High-Frequency Small-Signal and Noise Characterization of the E-mode pHEMT Fabricated Using Advanced ED25 Process Technology

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INTRODUCTION

The quarter micro gated ED-mode pHEMT was successfully developed using Wavetek ED25 process technology, a 0.25 um T-gate process exploiting low cost optical lithography. For the E-mode LNA 8x50um device, the noise figure is 0.6 dB and associated gain is 11 dB at 12GHz under the bias condition of V_{DS} = 3V and V_{GS} = 0.45V. To highlight its significant improvement over its forerunner ED50 process, the high-frequency small-signal characteristics of the E-mode pHEMT devices fabricated in both process technologies will be compared at the same DC power consumption in this paper.

The on-wafer two-port common-source s and noise parameters were measured on 8x50um pHEMT devices using Focus noise measurement system with microwave GSG probes. The OPEN and SHORT dummy structures were then used to perform the de-embedding procedure for s and noise parameters to eliminate the parasitic effects arising from the probing pads and connecting metal lines [1].

HIGH-FREQUENCY SMALL-GINAGL AND NOISE RELATED ELEMENT EXTRACTON

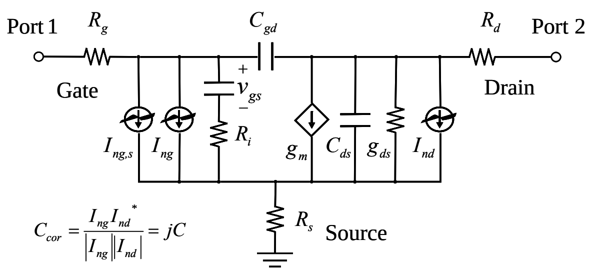

Figure 1 High-frequency small-signal and noise equivalent circuit for the pHEMT device.

Figure 1 shows the widely used high-frequency small-signal and noise equivalent circuit for the pHEMT device. It is very similar to that shown in ref [2], but for simplicity, the series inductances and the generation-recombination noise in the channel are excluded here. In this figure, the channel noise and its induced gate noise with correlation coefficient C_{cor} are represented by noise currents I_{nd} and I_{ng}, respectively, while $I_{ng,s}$ is the gate's shot noise current.

As usual, the series resistances R_g, R_d and R_s can be extracted using the Yang-Long method along with the COLD-FET approach [3][4], and the intrinsic small-signal elements can be directly determined from the intrinsic Y parameters manipulation. As to the noise currents, they can be deduced from the noise admittance representation of the intrinsic part, with the knowledge that $I_{ng,s}$, linked to the gate's DC leakage current I_G, can be estimated from the following expression:

$$I_{ng,s} = \sqrt{2qI_G\Delta f} \tag{1}$$

It should be noted that the series resistances have the resistive thermal noise, though it is not explicitly indicated by any noise source symbol here. Besides, a further parameter optimization procedure is always expected to be performed to obtain better s and noise parameter wide-band fitting results.

EXCELLENT HIGH-FREQUENCY PERFOMRANCE FOR ED25 PHEMT DEVICE

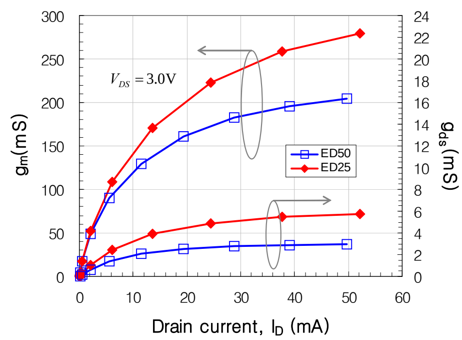

Figure 2 Trans-conductance and output conductance versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

The cut-off frequency (f_t) and maximum oscillation frequency (f_{max}) of a FET can be analytically expressed as the followings [5]:

$$f_t \approx \frac{g_m}{2\pi C_{gs}} \tag{2}$$

$$f_{max} \approx \frac{f_t}{2\sqrt{(R_g + R_i + R_s)g_{ds} + 2\pi R_g C_{gd} f_t}} \tag{3}$$

According to equations (2) and (3), the trans-conductance (g_m) and gate-to-source capacitance (C_{gs})

would play the major roles in determining these two figure-of-merits. Therefore, the larger g_m and smaller C_{gs} for ED25 as depicted in Fig. 2 and 3, respectively, can predict that ED25 would have better f_t and $f_{\max}$ than ED50 as shown in Fig 4.

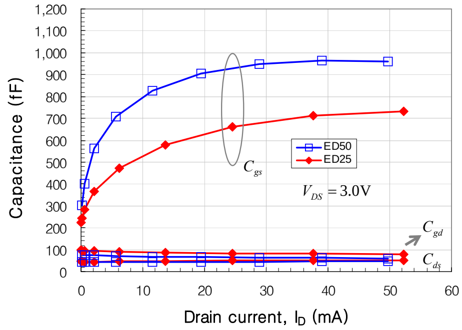

Figure 3 Gate-to-source, gate-to-drain and drain-to-source capacitances (C_{gs}, C_{gd}, and C_{ds}, respectively) versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

