Extraction of Substrate Resistance Parameters for RF MOSFETs Based on Three-Port Measurement

In Man Kang and Hyungcheol Shin
Inter-University Semiconductor Research Center (ISRC),
and School of Electrical Engineering,
Seoul National University, San 56-1, Shinlim-dong, Kwanak-gu, Seoul 151-742, Korea
Tel: (822) 880-7282, Fax: (822) 882-4658, e-mail: niceinmy@dreamwiz.com

Abstract

In this work, a new method for extracting substrate parameters of RF MOSFETs based on 3-port measurement is presented using device simulation. A T-type substrate resistance network is used. 3-port Y-parameter analyses were performed on the equivalent circuit of RF MOSFETs. All the components in the RF MOSFETs when the device is turned off were extracted directly from the 3-port device simulation data. The small-signal output admittance Y_{22} can be well modeled up to 40 GHz. From the 3-port simulation and modeling results, it was verified that the proposed equivalent circuit and parameter extraction method was more accurate than the single substrate resistance model.

I. Introduction

It is known that the substrate resistances have significant effect on output characteristics of radio frequency metal oxide semiconductor field effect transistors [1]-[2]. However, the substrate resistances were simplified to a single substrate resistance in some of the conventional models. Earlier reports even optimized substrate resistances by curve fitting techniques. It is due to that RF MOSFETs were always measured in conventional two-port common source configuration. Although a simple model with a single substrate resistance has been shown to be accurate up to 10 GHz, it deviates from the measured data at high frequencies above 10 GHz. Models with more substrate resistance components have been reported. However, complex optimization was used to extract the resistance components.

In this work, an extraction method based on three-port device simulation data is proposed. All the components of the substrate-signal coupling network including junction capacitances and substrate resistances can be directly extracted from the device simulation raw data. The modeled output admittance was also shown to match well with the simulated one up to 40 GHz.

II. Three-port Extraction Method

Fig. 1 shows a small-signal equivalent circuit of RF MOSFET in turn-off region [1]. When the gate voltage V_{GS} is 0 V. C_{gs0} and C_{gd0} represent the gate to source and gate to drain extrinsic capacitances, respectively. C_{gb} is the capacitance between gate and body. C_{js} and C_{jd} represent the junction capacitance of source and drain, respectively. R_{sb}, R_{db}, and R_{bb} represent resistances from source and drain to body, and body series resistance, respectively.

A 3 x 3 Y-parameter matrix can be obtained by three-port measurement.

$$\begin{bmatrix} i_G \\ i_D \\ i_S \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GD} & Y_{GS} \\ Y_{DG} & Y_{DD} & Y_{DS} \\ Y_{SG} & Y_{SD} & Y_{SS} \end{bmatrix} \begin{bmatrix} v_G \\ v_D \\ v_S \end{bmatrix} \qquad (1)$$

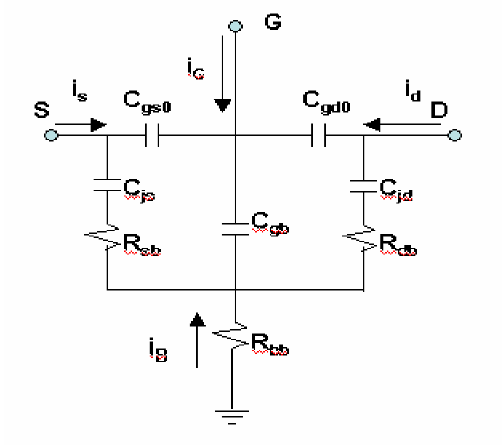


Fig. 1. Equivalent circuit of the RF MOSFET when the device is turned off and the intrinsic components are negligible.

The small-signal equivalent circuit shown in Fig. 1 can be analyzed in terms of Y-parameters. Some of Y-parameters are given by the following equations :

$$Y_{GG} \cong \omega^2 R_{bb} c_{gb}{}^2 + j\omega(C_{gs0} + C_{gb} + C_{gd0}) \tag{2}$$

$$Y_{DG} \cong \omega^2 C_{jd} C_{gb} R_{bb} - j\omega C_{gd0} \tag{3}$$

$$Y_{SG} \cong \omega^2 C_{js} C_{gb} R_{bb} - j\omega C_{gs0} \tag{4}$$

$$Y_{GD} \cong \omega^2 R_{bb} C_{gb} C_{jd} - j\omega C_{gd0} \tag{5}$$

$$Y_{DD} \cong \omega^2 C_{jd}{}^2 (R_{db} + R_{bb}) + j\omega\left(C_{jd} + C_{gd0}\right) \tag{6}$$

