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RF Small-Signal and Noise Modeling for SOI Dynamic Threshold Voltage MOSFETs

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1. Introduction

The Dynamic Threshold Voltage (DT) MOSFET is attractive for low power applications. Especially, several investigations have demonstrated its ability of RF applications with high cut-off frequency (f_t) and maximum oscillation frequency (f_{max}) [1-2]. However, a physical RF small-signal model along with an efficient parameter extraction method is needed. In this paper, we will conduct RF small-signal modeling and demonstrate a practical extraction method to facilitate the extraction work with physical accuracy.

In addition, based on the small-signal model structure, the RF noise model for DT MOSFETs will be built for the first time. This model can capture the noise behavior well. Finally, the effect of inherent access body resistance on the small-signal and noise performances will also be examined.

2. Device

The device used in this experiment was fabricated by UMC 65nm PD SOI technology, and the device geometry for gate length, finger length, finger number, and group number are $0.24\,\mu m$, $1\,\mu m$, 8, and 16, respectively. All the RF scattering (s) parameters and noise parameters were measured up to 12GHz, and the corresponding open dummy was used to eliminate the on-wafer probing pad parasitics. To further extract the series resistances, the proposed zero method has also been used [3].

3. Model and Discussion

The small-signal equivalent circuit for PD SOI DT MOSFETs has been presented [4] and is depicted in Fig. 1. For simplification, the neutral-body path between the two junction capacitances is ignored due to its lower effect below GHz [5]. Based on this circuit, its simple and analytic two-port admittance (Y) parameters can be derived when the effect of series resistances are neglected. Figure 2 shows some of the derived expressions benefiting the parameter extraction, and the suggested extraction procedure is shown in Fig. 3. Compared to the method proposed in [4], our extraction method relies only on local optimizations with definite fitting targets and model parameters, so the excellent Y parameter modeling results as shown in Fig. 4 can be expected.

Furthermore, based on the RF small-signal equivalent circuit, the RF noise equivalent circuit can be built by adding the corresponding noise current sources and is shown in Fig. 5. In this figure, $\overline{i_d}$ stands for the intrinsic channel noise current, and the high-frequency prominent drain-induced gate noise is neglected. Besides, the noise current sources related to series resistances and access body resistance are considered as thermal noise current sources ($\bar{i} = \sqrt{4kT/R}$). Finally, the inherent shot noise current caused by the source-side junction leakage current can be estimated using $\overline{i_{shot}} = \sqrt{2qI_g}$.

The only one unknown model parameter $\overline{i_d}$ can be directly extracted by optimizing the four high-frequency noise parameters ($NF_{min}, R_n, |\Gamma_{opt}|,$ and $\angle\Gamma_{opt}$). The good modeling results up to 12GHz are shown in Fig. 6. It is worth noting that both the measured and modeled equivalent thermal resistance (R_n) tend to decrease at low frequencies and then rebound at higher frequencies, and this is different from the conventional MOSFETs, which commonly have a monotonically decreasing R_n with frequency.

Since the RF small-signal and noise model have been built, the effect of parasitic access body resistance on the small-signal and noise behaviors can be examined. Figures 7 and 8 shows its impact on f_t and f_{max} , respectively. One can find that the decrease of R_b would benefit f_{max} but degrade f_t . In addition, its impact on noise performance is shown in Fig. 9 It shows that, for lower R_b , the lower NF_{min} and R_n can be achieved. Especially, R_b is found to have the greatest influence on R_n , which can be decreased to about 40% of the measured result if R_b approaches zero.

4. Conclusions

In this paper, we have demonstrated the RF small-signal and noise modeling for SOI DT MOSFETs. Based on a set of simple and analytic expressions of Y parameters, the model parameters can be physically extracted, and the model has been shown to be valid up to 12GHz. The abnormal frequency dependence occurred in R_n was also observed and modeled. Finally, the inherent R_b has been shown to have significant influence on both the small-signal and noise performances.

Acknowledgement

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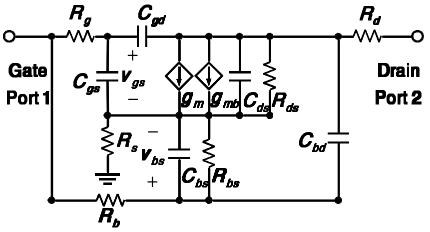


Fig. 1 RF small-signal equivalent circuit for the SOI DT MOSFET.

$$\Delta = R_b R_{bs}(C_{bs}+C_{bd})$$

$$den = (R_b+R_{bs})^2+\omega^2\Delta^2$$

$$Re(Y_{11}) = \frac{(R_b+R_{bs})+\omega^2\Delta^2/R_b}{den} \quad (1)$$

$$\frac{Im(Y_{11})}{\omega} = (C_{gs}+C_{gd})+\frac{\Delta^2/[R_b^2(C_{bs}+C_{bd})]}{den} \quad (2)$$

$$Re(Y_{gain}) = Re(Y_{21}-Y_{12}) = g_m+\frac{g_{mb}\Delta(R_b+R_{bs})/[R_b(C_{bs}+C_{bd})]}{den} \quad (3)$$

$$\frac{Im(Y_{gain})}{\omega} = \frac{Im(Y_{21}-Y_{12})}{\omega} = -g_m\tau-\frac{g_{mb}\Delta^2/[R_b(C_{bs}+C_{bd})]}{den} \quad (4)$$

$$Re(Y_{22}) = \frac{1}{R_{ds}} + \frac{\omega^2\Delta C_{bd}[g_{mb}\Delta+C_{bd}(R_b+R_{bs})]/(C_{bs}+C_{bd})}{den} \quad (5)$$

$$\frac{Im(Y_{22})}{\omega} = (C_{gd}+C_{ds}) + \frac{C_{bd}(R_b+R_{bs})[(R_b+R_{bs})+g_{mb}\Delta/(C_{bs}+C_{bd})]}{den} + \frac{\omega^2\Delta^2 C_{bd}[(C_{bs}+C_{bd})-C_{bd}]/(C_{bs}+C_{bd})}{den} \quad (6)$$

$$\frac{Im(Y_{12})}{\omega} = -C_{gd}-\frac{C_{bd}\Delta(R_b+R_{bs})/[R_b(C_{bs}+C_{bd})]}{den} \quad (7)$$

Fig. 2 Analytic expressions for *Y* parameters.