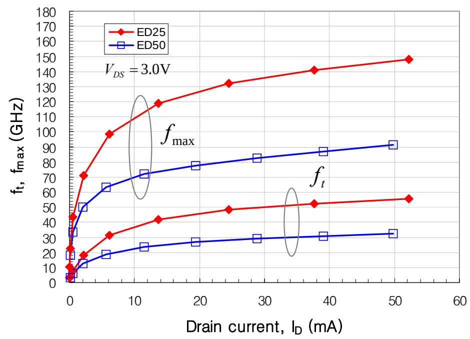

Figure 4 f_t and f_{max} versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

Figures 5 and 6, respectively show the power spectral density of channel noise (S_{id}) and gate noise (S_{ig}) versus drain current. To dismiss its frequency dependence, the gate noise is divided by the square of the operating frequency in GHz, and the result is designated as S_{ig0}. In addition, following the widely used PRC model, where S_{id}, S_{ig} and their correlation coefficient C_{cor} can be described as follows [6]:

$$S_{id} \equiv \frac{|I_{nd}|^2}{\Delta f} = 4kTg_m \cdot P \quad (4)$$

$$S_{ig} \equiv \frac{|I_{ng}|^2}{\Delta f} = 4kT\frac{(\omega C_{gs})^2}{g_m} \cdot R \quad (5)$$

$$C_{cor} \equiv \frac{I_{ng} \cdot I_{nd}^*}{|I_{ng}||I_{nd}|} = jC \quad (6)$$

, the corresponding noise coefficients of P and R for ED25 and ED50 devices can be extracted and depicted in Fig. 5 and 6, with their C values shown in Fig. 7.

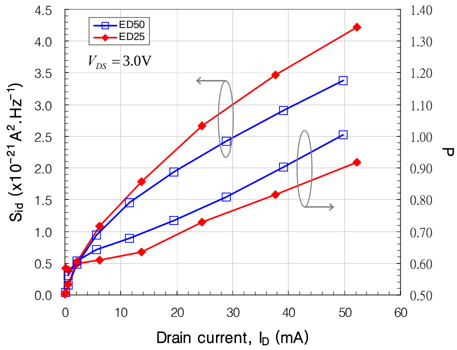

Figure 5 S_{id} and P versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

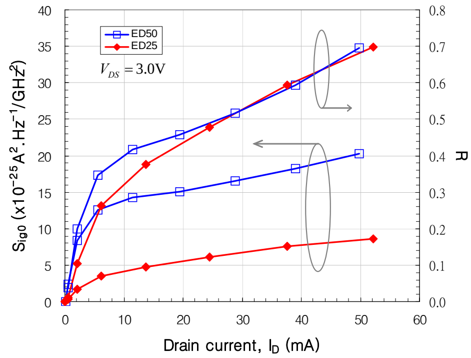

Figure 6 S_{ig0} and R versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

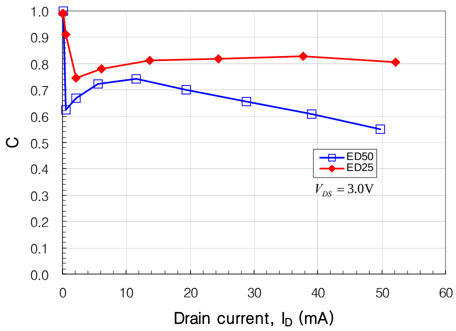

Figure 7 Correlation coefficient C versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

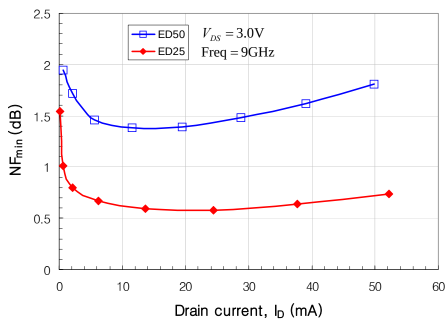

Figure 8 NF_{min} versus drain current at V_{DS} = 3.0V for ED25 and ED50 pHEMT devices.

Furthermore, considering that, for $I_{ng,s}$ much smaller than I_{ng} , the minimum noise factor $F_{\min}$ for a pHEMT device can be approximately expressed as [6]:

$$F_{\min} \approx 1 + 2\left(\frac{f}{f_{t,}}\right)\sqrt{K_g\left(K_r + g_m\left(R_g + R_s\right)\right)} \tag{7}$$

, where

$$K_g = \mathrm{P}\left[\left(1 - C\sqrt{R/\mathrm{P}}\right)^2 + \left(1 - C^2\right)R/\mathrm{P}\right], \text{ and} \tag{8}$$

$$K_r = \frac{R\left(1 - C^2\right)}{\left(1 - C\sqrt{R/P}\right)^2 + \left(1 - C^2\right)R/P}. \tag{9}$$

One can find that since ED25 has higher f_t and lower P (as shown in Fig. 2 and 5, respectively) compared to ED50, equation (7) suggests that ED25 pHEMT would have highly improved $F_{\min}$ at the low frequency region. This explained the better minimum noise figure $NF_{\min}$ presented in ED25 as shown in Fig. 8.

CONCLUSIONS

In this paper, we have demonstrated the high-frequency small-signal and noise performance of the E-mode device fabricated using Wavetek ED25 process technology. Due to its highly improved g_m , f_t and non-degenerate noise coefficients, ED25 has significantly improved performance over the ED50.

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