RF Extraction Techniques for Series Resistances of MOSFETs: Major Concerns

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Introduction

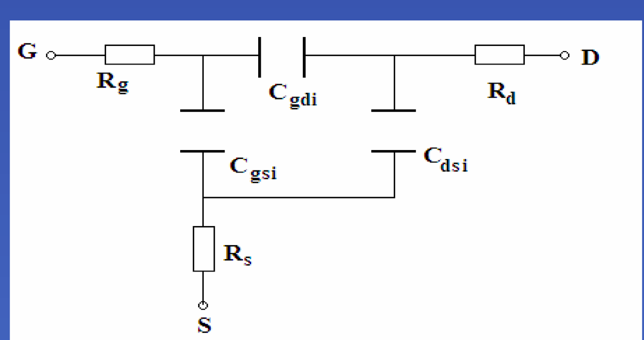
RF MOSFET modeling and characterization are based on measurement of scattering parameters (*S*-parameters) and lumped equivalent circuit definition.
Adequate description of the MOSFET behavior requires accurate extraction of the extrinsic series resistances.

RF Extraction Methods

- **DC methods**
  Do not allow to determine independently R_{se} and R_{de}
- **RF methods**
  Allow to determine independently R_{se}, R_{de} and R_{ge}

Lovelace´s Method

$V_{DS} = V_{GS} = 0 \quad G_{mi} \to 0 \quad \& \quad G_{di} \to 0$



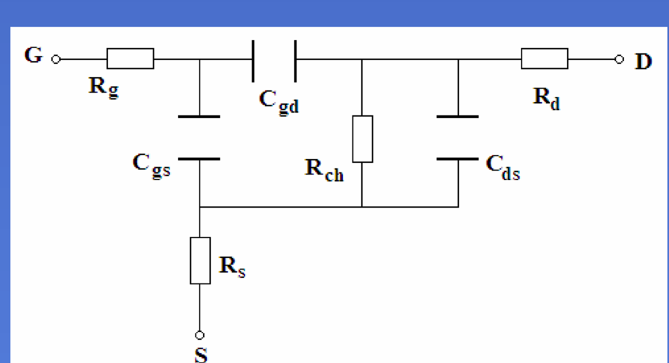
Impedance Parameters

$$Re(Z_{11}-Z_{12}) = R_g$$
$$Re(Z_{12}) = Re(Z_{21}) = R_s$$
$$Re(Z_{22}-Z_{12}) = R_d$$

Torres-Torres´ Method

$V_{DS} = 0 \quad V_{GS} > V_T \quad G_{mi} \to 0$

Symmetric Device: $C_{gsi} = C_{gdi} = C$

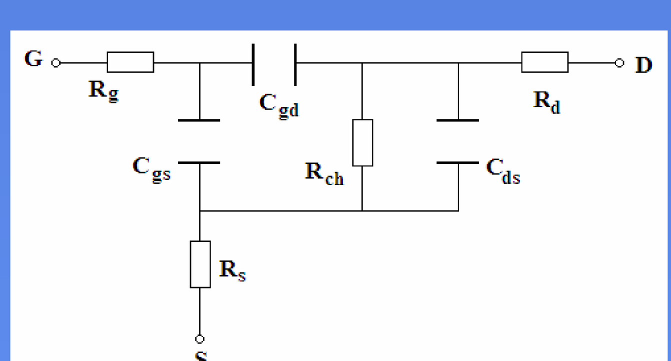


$$\mathrm{Re}(Z_{11}) = R_s + R_g + \frac{A}{4}$$
$$\mathrm{Re}(Z_{12}) = \mathrm{Re}(Z_{21}) = R_s + \frac{A}{2}$$
$$\mathrm{Re}(Z_{22}) = R_d + R_s + A$$
$$A = \frac{R_{ch}}{1+\omega^2 C_x^2 R_{ch}^2} \qquad C_x = C_{ds} + \frac{C_{gs}C_{gd}}{C_{gs}+C_{gd}}$$
$$-\frac{\omega}{\mathrm{Im}(Z_{22})} = C_x\omega^2 + \frac{1}{C_x R_{ch}^2}$$