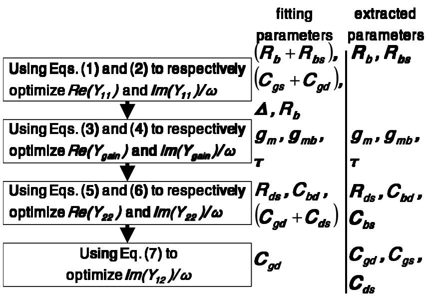


Fig. 3 Proposed extraction flow.

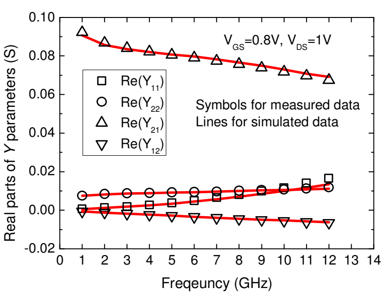
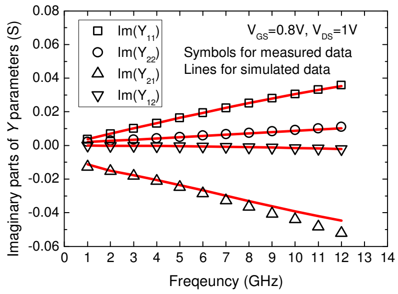


Fig. 4 (a)



(b)

g_m (mS)	R_{ds} (Ω)	C_{gs} (fF)	C_{gd} (fF)	C_{ds} (fF)	τ (ps)	g_{mb} (mS)	R_b (Ω)	R_{bs} (Ω)	C_{bs} (fF)	C_{bd} (fF)	$\overline{i_d}$ (pA/$\sqrt{Hz}$)
127	93	550	79	1.3	1.6	38	597	2083	246	20	60

(c)

Fig. 4 Modeling results for (a) $Re(Y)$ and (b) $Im(Y)$ with (c) extracted values.

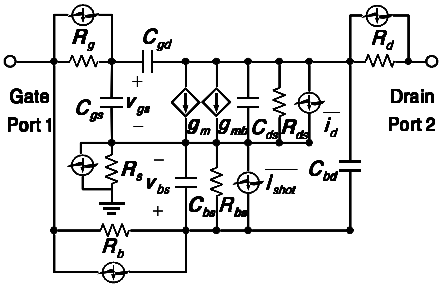
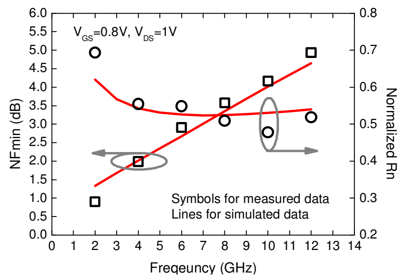
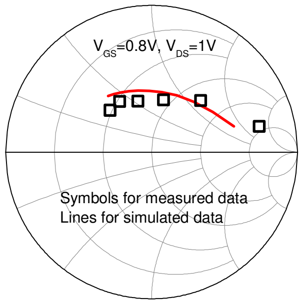


Fig. 5 RF noise equivalent circuit for the SOI DT MOSFET.



(a)



(b)

Fig. 6 Noise modeling results for (a) NF_{min}, R_n, and (b) Γ_{opt}.

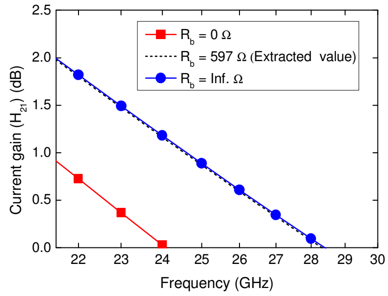


Fig. 7 The impact of R_b on f_t.

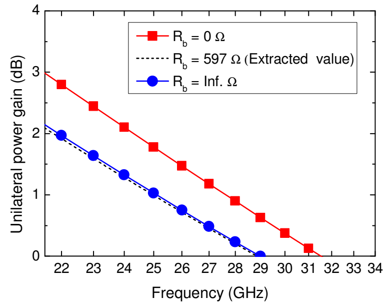
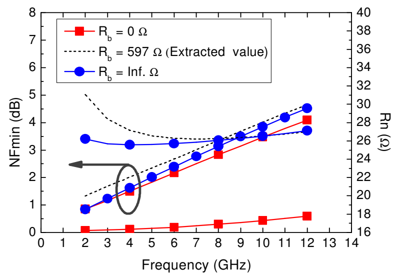
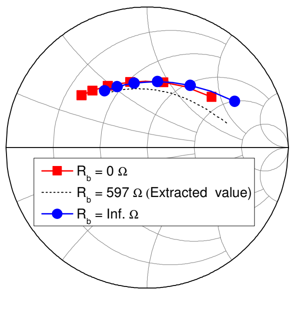


Fig. 8 The impact of R_b on f_{max}.



(a)



(b)

Fig. 9 The impact of R_b on (a) NF_{min}, R_n, and (b) Γ_{opt}.