A SIMPLE BIAS DEPENDANT LF FET NOISE MODEL FOR CAD

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ABSTRACT

Extensive multi-bias low frequency noise (LFN) measurements were performed on MESFET, HEMT and InP HEMT devices in order to obtain a simple bias dependent LF noise model usable in CAD tools and consistent with small and large signal models and high frequency noise models. The model was experimentally evaluated with a 10 GHz DRO and good correspondence was obtained between the modelled and measured LFN.

INTRODUCTION

Oscillator Phase Noise (PN) is an important parameter of modern telecommunication systems and improvement of the PN results in the improved quality of the commutations with a smaller dissipated power and longer operating time for the portable systems. It has always been of great interest to improve the noise characteristics in all oscillator and mixer types using every kind of transistor in the oscillator and mixer circuits. Today GaAs FET and InP FET are used in a broad line of oscillator and mixer applications and LFN analyses and modeling is the subject of this paper. There is already a significant amount of papers published on the subject [1-14] but still there is a need of understanding how to improve the LFN of FET devices, how LFN is up-converted and for a simple, bias dependent LFN Noise model for CAD applications. The model should be consistent with the small and large signal models and with the high frequency noise models.

DEVICE MODELING

Extensive, multiple bias LFN measurements with or without LO signal at the input were performed on different MESFET, HEMT and several InP HEMT devices in order to collect sufficient data for understanding how the LFN changes with the bias voltages and up converted. LF noise measurements were performed at Vgs and Vds voltages covering both the linear and saturated regions of operation using a HP3567 dynamic analyzer. From the measured LF gain and output noise characteristics the noise translated to the input can be calculated. This is the simplest way to model LFN when the model is needed for fixed bias point. Fig. 1, 2, 3 show typical results for some bias points for MESFET (MGF1303), HEMT (MGF4419) and InP HEMT. A known problem is that these characteristics do not describe the up-conversion of the LFN to the LO phase noise properly.

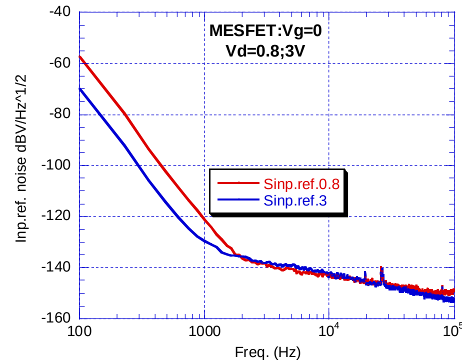

Fig.1. MESFET input ref noise Vg=0

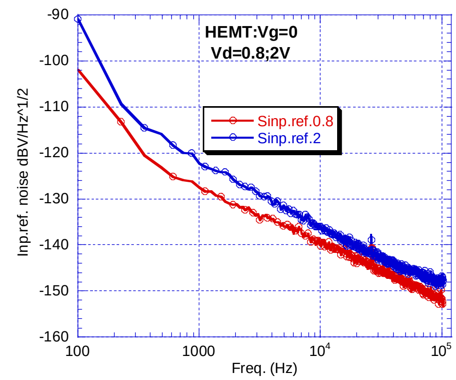

Fig.2. HEMT input ref noise, Vg=0

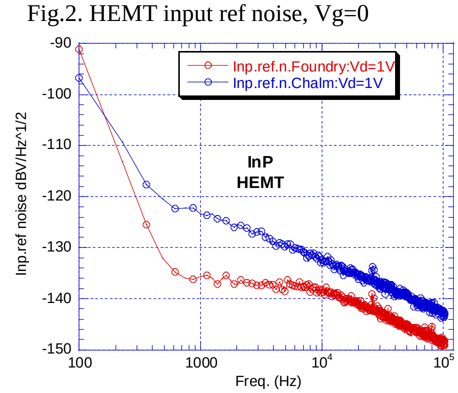

Fig.3. InP HEMT input ref noise Vg=0

This discrepancy can be overcome and much better accuracy can be obtained by measuring the transistor LF noise with a large input signal applied at the gate [9].