$$Y_{SD} \cong \omega^2 C_{js} C_{jd} R_{bb} - j\omega^3 R_{bb} R_{sb} C_{js}{}^2 C_{jd} \tag{7}$$

$$Y_{GS} \cong \omega^2 R_{bb} C_{gb} C_{js} - j\omega C_{gs0} \tag{8}$$

$$Y_{DS} \cong \omega^2 R_{bb} C_{jd} C_{js} - j\omega^3 R_{bb} R_{db} C_{js} C_{jd}{}^2 \tag{9}$$

$$Y_{SS} \cong \omega^2 C_{js}{}^2 \left(R_{bb} + R_{sb}\right) + j\omega\left(C_{gs0} + C_{js}\right) \tag{10}$$

Using equations (2)~(10), C_{gd0}, C_{gs0}, C_{gb}, C_{js}, C_{jd}, R_{sb}, R_{db}, and R_{bb} can be extracted from the Y-parameters.

$$C_{gd0} = -\frac{\mathrm{Im}\left(Y_{DG}\right)}{\omega} \tag{11}$$

$$C_{gs0} = -\frac{\mathrm{Im}\left(Y_{SG}\right)}{\omega} \tag{12}$$

$$C_{gb} = \frac{\mathrm{Im}\left(Y_{GG}\right) + \mathrm{Im}\left(Y_{DG}\right) + \mathrm{Im}\left(Y_{SG}\right)}{\omega} \tag{13}$$

$$C_{jd} = \frac{\mathrm{Im}\left(Y_{DG}\right) + \mathrm{Im}\left(Y_{DD}\right)}{\omega} \tag{14}$$

$$C_{js} = \frac{\mathrm{Im}\left(Y_{SG}\right) + \mathrm{Im}\left(Y_{SS}\right)}{\omega} \tag{15}$$

$$R_{bb} = \frac{\mathrm{Re}\left(Y_{SD}\right)}{\omega^2 C_{jd} C_{js}} \tag{16}$$

$$R_{db} = \frac{\mathrm{Re}\left(Y_{DD}\right)}{\omega^2 C_{jd}{}^2} - R_{bb} \tag{17}$$

$$R_{sb} = \frac{\mathrm{Re}\left(Y_{SS}\right)}{\omega^2 C_{js}{}^2} - R_{bb} \tag{18}$$

0.18-μm nMOSFETs with 10-μm-width were simulated for frequencies up to 40 GHz using ATLAS. Fig. 2 and 3 show the extracted results of C_{gd0}, C_{gs0}, C_{gb}, C_{sb}, C_{db}, R_{sb}, R_{db}, and R_{bb} from the device simulation data. The bias conditions are V_{DS} = 0 V and 1 V at zero gate bias. Fig. 2 and 3 show that the extracted parameters remain almost constant with frequency and verifies that the proposed model and extraction method is accurate and reliable.

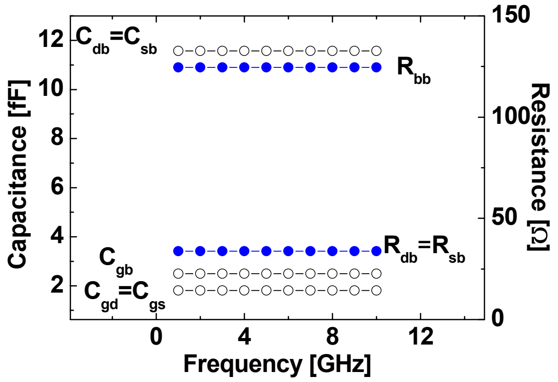


Fig. 2. Small-signal parameters extracted at $V_{GS} = V_{DS}$ = 0 V.

