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Non-Quasi-Static Small-Signal Model of RF MOSFETs Valid up to 110 GHz

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Abstract **— A complete non-quasi-static (NQS) model of RF MOSFETs is presented for 110 GHz application. Direct extraction of all the parameters was performed without any optimization. The total modeling error of *Y*-parameters up to 110 GHz was calculated to be below 5 %. Bias dependency of the small-signal parameters is presented.**

I. NON-QUASI-STATIC SMALL-SIGNAL MODEL OF RF MOSFETS AND ITS PARAMETER EXTRACTION

For modeling of RF MOSFETs, NQS effect and substrate resistance network model are important at high frequency close to and higher than f_T. Fig. 1 shows the complete non-quasi-static small-signal equivalent circuit with π-type substrate resistance network of the RF MOSFET. R_{gs} and R_{gd} are the distributed channel resistance for representing the charging delay by the non-quasi-static effect. Fig. 2 and 3 show the Rpoly and substrate related parameters extracted from measurement data. The equivalent circuit can be analyzed in terms of Y-parameters as follows.

$$Y_{gg} \approx \omega^2\left(R_{gs}C_{gs}^2 + R_{gd}C_{gd}^2\right) + j\omega\left(C_{gs} + C_{gd} + C_{gb}\right) \quad (1)$$

$$Y_{gd} \approx -\omega^2 R_{gd}C_{gd}^2 - j\omega C_{gd} \quad (2)$$

$$Y_{dg} \approx g_m - \omega^2 R_{gd}C_{gd}^2 - j\omega\left(g_m\tau_m + C_{gd}\right) \quad (3)$$

$$Y_{dd} \approx g_{ds} + \omega^2\begin{pmatrix} R_{gd}C_{gd}^2 \\ + g_{mb}R_{sub.eq.}{}^2 C_{jd}\left(C_{jd} + C_{js} + C_{bd} + C_{bs}\right) \\ + g_{mb}\tau_m R_{sub.eq.}\left(C_{jd} + C_{bd}\right)\end{pmatrix} \quad (4)$$
$$+ j\omega\left(C_{gd} + g_{mb}R_{sub.eq.}\left(C_{jd} + C_{bd}\right) - g_{ds}^2 L_{sd}\right)$$

$$R_{sub.eq.} = \frac{R_{db} \times \left(R_{sb} + R_{dsb1} + R_{dsb2}\right)}{R_{db} + R_{sb} + R_{dsb1} + R_{dsb2}} \quad (5)$$

With theses expressions, we can directly extract the small-signal parameters. We also extracted C_{bd}, C_{bs} and C_{gb} from 3-port measurement [2],

$$\mathrm{Im}\left(Y_{gb}\right) \approx -j\omega C_{gb} = -j\omega\left(C_{gbo} + C_{gbi}\right) \quad (6)$$

$$\mathrm{Im}\left(Y_{bs}\right) \approx -j\omega\left(C_{bs} + C_{js}\right) \quad (7)$$

$$\mathrm{Im}\left(Y_{bd}\right) \approx -j\omega\left(C_{bd} + C_{jd}\right) \quad (8)$$

From 3-port measurement results, we extracted C_{bd} + C_{jd}, C_{bs} + C_{js} and plot them as a function of effective channel length in Fig. 4. C_{bd} and C_{bs} are proportional to the channel length. Therefore, we can extract C_{jd} and C_{js} from the Y-intercept. C_{bd} and C_{bs} were 1.4 fF and 5.1 fF. R_{bs} and R_{bd} were extracted by relationships of $\tau_{gs} = R_{gs}C_{gs} = R_{bs}C_{bs}$ and $\tau_{gd} = R_{gd}C_{gd} = R_{bd}C_{bd}$ presented in [2].