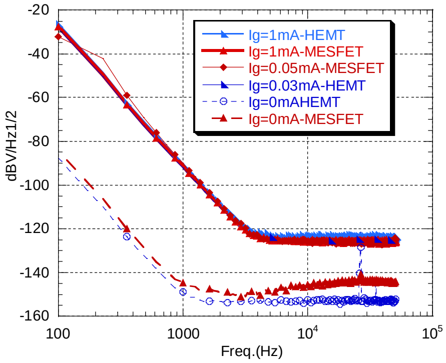

Fig.4. Gate noise characteristics

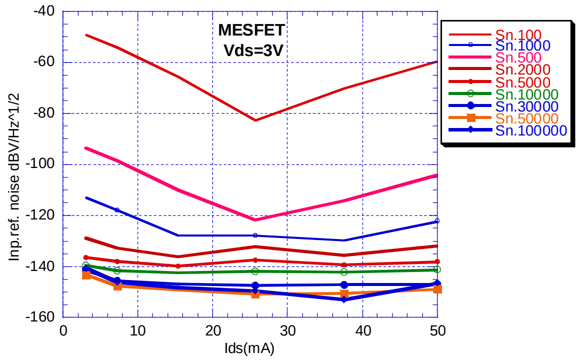

Fig 5. MESFET input ref. noise. Vds=3

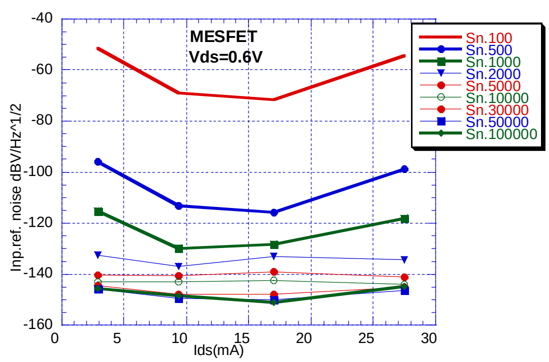

Fig. 6. MESFET input ref noise. Vds=0.6

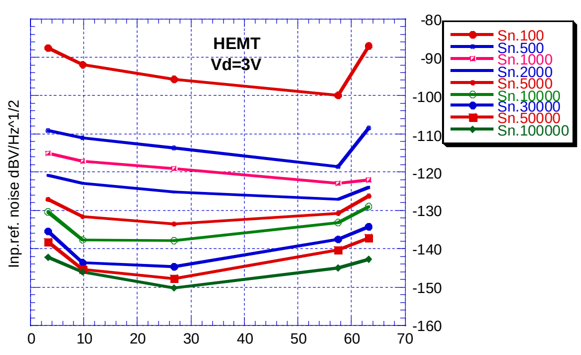

Fig. 7. HEMT input ref. noise Vds=3

One of the reasons for these discrepancies (when the LFN is measured without the LO signal) occurs because the LFN is usually measured with the gate Schottky diode reverse biased and in these conditions the gate noise is very small (Fig. 4). With the presence of a small gate current there is a significant increase of the LFN in all of the devices we have studied. Similar results were obtained in [14]. Often, when the FET in oscillator is biased to have a high transconductance, due to the large gate voltage swing there is a gate current and a significant contribution of the PN is due to up-converted LFN of the Schottky diode of the gate. The LFN from the diode part can be described with the following equation:

$$\overline{I^2_{gaten}} = 2.e.I_{gate}.\Delta f + kf\,\frac{I_{gate}{}^{AF}}{f} \quad (1)$$

For all of the transistors the LFN changes with the drain current- Fig. 5-10 and these should be accounted for LFN model. The equivalent circuit of the transistor including the noise generators is shown in Fig. 11. The noise current generators connected at the input and output are:

$$I_{dt} = |I_{ds}| + |I_{gd}| \quad (2)$$

$$I_{dn} = 4kTt_{mn}\sqrt{I_{dt} + K_{nd2}I_{dt}^{\,2}}\,(1 + Klfd)(w10^{-2})$$

$$I_{gn} = 4kT(I_{gate} + I_{dt}/K_{ng1})(1 + Klfg)(2w\cdot 10^{-2}) \quad (3)$$

where K_{ng1}, t_{mn} and K_{nd2} are fitting coefficients and ***w*** is the device size in mm and K_{lfd}, K_{lfg} are extensions for the LFN. The coefficient t_{mn} is equal tmn= T_d/T_{amb} and shows how much the noise temperature of R_{ds} is higher then the ambient T_{amb}. This equation is in fact a large signal representation of Pospieszalski noise model [11] with a LFN extension. In MESFET and HEMTs the noise generated is higher than the pure Johnson noise generated by the channel current (resp. drain resistance R_{ds}) and can be considered as a noise created by R_{ds}, but working at temperature T_d higher then the ambient T_{amb}.

