Drain Temperature Dependence on Ambient Temperature for a Cryogenic Low Noise C-Band Amplifier.

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ABSTRACT

A comparison between predicted and measured noise temperatures for cryogenic HEMT amplifiers is presented by using the Pospieszalski's noise model. A good agreement between predicted and measured amplifier's noise performance is obtained both at room and cryogenic temperatures. However, the predicted values overestimate noise temperature in the center part of the measured temperature range (50K - 230K). A parabolic dependence for the drain temperature with ambient temperature is proposed to obtain a better fitting to the experimental results.

INTRODUCTION

In order to reduce the number of measurements needed to obtain noise figure predictions the analysis of the FETs' (MODFETs) noise performance has became a subject of primary interest. It has already been shown (1) that a complete noise analysis can be performed using a simple noise measurement and an equivalent circuit model. More recently (2,3), other models have been described that further simplify the measurement requirements while improving the noise figure predictions. These models predict the four noise parameters at any frequency provided that two frequency independent constants and the transistor's equivalent circuit are known. These two constants are the equivalent temperatures of the intrinsic gate resistance and drain conductance, T_g and T_d respectively.

Verifications of these models have already been carried out with noise and S-parameters data taken for different active devices at a single operating bias point and as a function of operating bias (4). The validity of a simplified noisy model has recently been checked for packaged pseudomorphic devices by comparison between the measured noise parameters with those obtained from a computer analysis of the simplified noisy model of the device (5).

The values of T_d and T_g are known for typical HEMT devices (6) at room and cryogenic temperatures. Our previous simulations assumed that T_g was very close to the transistor's physical temperature and that T_d could be obtained from linear interpolation of the values known at room and cryogenic temperatures (297K and 14K respectively) (7).

This work shows a comparison between predicted and measured noise temperature for cryogenic HEMT amplifiers designed over the frequency range 3.2GHz - 4.7GHz. The noise temperature is simulated by using the model proposed by Pospieszalski (3). The experimental results suggest a non linear dependence of T_d on ambient temperature since a linear interpolation overestimates T_n at ambient temperatures in the range 50K - 230K.

NOISE TEMPERATURE MEASUREMENTS

Four cryogenic C-band amplifiers have been designed and built with transistors from different manufactures and batches. Each amplifier consists of three stages as shown in Figure 1.

The source inductance and loading resistor values were selected for each stage so that both unconditional stability and low power dissipation across the full band were achieved. Therefore, no oscillation was produced for any combination of passive input and output impedances at any operating temperature. The input matching circuit was optimized for minimum cryogenic noise and the output matching circuit for low reflection. The two interstage coupling networks provide flat gain of approximately 34 dB for the amplifier.

The noise temperature was measured with a fully automated system in the range 15K - 275K. Cryogenic measurements were taken with the "cold attenuator" method by using a calibrated noise diode at room temperature, a 15dB attenuator and a DC-block cooled at cryogenic temperatures. Room temperature data were obtained with the noise diode. The accuracy of measured noise temperature is estimated in ± 9K for the room temperature and ± 1K for the lowest cryogenic temperature, in the worst case (8).

All the amplifiers were biased for minimum noise operation at room temperature (V_{ds} = 2V; I_{ds} = 10mA). When the amplifiers were cooled below 100K, the bias was changed to a new value of V_{ds} = 1.5V; I_{ds} = 5mA which corresponds to the optimum noise for T_{amb} = 15K.

Figure 2 shows the measured mean noise temperature for the four amplifiers as a function of ambient temperature in the range 15K - 270K.

As is observed, amplifiers 1 and 2 show the best performance with a mean noise temperature of approximately 10K @ T_{amb} = 60K with a ripple of ± 0.5K in the band.

Amplifiers 3 and 4 had an anomalous performance showing a bump around 125K that may be due to trap effects at cryogenic temperatures.

MODELING NOISE TEMPERATURE.

