3. EXPERIMENTAL RESULTS

3.1 Small signal measurements

Figure 2 compares S-parameter measurements at 77 K to those at 300 K. The device selected was the Toshiba JS8905_AS HEMT chip.

Previous investigations (Ref. 10) showed that the Toshiba JS8905 is a type of device which behavior at low temperatures is quite good. After several temperature cycles under varied bias conditions, no effect of the DX-centers has been observed.

At liquid nitrogen temperature or at room temperature, a TRL calibration was first performed with the microstrip standards to take into account systematic effects from the network analyser and insertion losses of the cables. Scattering parameter measurements of the device(mounted in its test fixture) were then immediate. The measurements include the bonding wire inductances L_s, L_d, L_g (figure 3) which we supposed temperature insensitive. The device was biased at an I_{ds} of 10 mA and a V_{ds} of 2 Volts.

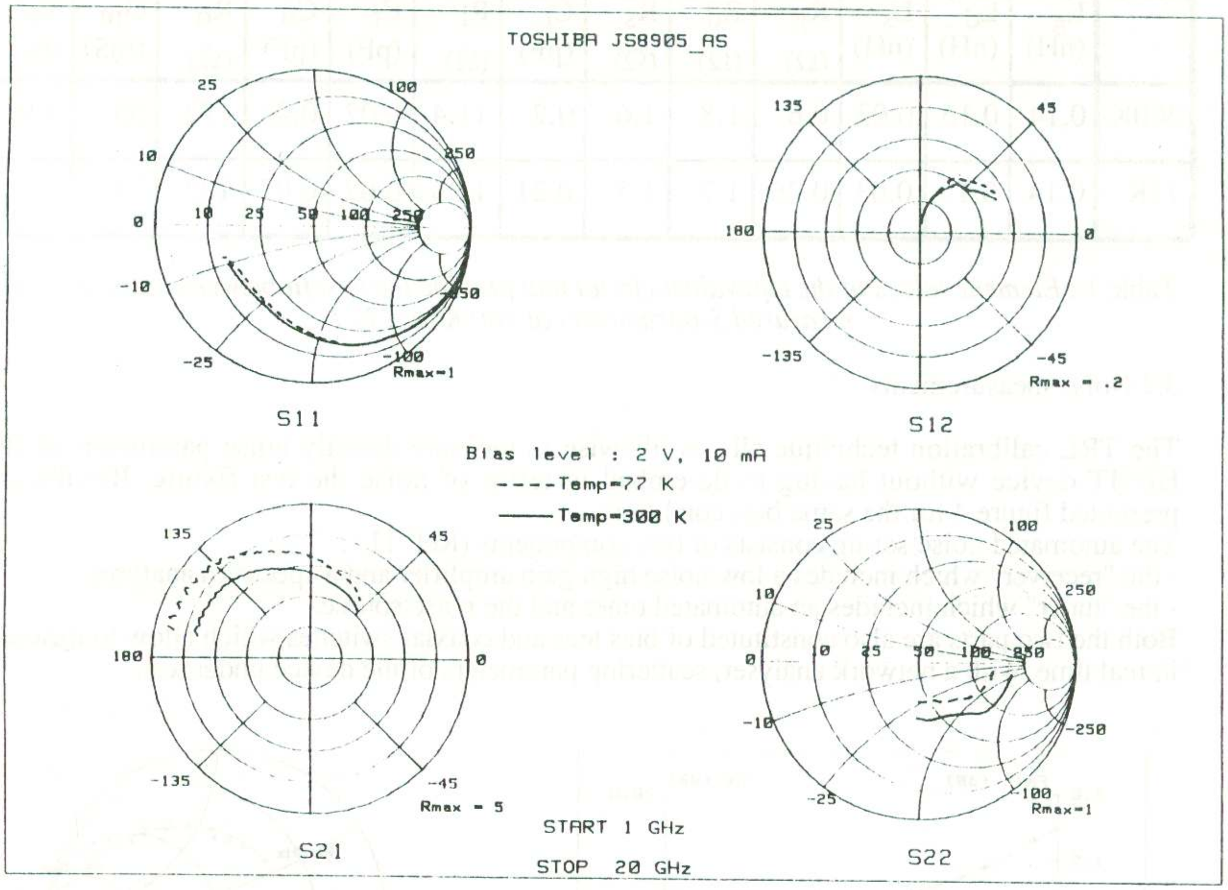

Figure 2 : *Scattering parameters of the Toshiba JS8905_AS HEMT chip measured in the 1-20 GHz frequency band and at room and liquid nitrogen temperatures.*

Elements of the equivalent circuit (figure 3) were determined by measured S-parameter fitting (table 1). A comparison between the circuit element values at the two temperatures leads to the following conclusions.

