MOS RF Modelling and Parameter Extraction

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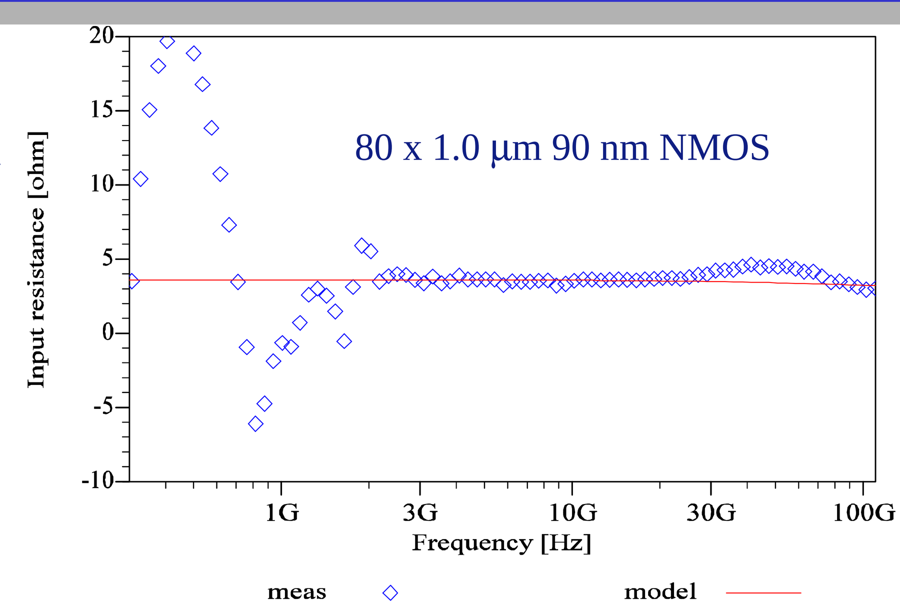
Introduction

The effect of S parameter measurement errors resulting from vector network analyzer uncertainties on RF MOSFET parameter extraction were analyzed [1]. The uncertainty effects on the MOSFET small signal equivalent circuit were studied. The lower uncertainty specification of a high-end HP 8510B network analyzer were used as the basis for the analysis.

For instance, R_{in} extraction has been inaccurate at lower frequencies.

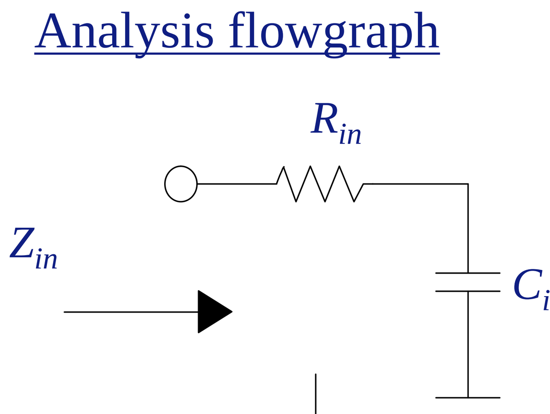


The relative total differential error is calculated for input resistance, R_{in}; input capacitance, C_{in}; transconductance, g_m; feedback capacitance, C_{gd}; output capacitance, C_{out}; and output resistance, R_{out}.

De-embedding errors were considered negligible.

Input Related Extraction Uncertainty

Analysis flowgraph



Simplified input equivalent circuit in this study

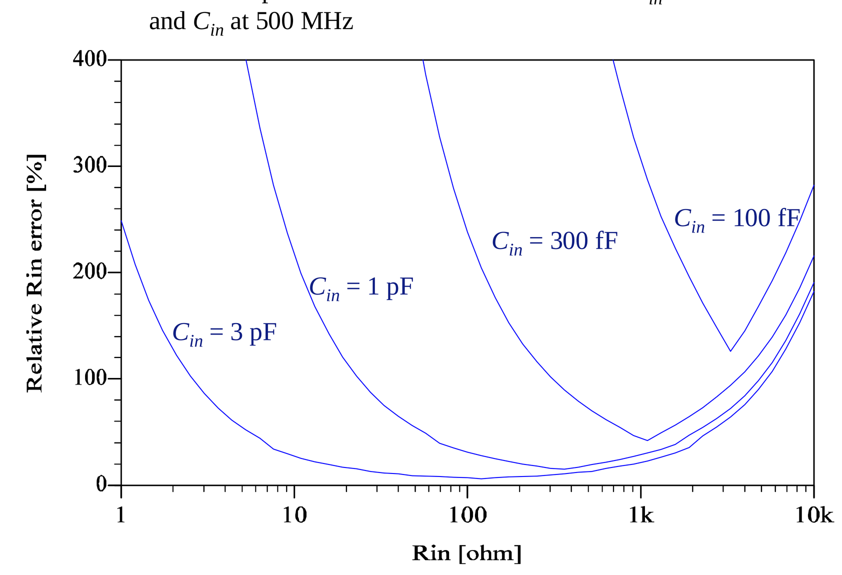
Calculate S_{11} parameter

$S_{11m}(R_{in},C_{in})$ and $\theta_{11}(R_{in},C_{in})$

Take errors ΔS_{11m} and $\Delta\theta_{11}$ into account

$\Delta R_{in}(R_{in},C_{in},\Delta S_{11m},\Delta\theta_{11})$ and $\Delta C_{in}(R_{in},C_{in},\Delta S_{11m},\Delta\theta_{11})$

