The Effects of Extended Depletion Region on Noise Modeling of HEMT's

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Abstract -**In this paper we present a high frequency noise model for short channel HEMTs. This model takes into account the effect of depletion region that extends into gate to drain spacing. The effect of this high field extension region on the noise performance of three HEMT structures is analytically calculated and compared with measured data.**

I. INTRODUCTION

During the past several years significant improvements have been reported concerning the high frequency and noise performance of the High Electron Mobility Transistors. Low-noise HEMTs are already commercially available and are widely used in the front-end receiver system for satellite communication, radio astronomy and direct broadcasting by satellite. For the design of high-speed and low-noise integrated circuits such as low-noise amplifiers or broadband receivers, it is often necessary to perform the computer simulations involving an appropriate noise to predict the noise performance of the device accurately.

Many numerical and analytical noise models have been reported in the literature. [1-4]. Ando and Itoh [4] presented an analytical noise model based on the charge control model proposed by Shey and Ku [5]. This model takes into account the effects of variation of the Fermi level with the 2-DEG sheet carrier concentration, and explains the U-shape variation of the noise figure with operating drain current. However their reported experimental data agree with the analytical calculations only when a reduced value of carrier saturation velocity is assumed.

It is well known that in a HEMT structure as the gate length decreases to sub-micron levels, two-dimensional effects of gate to drain bias voltages become extremely important. These effects arise due to extension of depletion region in gate to drain spacing [6]. In this paper we have extended Ando and Itoh's noise model [4] by taking into account the effects of the depletion region extension into gate to drain spacing and studying the effects of this extension on the noise performance of the device.

II. CHARGE CONTROL MODEL

In order to calculate the noise performance of a given device, the first step is to calculate the DC characteristics and the small signal equivalent circuit parameters of the device. Next, is to determine the drain and gate noise sources and their correlation coefficient. The third step is to add the extrinsic noise sources and calculate the Noise Figure of the device. Fig.1 shows the cross-sectional view of the HEMT. The channel can be divided into three regions; L_1 is length of the constant mobility region shown as region I. The high field region is divided into two sub-regions of lengths L_{os} and L_{od} where L_{os} is the high field region below the gate shown as region II and L_{od} lies between the edge of the gate and drain edge shown as region III as was originally suggested in [6].

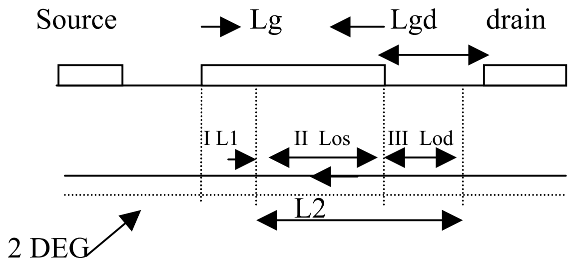

Fig. 1. Cross-sectional view of HEMT

For the calculation of the lengths of the three regions the two dimension Poisson equation is solved. For this we have followed the approach given in [6]. It is assumed that two sub regions are completely depleted and depletion region between gate and drain is assumed to be rectangular in shape. The field and the potential distributions can be obtained by solving the two-dimensional Poisson equation. The resulting equations are as follows

$$\left(\frac{L_{od}}{d}\right)^2 = \frac{E_0}{E_B}\left(e^{\frac{\pi L_{os}}{2d}} - Sinh\left(\frac{\pi L_{os}}{2d}\right)e^{\frac{-\pi L_{od}}{2d}} - 1\right), \qquad (1)$$

$d = d_d + d_i$, E_0 is the saturation electric field

$$E_B = \frac{q}{\varepsilon}\left(\int N_d(y)dy - n_{sat}\right) + E_{sc} - E_0 Cosh\left(\frac{\pi L_{os}}{2d}\right)$$

$$n_{sat} = \frac{I_d}{q} z v_s E_0$$

And E_{sc} is the surface field. Drain to source voltage V_{DS} can be written as

$$V_{DS} = V(L_1) + V_{DG} + 2dE_0 Sinh\left(\frac{\pi L_{os}}{2d}\right) \tag{2}$$

Where V_{DG} is the channel voltage drop beneath gate to drain depletion region and is given

$$V_{DG} = 2dE_0 Sinh\left(\pi \frac{\pi L_{os}}{2d}\right)\left(e^{-\frac{\pi L_{0s}}{2d}} - 1\right) + E_0 L_{0d} e^{\frac{\pi L_{os}}{2d}} - \frac{L_{od}^3 E_B}{3d^2} \tag{3}$$

Using these equations L_1, L_{os} and L_{od} are calculated and DC and small signal parameters are calculated. Fig. 2 shows the variation of L_{os}/d and L_{od}/d with drain voltage. It shows the variation of L_{os}/d and L_{od}/d with drain voltage. It is observed that there is a constant growth of region III because L_{od} is a linear function of V_{ds} and at higher V_{ds} , L_g+L_{od} becomes invariant but L_{os} moves closer towards the source. As the gate length decreases the percentage of extension of depletion region in gate drain separation (L_{od}) to gate length L_g becomes more significant. Also it is observed that for a fixed gate length as the drain current increases the length of region III increases [6].

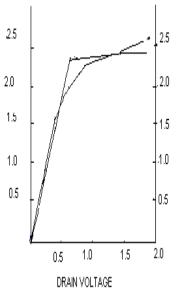

Fig. 2. Variation of lengths of region I and II with gate voltage.