In Fig. 5, the *Y*-parameters simulated with the extracted parameters were compared with the measured data up to 110 GHz at $V_{GS} = V_{DS} = 1\ V$. For the 0.13-μm device, NQS effect was visible above around 20 GHz, which is approximately 30 % of the f_T, indicating that accurate high frequency characteristic prediction with the QS model is impossible due to NQS effects, and that the NQS model must be used. The NQS model agreed well with the measured Y-parameters above f_T as shown in Fig. 5. Fig. 5 also shows the results obtained using T-model and single resistance model as substrate resistance model, compared with π-type model. The accuracy of modeling was better improved due to the excellence of the physical modeling structure and the accurate extraction of the substrate resistance. Fig. 6 (a)~(d) show the extracted results of conductances, intrinsic capacitances, distributed channel resistances, and transport delay as a function of bias. Fig. 6(c) shows the distributed channel resistance as a function of drain bias. As shown in Fig. 6(c), R_{gd} increases due to the velocity saturation. Fig. 6(d) shows the extracted time constants as a function of bias.

II. CONCLUSION

A complete non-quasi-static small-signal modeling of RF MOSFET was presented. The total RMS modeling error of *Y*-parameter up to 110 *GHz* for 0.13 μm RF nMOSFET was calculated to be below 5 %. Finally, we extracted the device parameters of MOSFETs at different bias.

ACKNOWLEDGEMENT

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REFERENCES

[1] M. K. Je, J. H. Han, H. C. Shin, and K. R. Lee, "A Simple Four-Terminal Small-Signal Model of RF MOSFETs and its Parameter Extraction," *Microelectronics Reliability*, pp. 601-609, April 2003.

[2] Y. Tsividis, Operation and Modeling of the MOS Transistor, 2nd ed. New York: McGraw-Hill, 1999.

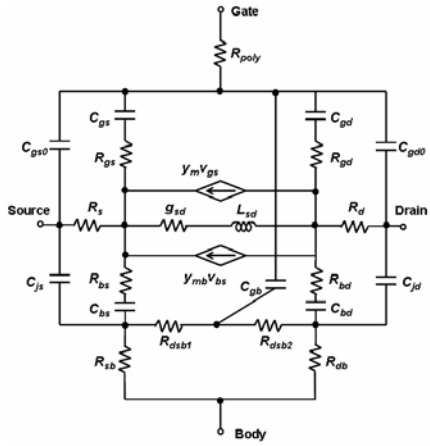


Fig. 1. A small-signal non-quasi-static (NQS) equivalent circuit of a RF MOSFET.

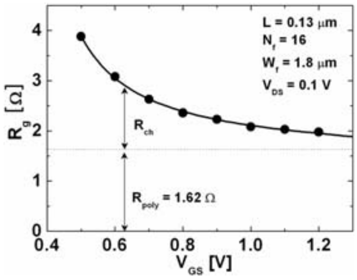


Fig. 2. Gate bias dependency of the effective gate resistance. (0.13 μm nMOSFET having 16 fingers with 1.8-μm unit finger width)

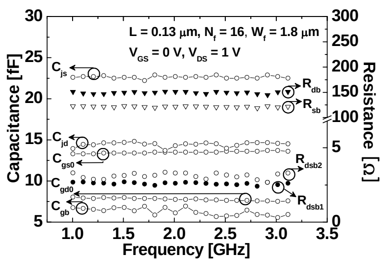


Fig. 3. The substrate-related parameters extracted at zero gate voltage.