Bracale´s Method

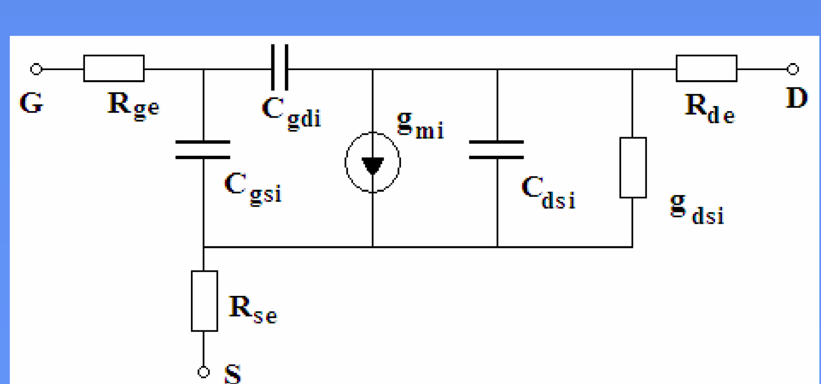
$V_{DS} = 0 \quad V_{GS} > V_T \quad G_{mi} \to 0$

Symmetric Device: $C_{gsi} = C_{gdi} = C$



$$\mathrm{Re}(Z_{22} - Z_{12}) = R_d + \frac{1}{2K(V_{gs} - V_T)}$$
$$\mathrm{Re}(Z_{12}) = R_s + \frac{1}{2K(V_{gs} - V_T)}$$
$$\mathrm{Re}(Z_{11} - Z_{12}) = R_g + \frac{1}{4K(V_{gs} - V_T)}$$

Raskin´s Method



$$\mathrm{Re}(Z_{\sigma\pi ij}) = \mathrm{Re}(Z_{\sigma ij}) + \frac{A_{ij}}{\omega^2 + B}$$

Parametric plots of

$$[\mathrm{Re}(Z_{\sigma\pi ij}(\omega)), \mathrm{Re}(Z_{\sigma\pi kl}(\omega))]$$

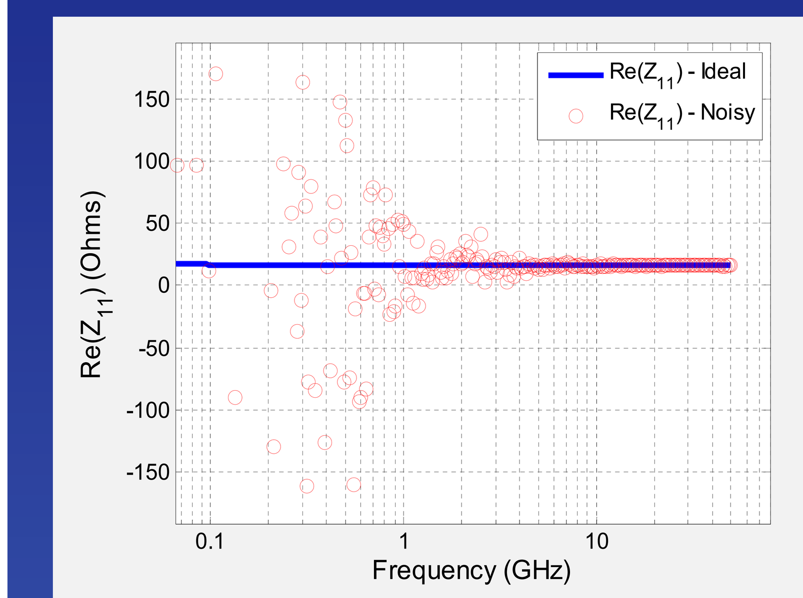
Simulations

- S-Parameters of Partially-Depleted SOI n-MOSFET were simulated;
- The BSIM3SOI model, version 3.11, from ST Microelectronics was used;
- S-Parameters were transformed to Z-Parameters.