III. RESULTS

Intrinsic noise arises from two mechanisms: The first one is the thermal noise produced in the ohmic section of the channel i.e. region I. The second is the diffusion noise arising from the velocity saturation region. In our model the high field carrier velocity saturated region is divided into two sub regions viz. one under the gate (region II) and the other between the gate and drain (region III). Previous noise models have assumed [2,4] that region between the gate and the drain can be taken into consideration by taking the contribution of the region as a lumped resistance. In our calculations we have assumed that region III also contributes to the diffusion noise. The calculations were carried out for studying the variation of extended portion of the depletion region in the gate to drain spacing. Taking L_{od} into account the noise performance of two devices were studied and compared with measured results available in published literature.

In order to calculate the noise, HEMT is replaced by a black box and the noise generators are connected across input and output terminals [7,8]. The noise coefficients are calculated taking into account extended L_2 i.e. L_{os}+ L_{od}. Using these results noise coefficients and minimum noise figure was calculated for the AlGaAs/GaAs HEMT device with gate length of 0.25µm, gate width of 200µm and doped layer thickness is 200 A [4]. The calculations were carried out for drain supply of 3V. Fig.3 shows the comparison of experimental results of variation of Noise figure with drain bias current of the device mentioned above. The saturation velocity in this case is taken as 1.2E7 cm/sec. The results show the noise performance of the device with and without the extended depletion region taken into consideration. It is observed that if the extended depletion region is not taken into account, satisfactory agreement between the calculated and measured Noise Figure at all bias points can be obtained only by assuming a lower value of saturation velocity for electrons. However, if the noise contribution from the region III i.e. the extended depletion region beyond the gate is also taken into account the Noise Figure at all the bias points agree well with the measured data without unjustifiable choice of low carrier saturation velocity. We also studied the frequency dependence of Noise Figure with and without the extended depletion region taken into account. Calculations were carried out for the device examined in ref [9]. Fig.4 shows the experimental data of variation of Noise Figure with frequency and its comparison with the simulated data with and without the

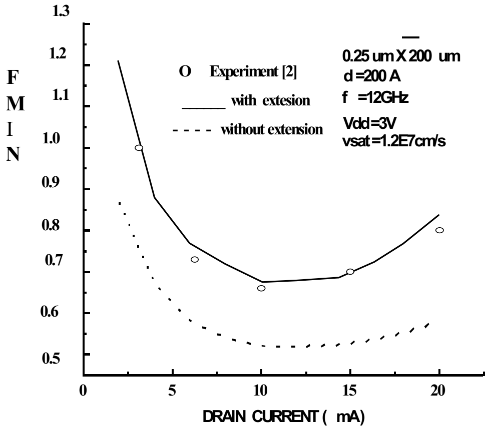

Fig 3 Comparison of calculated Noise figure data with and without considering the extended region with the measured data [4].

extension of depletion region taken into account. It is observed that the predicted values of the Noise Figure with the extension of the depletion region taken into account, agree reasonably well with the measured values. To examine the general validity of our model we have carried out the noise calculations for a commercial HEMT (NEC 33200). Fig 5 shows that the simulated results are in good agreement with the measured data given in the manufacturer's data sheet [10].

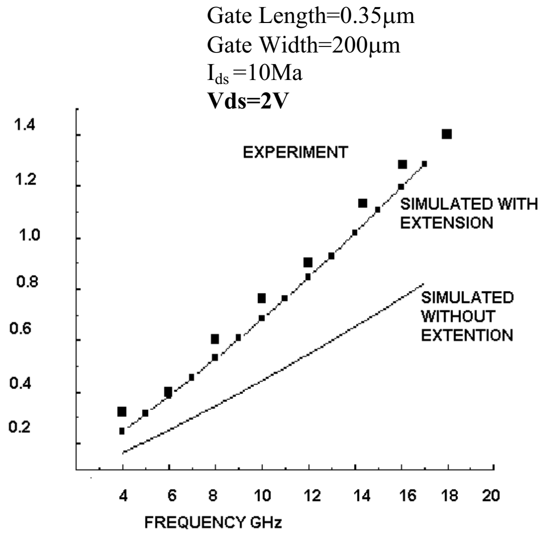

Fig 4 Comparison of Experimental Results of Variation of Noise Figure versus Frequency with simulated results with and without taking into account of the extension of depletion region. [9]

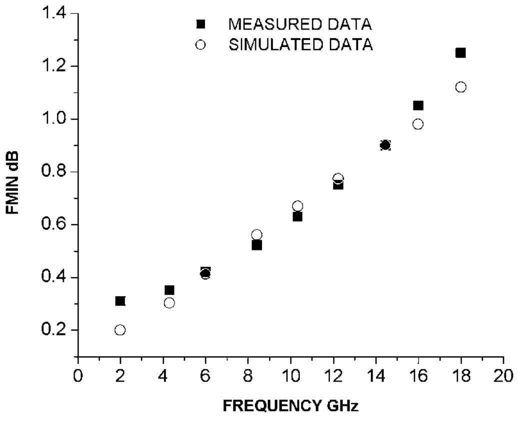

Fig. 5. Comparison of Measured and Simulated values of Fmin for NEC33200 [10].

IV. CONCLUSIONS

In this paper we have presented a noise model, which predicts accurately the noise performance of three devices reported earlier in the literature. In these cases the variation of noise figure with frequency as well as bias current have been studied and compared with the measured results. We have also demonstrated the general validity of our improved noise model by performing calculations of important noise parameter of a commercial HEMT (NEC 33200) and comparing them against the measured data provided by the manufacturer. Hence we conclude that the contribution of noise from extended depletion (region III) caused by the two-dimensional effects in short channel HEMTs, is significant and should be taken into account in the calculation of the Noise Figure.

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