The amplifiers were simulated with MMICAD (9) by using the Pospieszalski's noise model and a HEMT equivalent circuit obtained from DC and S parameters measurements of the active device at room temperature. Capacitors were modeled as RCL circuits and resistors as RL circuits. In order to obtain unconditional stability and an acceptable input reflection across the full band, an inductive feedback was used at the source and the drain was resistively loaded. The noise added by the drain loading resistors to the total noise of the amplifiers is 0.4K for T_{amb} = 15K and 10K for T_{amb} = 300K. This noise represents about 10% of the total noise at cryogenic temperature and 20% at room temperature.

In the Pospieszalski's noise model, the HEMT's noise properties are only determined by the values of the equivalent gate and drain temperatures T_g and T_d. The equivalent gate temperature is considered to be equal to the ambient temperature as typically shown by HEMT devices (3). In order to model the noise temperature of the amplifiers at any ambient temperature, T_d is obtained as a first approximation by using a linear interpolation from the temperature values originally proposed by Pospieszalski (4,6). However, the linear interpolation does not predict the experimental data accurately and therefore another approach has been considered. The experimentally observed deviation from linearity and the overestimation of the noise at high temperatures suggested us that a non linear dependence of T_d with

T_{amb} may improve the predictions. The parabolic dependence shown in Fig. 3 may be easily included in MMICAD.

Figure 4 shows a comparison between predicted (with linear and non linear dependence) and measured noise temperature for all amplifiers as a function of ambient temperature in the range 15K - 270K.

As is observed, the non linear drain temperature dependence on ambient temperature predicts the best fitting to measured mean noise temperature in the center part of temperature range. A better value for amplifiers noise performance at room temperature is also provided by the non linear dependence.

CONCLUSIONS

As observed in Figure 4, a parabolic dependence of T_d predicts a good fitting of the noise temperature in the ambient temperature range 15K to 300K. Pospieszalski's values were correct for T_{amb} = 15K but they overestimate the noise at room temperature. This may be due to the improvement of the devices presently available. The results shown in Figure 4 suggest that the new proposed T_d function leads to a more accurate prediction of the noise temperature of cryogenic amplifiers in a broad ambient temperature range, modeling the nonlinear dependence of T_n with T_{amb}.

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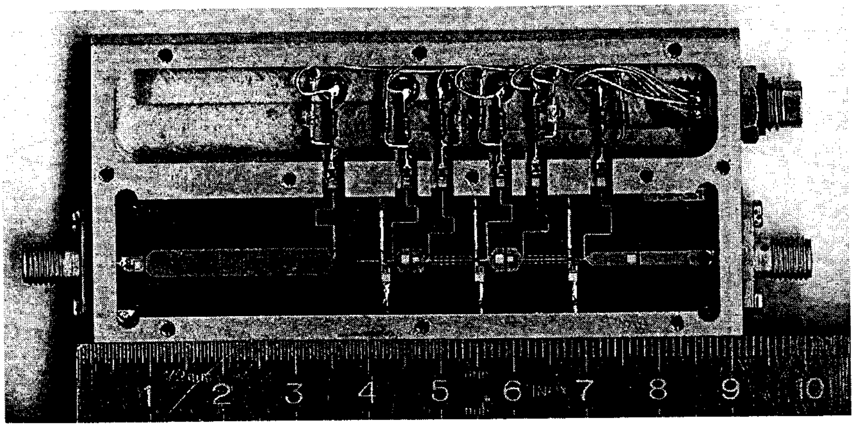

Fig. 1. A three stage cryogenic C-band amplifier.