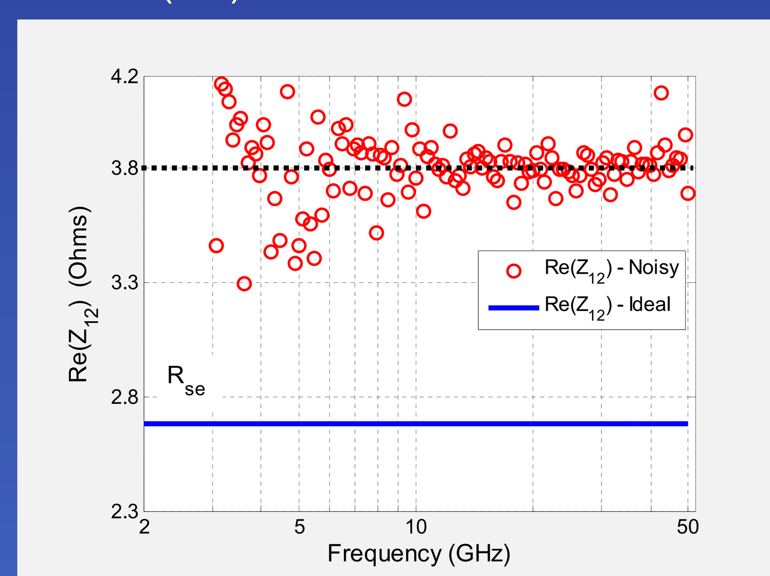
- **Complex noise signal was added to ideal S-Parameters**