The coefficients t_{mn}, K_{nd2} *reflect* the effect of impact ionization and K_{nd2} describe the sharp increase of the noise at high drain currents. The low frequency part of the noise contribution consists of two parts – the flicker noise (1/f) and the generation/recombination noise (GRN). The flicker noise is typically attributed to traps associated with the contaminations, crystal and surface defects and it is bias dependent. The GRN is observed in nearly every FET device and is due to trapping. It is bias and temperature dependent. The main LFN contribution comes from the input where the 1/f noise is usually dominant. In some devices GRN can be found [14] that is why 1/f and GR noise at the input and output can be described with one and the same formula as:

$$K_{lfg} \approx K_{llfd} \approx K_{lf}\left(\frac{1}{f^{n}} + \frac{B}{1+(\frac{f}{Fgr})^{2}}\right) \quad (4)$$

where Klf is the noise at 1 Hz, B and Fgr are parameters of the GRN,Table1. When several trapping processes exist more terms should be to added eq.4.

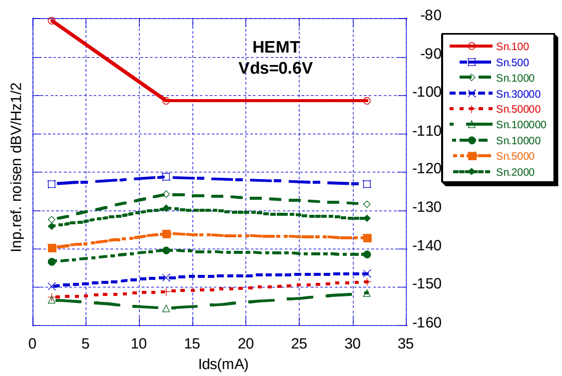

Fig. 8. HEMT input ref noise. Vds=0.6

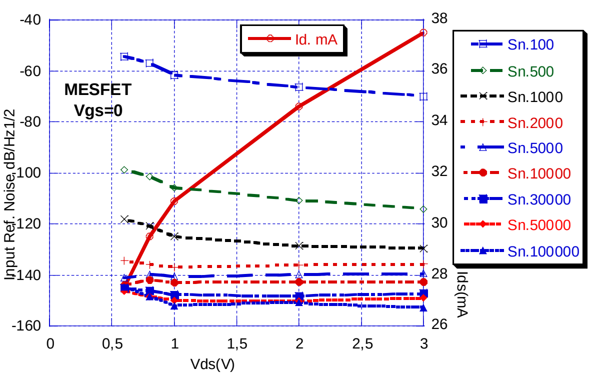

Fig.9. MESFET input ref. noise vs. Vd; Vgs=0

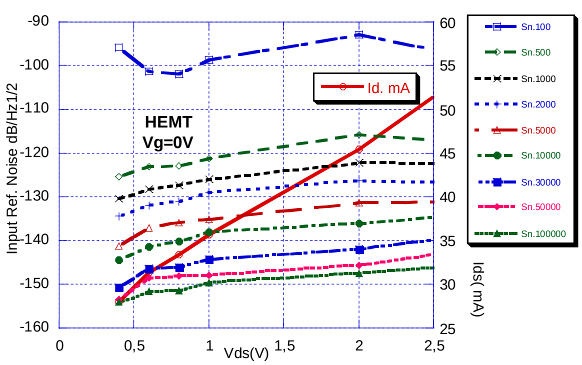

Fig.10. HEMT input ref. noise vs. Vd: Vgs=0

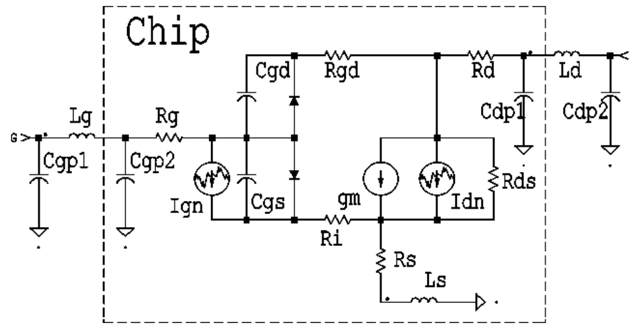

Fig. 11. Equivalent circuit of the transistor

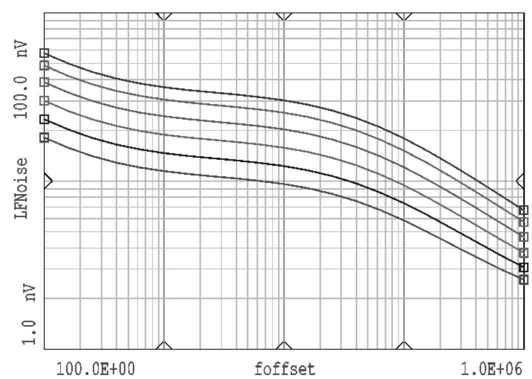

Fig. 12.Simulated LF noise, Vg=0,Vd=3,Pin=-10->0dbm

Working with such a definition of the noise model when the large signal model is available [15,16], allows us to use the current equation from the large signal model directly. The LFN model was implemented as a user-defined model in MDS-HP and in fig. 12 is shown simulated LF noise of a MESFET.