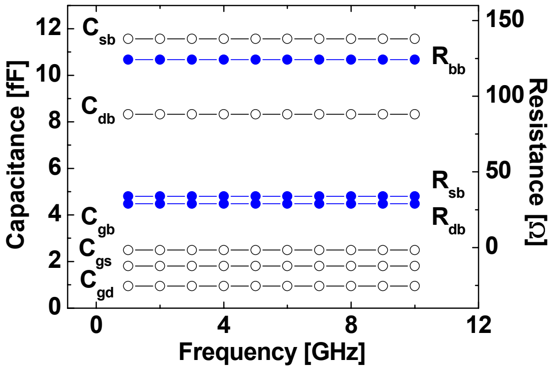
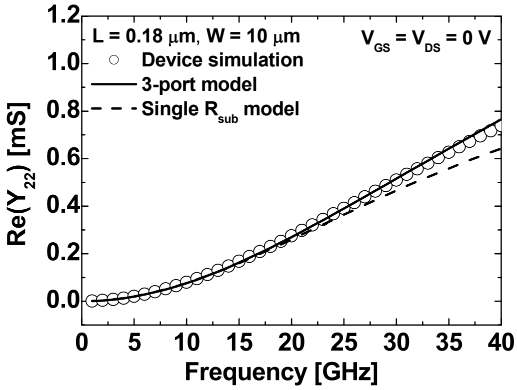
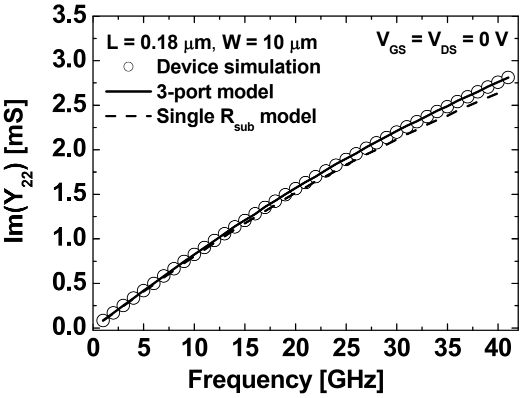


Fig. 3. Small-signal parameters extracted at V_{GS} = 0 V and V_{DS} = 1 V.

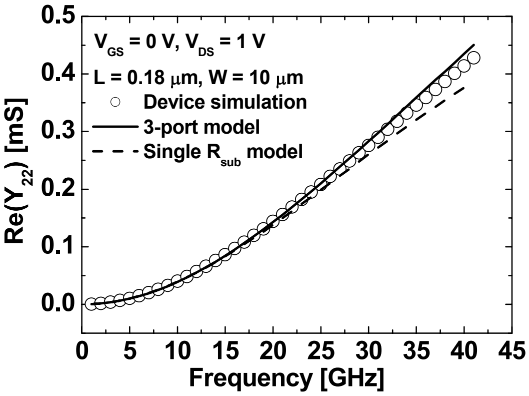
To verify the validity of the proposed method, the modeled output admittances were compared with the simulated ones. Fig. 4 (a)~(d) show the simulated and modeled Y_{22} which the substrate resistance affects most. The modeled Y-parameters match well with the simulated ones up to 40 GHz. This indicates that the extracted resistance components extracted by the method in this paper are valid up to 40 GHz. The model with a single substrate resistor was also presented in Fig. 4 as dashed lines. Note that the single resistor models deviate from the simulated ones for frequencies higher than 20 GHz.



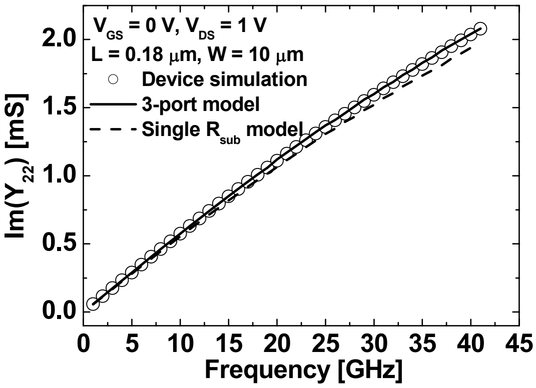
(a)



(b)



(c)



(d)

Fig. 4. Modeled and simulated Re[Y_{22}] for frequencies up to 40 GHz. Single R_{sub} model is denoted by dashed lines. (a) Re(Y_{22}) at $V_{GS} = V_{DS} = 0$ V, (b) Im(Y_{22}) at $V_{GS} = V_{DS} = 0$ V, (c) Re(Y_{22}) at $V_{GS} = 0$ V and $V_{DS} = 1$ V, and (d) Im(Y_{22}) at $V_{GS} = 0$ V and $V_{DS} = 1$ V.

V. Conclusion

A new method for extracting substrate parameters of RF MOSFETs based on 3-port measurement was presented using by device simulation. A T-like substrate resistance network was used and the small-signal parameters were extracted from 3-port device simulation data. The small-signal output admittance Y_{22} can be well modeled up to 40 GHz.

Acknowledgements

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Reference

[1] S. D. Wu, G. W. Huang, K. M. Chen, C. Y. Chang, H. C. Tseng, and T. L. Hsu, “Extraction of Substrate Parameters for RF MOSFETs Based on Four-Port Measurement,” IEEE Microwave and Wireless Components Lett., vol. 15, no. 6, pp. 437-439, Jun. 2005.

[2] J. Han, and H. Shin, “A Scalable Model for the Substrate Resistance in RF MOSFETs”, IEEE MTT-S Int. Microwave Symp. Dig., vol.3, pp.2105-2108, 2003.
