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An Evolution Algorithm for Noise Modeling of HEMTs down to Cryogenic Temperatures

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INTRODUCTION

The implementation of an evolution algorithm (EA) for the cryogenic noise modeling of microwave devices has been the object of the present work. The characterization of advanced microwaves devices, like High Electron Mobility Transistors (HEMT), in terms of the noise parameters results in a set of time consuming measurements to be performed with very expensive instrumentation [1 – 3]. A complete noise characterization is required for an accurate design of low-noise front-ends for high-sensitivity cryogenic receivers, wireless telecommunication circuits, nuclear and aero-spatial instrumentation.

NOISE PARAMETERS

The Noise Parameters (NP), together with the Scattering (S-) parameters, provide a full small-signal characterization (i.e., a *black-box* model) of any device dependent on the frequency, the bias conditions and the operating temperature. The four NP's here employed are the minimum noise figure (F_{min}), the noise resistance (R_n), the magnitude and phase of the optimum noise source reflection coefficient (Γ_{opt}). The NP's are related to the global noise figure $F(\Gamma_S)$ as reported in the following expression, where Z_0 is the normalization impedance, typically 50 Ω:

$$F(\Gamma_S) = F_{min} + \frac{4R_n}{Z_0} \cdot \frac{\left|\Gamma_S - \Gamma_{opt}\right|^2}{\left|1+\Gamma_{opt}\right|^2 \cdot \left(1-\left|\Gamma_S\right|^2\right)} \quad (1)$$

The eq. (1) represents a parabolic-like surface on the Smith Chart.

IMPLEMENTATION OF THE EVOLUTION ALGORITHM

EA's are adaptive procedures that are mostly used for optimization and research problems [4]. These procedures are conceptually based on the principles of the natural evolution of the species. Living organisms consist of many cells and each cell contains one or more chromosomes that can be divided in genes. Each gene codifies a specified feature of the living organism. From the point of view of the information theory, the chromosome refers to a candidate solution.

In our analysis, an eight base function set constitutes the collection of the chromosomes, namely the initial population. The main program of the EA assigns a set of suitable coefficients to the base functions. Subsequently, these functions combine with each other. The high number of the potential solutions obtained ensures the generation of an optimum solution that exhibits the lowest error compared to the maximum fixed threshold. The "fitness" is warranted by a continuous comparison between the candidate solution and the measured value of each NP. The comparison ends when a chosen threshold for the fitness is reached. A convergence procedure is also carried out to refine the generated solutions by exploring its neighbor regions. The selection is achieved by successive "mutation" steps.

The obtained analytical equations thus provide an estimation of the behavior of the NP's down to cryogenic temperatures and also outside the frequency range under observation. This approach is original and very flexible because it does not require a training procedure like in the Artificial Neural Networks (ANNs) − based systems [5, 6]. Moreover, the performance of this EA technique

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shows to be independent from the particular device typology.

RESULTS

By the procedure here presented we have obtained a complete set of the NP's for a commercial super low-noise pseudomorphic HEMT (MGF4319 by Mitsubishi Semiconductors). This transistor was previously measured in our laboratory and a complete noise characterization was performed vs. frequency and temperature. Therefore, the EA performance for the noise modeling of the device under test (DUT) has been checked by using these experimental data in the 6-18 GHz frequency range and down to cryogenic temperatures. The comparison between measured data and EA simulation of the NP's vs. frequency and temperature (290-90 K, step 50 K) for the chosen DUT was performed and the results are reported in Figs. 1-3. Finally, a thorough analysis of these plots allows us to establish that application of the EA technique produces reasonably good values of the NP's down to cryogenic temperatures for the DUT.

CONCLUSION

In this work, an evolution algorithm was implemented for estimating to a good accuracy extent the behavior of the NP's for a low-noise HEMT down to cryogenic temperatures. By this original procedure, we have also obtained the analytical expressions of the derived curves whose coefficient behavior vs. temperature is currently under analysis.

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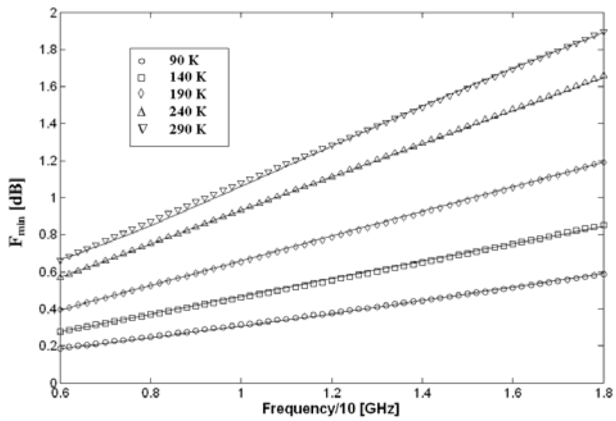

Fig. 1. Comparison between experimental data and EA simulation of the minimum noise figure F_{min} vs. frequency and temperature for the MGF4319 device.

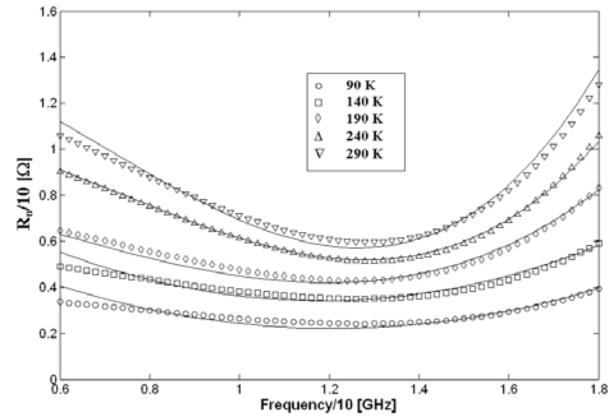

Fig. 2. Comparison between experimental data and EA simulation of the noise resistance R_n vs. frequency and temperature for the MGF4319 device.

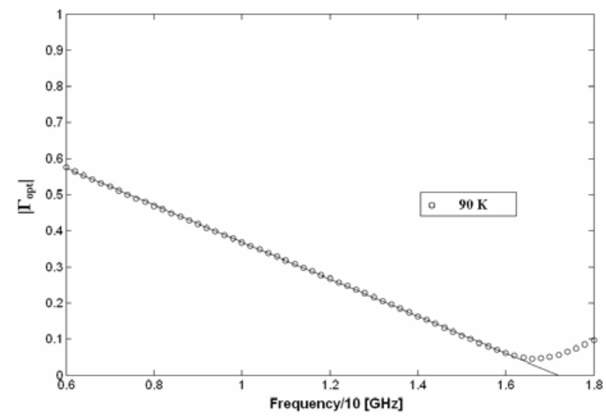

Fig. 3. Comparison between experimental data and EA simulation of the magnitude of the optimum noise reflection coefficient Γ_{opt} vs. frequency for the MGF4319 device at 90 K.