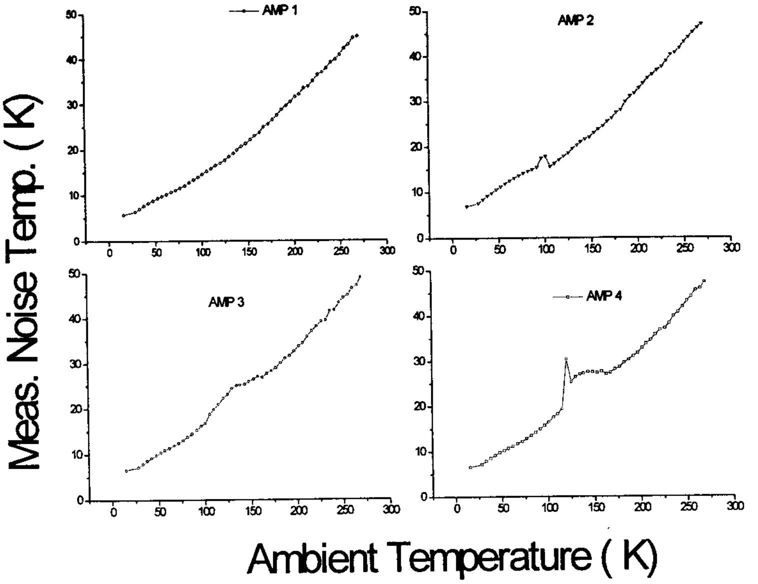

Fig 2. Noise temperature of different cryogenic C-band amplifiers.

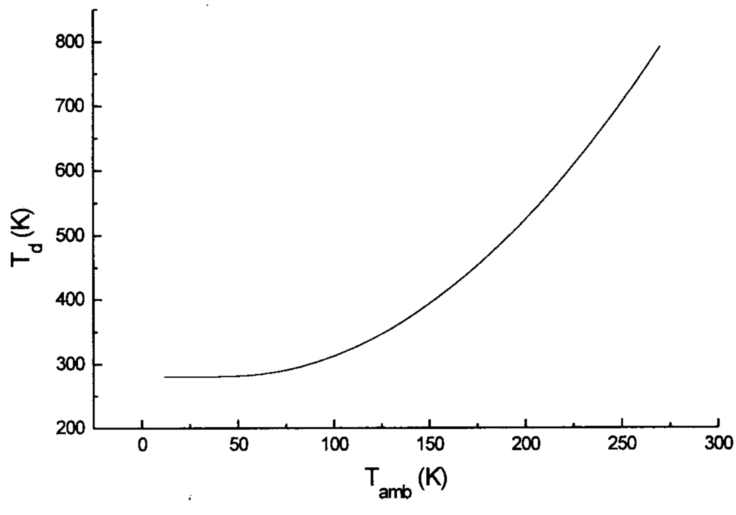

Fig. 3. Drain temperature non linear dependence on ambient temperature.

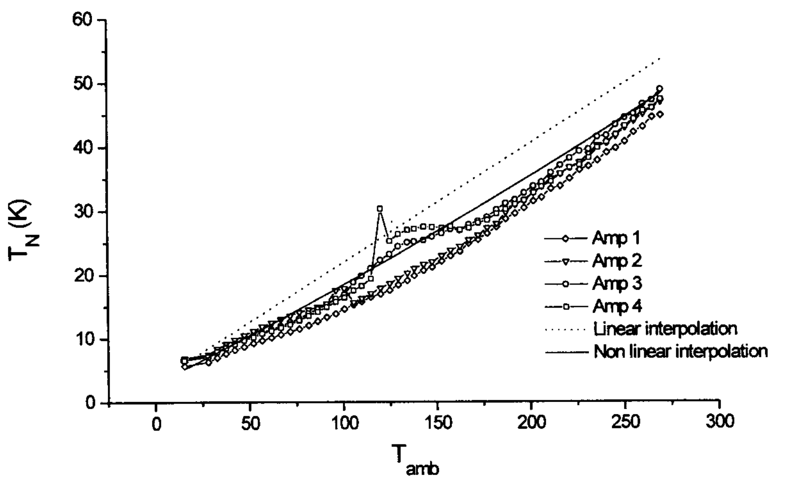

Fig. 4. A comparison between predicted and measured noise temperatures for cryogenic HEMT amplifiers.