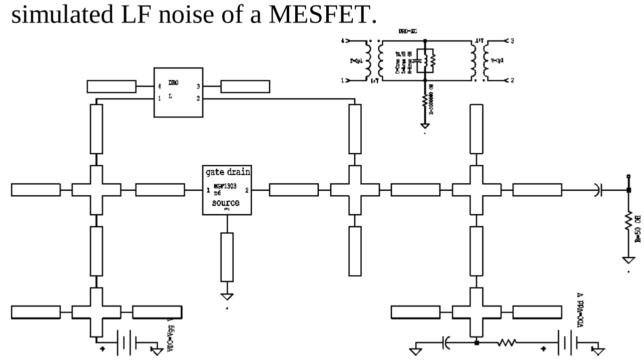

Fig.13. Equivalent circuit of the oscillator

In order to evaluate the model a 10 GHz DRO was built. The oscillator is a parallel configuration DRO connected between the drain and gate and the EQ circuit of the oscillator is shown on Fig. 13. The resonator was modelled as a parallel tank circuit connected with the coupling transformer. The loaded quality factor of the resonator in the experimental configuration was measured using injection locking and was estimated to Q=250.

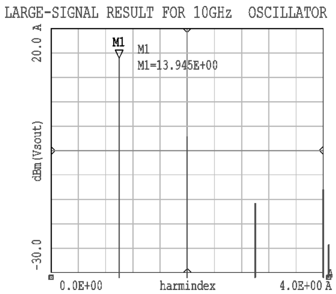

Fig.14. Simulated oscillator output

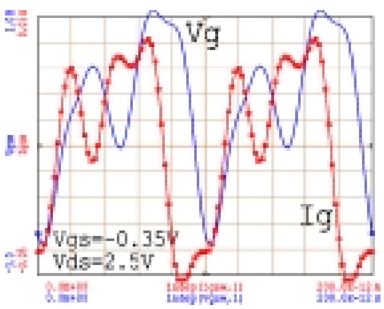

Fig.15. Simulated gate voltage and current

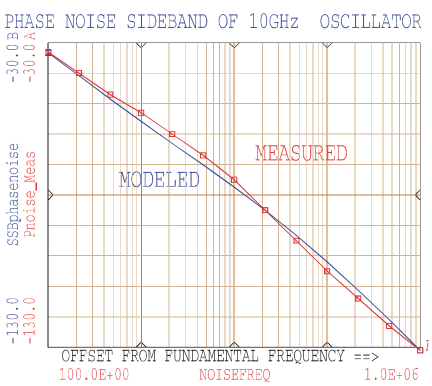

Fig.16. Simulated and measured phase noise.

The simulated output spectrum and gate voltage and current are shown in Fig. 14,15. From the simulated waveform can be seen that the gate voltage swing is very large and the instantaneous gate current can reach very high values with such output power and will influence the LFN.

The measured and simulated phase noise of the oscillator is shown on Fig. 16. The correspondence between the simulated and measured PN is better than 3 dB.

CONCLUSIONS

A simple bias dependent LFN model applicable to CAD tools and consistent with small and large signal models and with high frequency noise models was proposed. The model was experimentally evaluated with a 10 GHz DRO and good correspondence was obtained between the modelled and measured phase noise.

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Table1

t_{mn}	K_{nd2}	K_{ng1}	K_{lf}	*n*	F_{gr}kHz	B
3.93	0.016	80	$1.5*10^{14}$	0.3	60	1.5