(i) An increase of 34 percent of the transconductance G_m is responsible for the increase of the S_{21} parameter at 77 K.

(ii) The S_{11} parameter is practically temperature insensitive and this reflects the small change of the gate to source capacitance C_i.

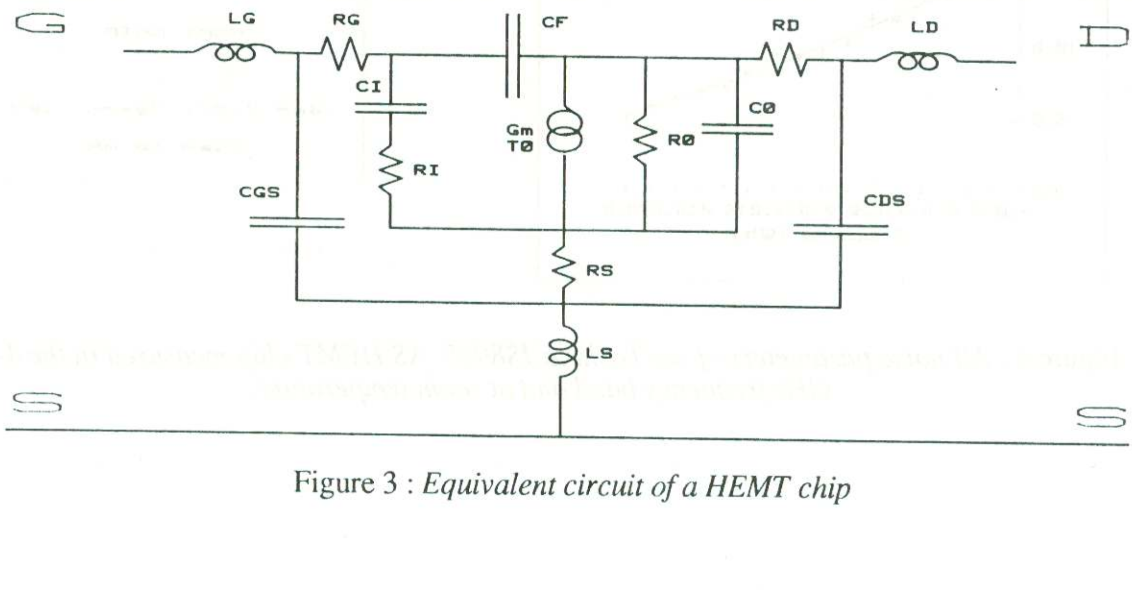

Figure 3 : *Equivalent circuit of a HEMT chip*

	L_g (nH)	L_d (nH)	L_s (nH)	R_g (Ω)	R_d (Ω)	R_s (Ω)	C_i (pF)	R_i (Ω)	C_f (pF)	C_o (pF)	R_o (Ω)	G_m (mS)	T_o (ps)
300K	0.14	0.15	0.03	0.6	1.8	1.6	0.2	11.4	0.02	0.08	172	55	2.9
77K	0.14	0.15	0.03	0.26	1.7	1.5	0.21	11.3	0.02	0.07	122	74	2.9

Table 1 : *Element values of the equivalent circuit that provide the best fit between calculated and measured S-parameters at 300 K and 77 K.*

3.2 Noise measurements

The TRL calibration technique allows likewise to measure directly noise parameters of the HEMT device without having to de-embed in terms of noise the test fixture. Results are presented figure 4 for the same bias conditions.
The automated noise set-up consists of two components (Ref. 11) :
- the "receiver" which includes a low noise high gain amplifier and a spectrum analyser.
- the "tuner" which includes an automated tuner and the noise source.

Both the two parts are also constituted of bias tees and coaxial switches which allow to measure in real time, with a network analyser, scattering parameters of the device under test.