$$N = (\alpha + i\beta)\sqrt{P/2}$$

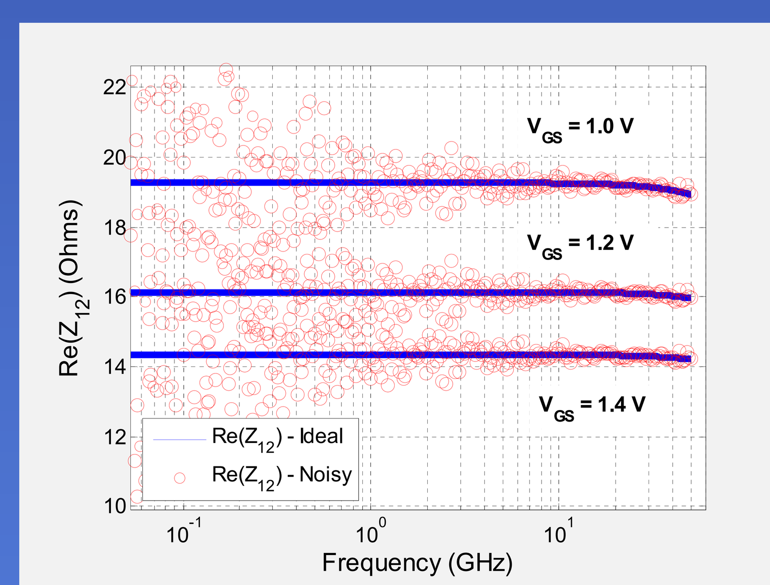
Results



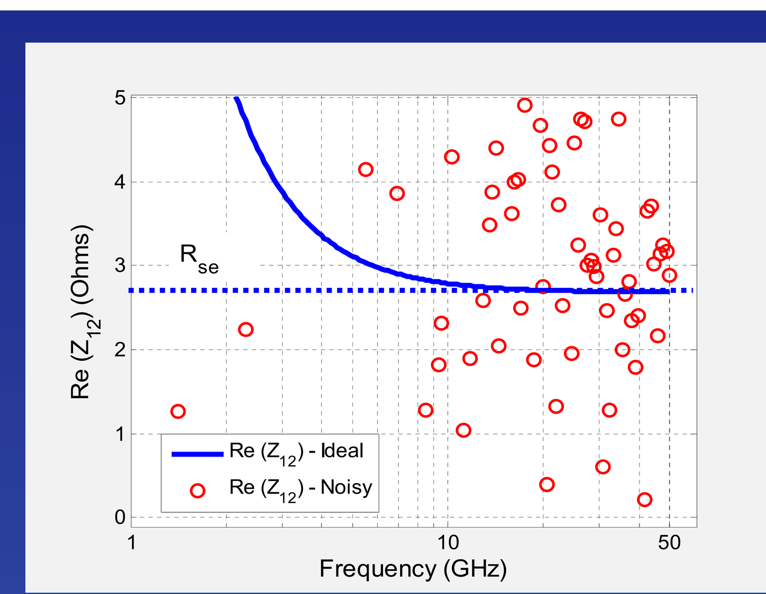
Re(Z_{11}) with and without noise



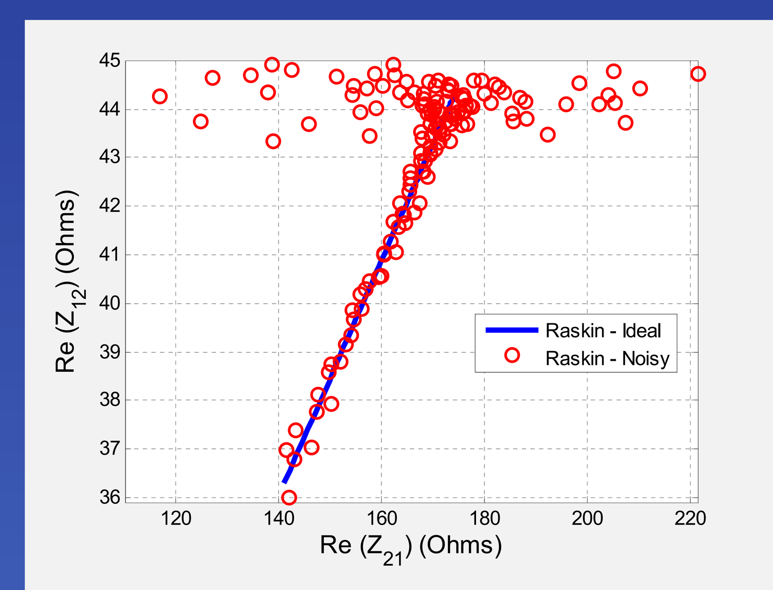
Re(Z_{12}) Torres-Torres´ method



Re(Z_{12}) vs frequency, Bracale´s method



Re(Z_{12}) Lovelace´s method



Parametric plot Re(Z_{12}) vs. Re(Z_{21})
Raskin´s method

Extraction Methods	Extrinsic series resistances without noise			Extrinsic series resistances with noise		
	R_{se}	R_{de}	R_{ge}	R_{se}	R_{de}	R_{ge}
Lovelace	2.68	2.8	5	--	--	--
Torres-Torres	2.68	2.84	5	3.8	3.5	4.8
Raskin	2.79	2.88	5.03	3.19	4.65	5.8
Bracale	7.84	7.05	2.43	7.36	6.57	3.34
Used in Simulations	**2.87**	**2.87**	**5**	**2.87**	**2.87**	**5**

Extracted values: Summary

- ***Lovelace, Torres-Torres and Raskin´s methods are quite sensitive to noise.***
- **Some signal pre-treatments do not improve the extraction for the Lovelace and Torres-Torres´ methods.**
- **The Raskin´s method shows some improvements but seems limited for deep-submicron devices.**
- **Bracale´s methods is less sensitive to noise. However, it does not consider the carriers mobility degradation and the transistor asymmetry.**

Mobility degradation and asymmetry effect on Bracale´s method

Extraction Methods	R_{se}	R_{de}	R_{ge}
Classical Bracale	***7.5***	***7.3***	***2.8***
Mobility included	3.4	2.77	4.84
Mobility and asymmetry included	3	3.2	4.85
Used in Simulations	**3**	**3**	**5**

Conclusions

- Noise strongly affects the extracted values.
- Signal pre-treatments do not improve significantly the extraction results.
- Bracale´s method shows less impact to noise, however fails in order to determine the correct resistance values.
- The main limitations are related with the degradation of the free carriers mobility and the channel asymmetry.
- ***New method it is necessary to overcome such limitations.***