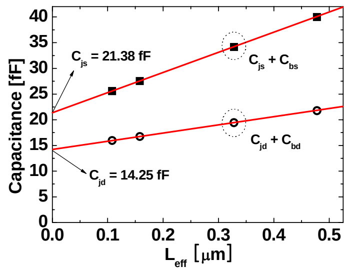
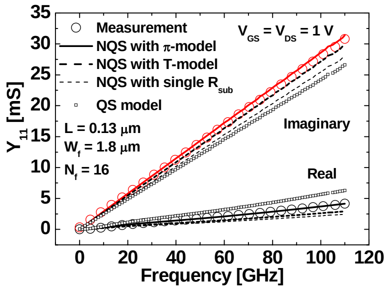
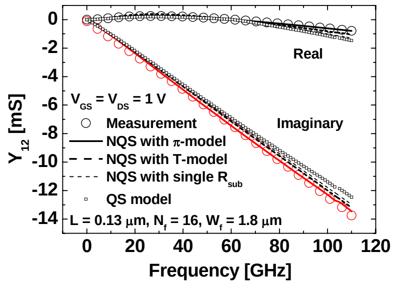


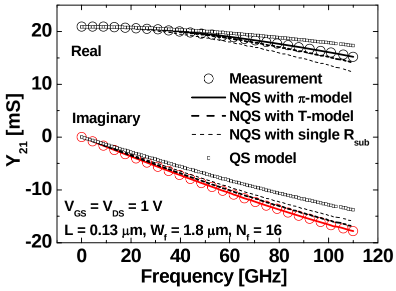
Fig. 4. C_{js} + C_{bs} and C_{jd} + C_{bd} from 3-port measurement data versus effective channel length L_{eff}.



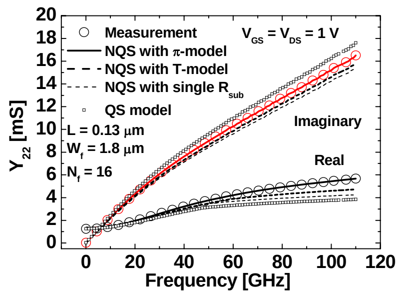
(a)



(b)

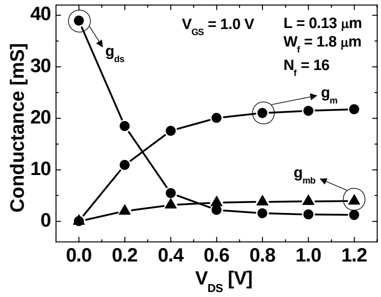


(c)

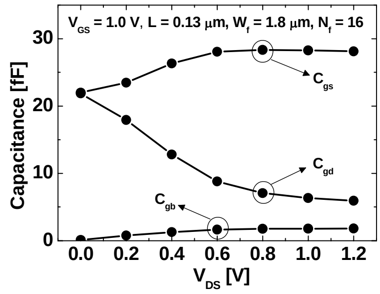


(d)

Fig. 5. Y-parameters verification of measurement (symbol: circle), proposed NQS model (solid line), and QS model (symbol: rectangular) presented in [1] for the 0.13 μm n-MOSFETs biased to V_{GS} = 1 V and V_{DS} = 1 V (Saturation region). (a) Y_{11}, (b) Y_{12}, (c) Y_{21}, and (d) Y_{22}.



(a)



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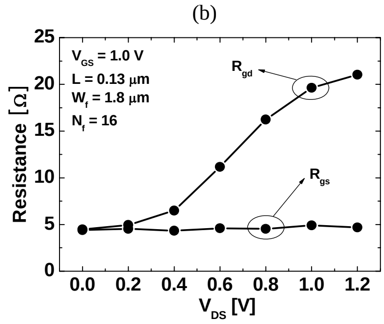

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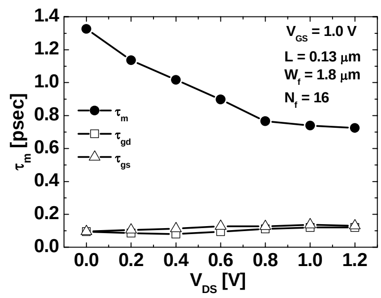

(d)

Fig. 6. (a) conductance g_m, g_{ds}, g_{mb}, (b) intrinsic capacitance Cgd, Cgs, Cgb, (c) resistance Rgd, Rgs, and (d) transport and charging delay as s function of bias.