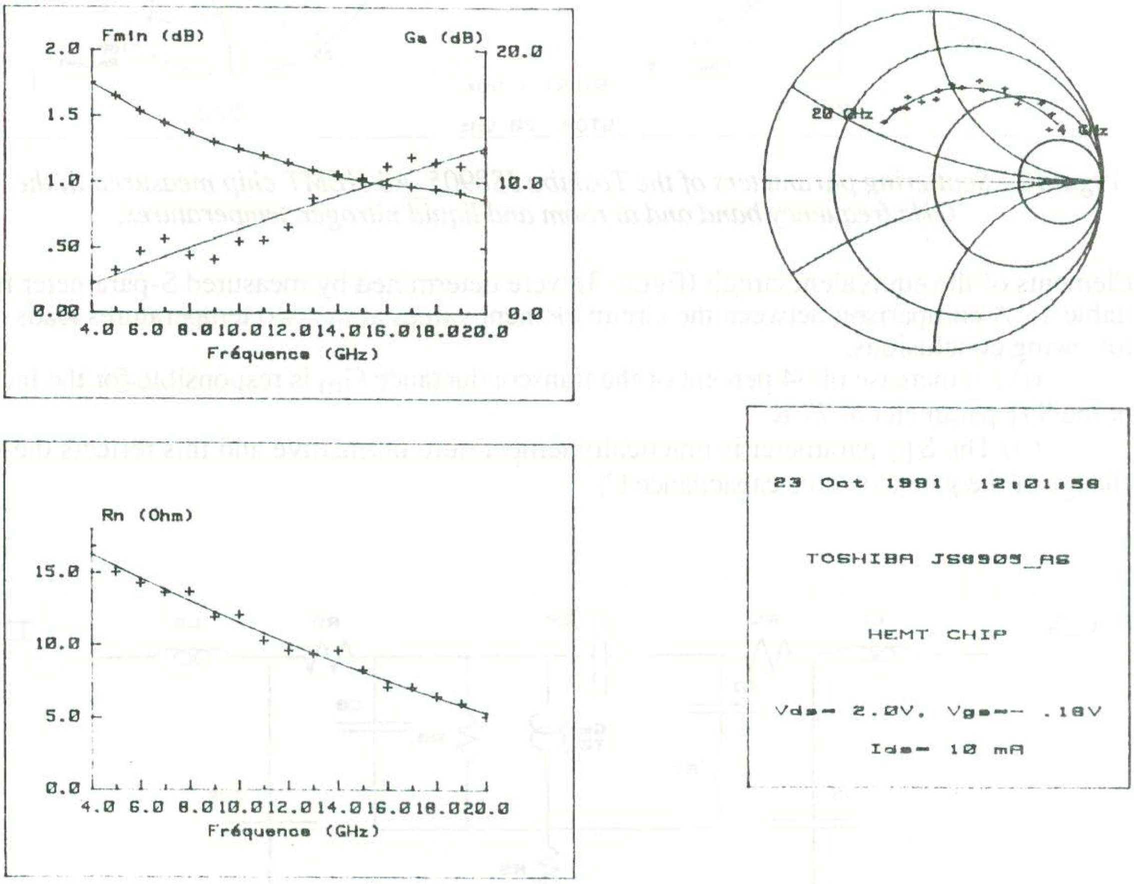

Figure 4 : *All noise parameters of the Toshiba JS8905_AS HEMT chip measured in the 4-20 GHz frequency band and at room temperature.*

4. APPLICATION TO THE DESIGN OF A LOW NOISE AMPLIFIER

S-parameters and noise parameters of a Toshiba JS8905 HEMT chip, measured at room temperature with the TRL calibration technique previously described, have been used to design a single stage low noise amplifier for the K-band (figure 5). Without any tuning this amplifier has an overall noise figure value of 1.6 dB with a 7 dB associated gain at 18 GHz which is in satisfactory agreements with simulations (figure 6).

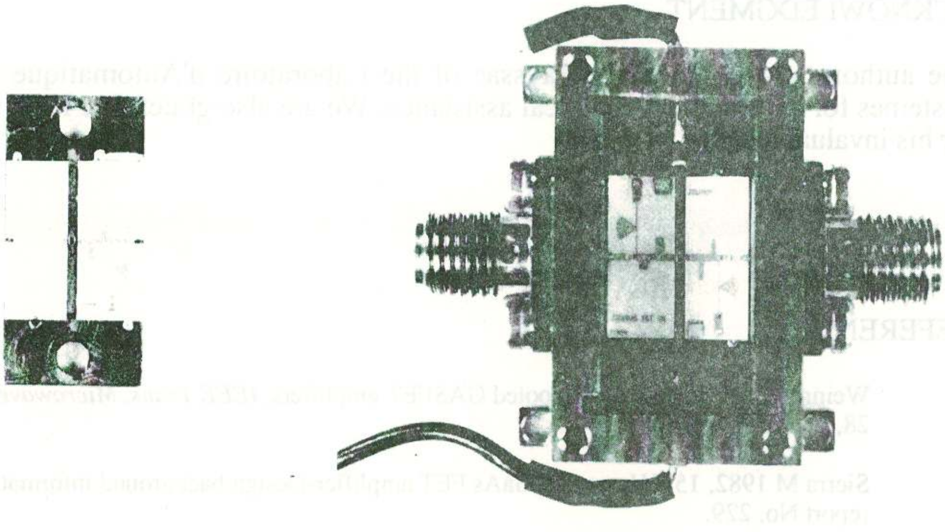

Figure 5 : *Photographs of a single stage low noise HEMT amplifier.*

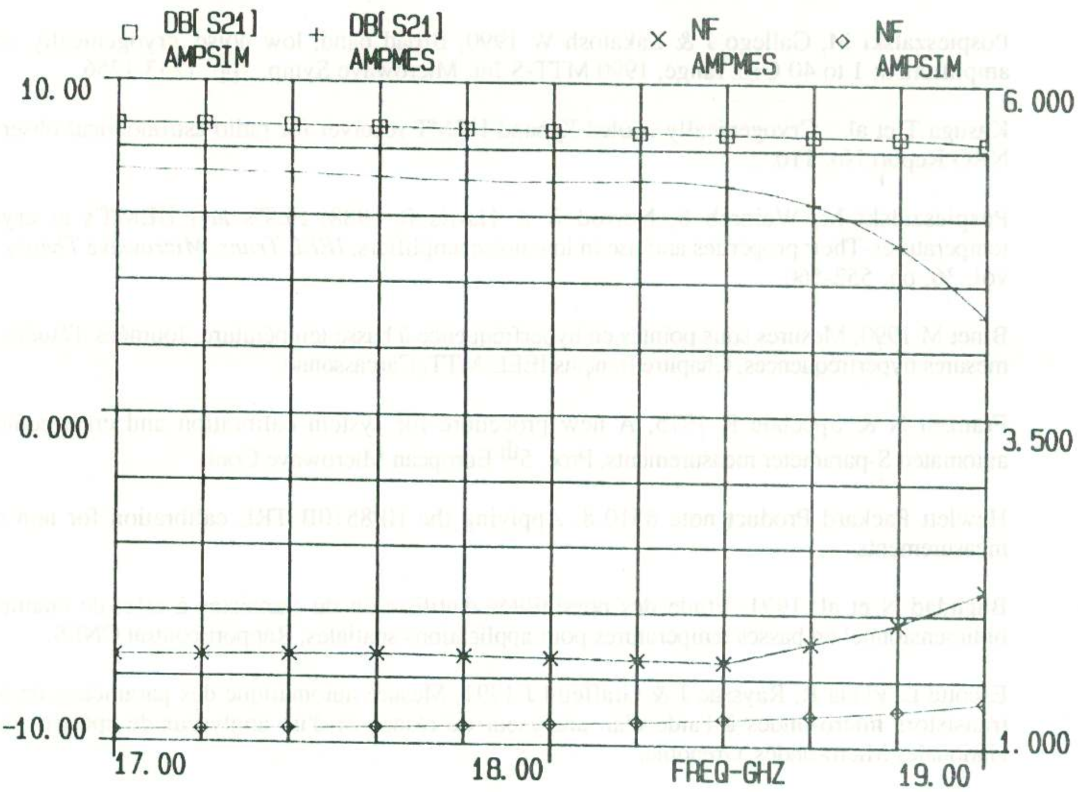

Figure 6 : *Measured gain and noise figure of the microstrip low noise HEMT amplifier compared to simulations.*

CONCLUSION

A specially designed microstrip test fixture for TRL calibration at cryogenic temperatures has been presented. It allowed us to measure with good accuracy S-parameters of a HEMT chip in the 1-20 GHz band and at the two temperatures of 300 K and 77 K. S-parameters and noise parameters measured at room temperature by means of this technique have been used to design a microstrip low noise amplifier. The results, really closed to the simulations, validate these measurements. We are now working on the method for the measurements of noise parameters at cryogenic temperatures.

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