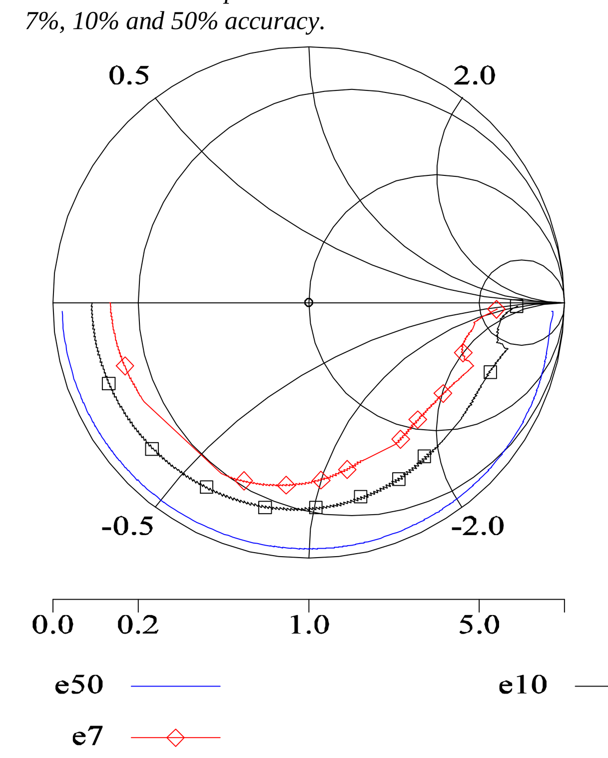
Relative input resistance error as a function of R_{in} and C_{in} at 500 MHz



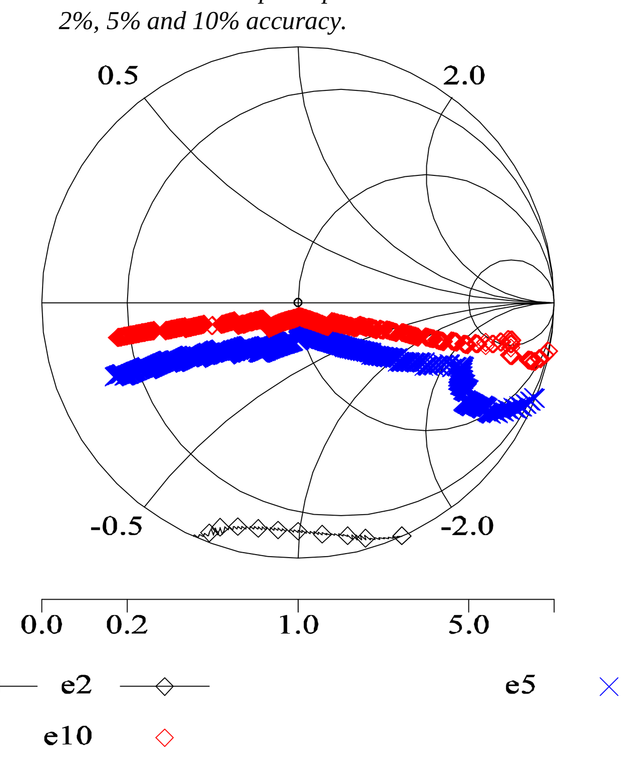
→ Input resistance extraction very inaccurate at low frequencies!

Total differential error can be easily over 100%.

Input resistance extraction accuracy as a function of input impedance at 500 MHz. Impedance curves are shown where the input resistance can be extracted with 7%, 10% and 50% accuracy.



Input capacitance extraction accuracy as a function of input impedance at 500 MHz. Impedance curves are shown where the input capacitance can be extracted with 2%, 5% and 10% accuracy.



The study suggests that quite large RF characterization devices should be used for input parameter extraction to achieve lower impedance levels. Optimum R_{in} extraction requires also as a wide device as possible, but with an optimized length and finger number to get the resistance higher than in typical RF MOS transistors.

R_{in} extraction error decreases proportional to $1/f$ to some extent. *Rin* extraction should be done at higher frequencies.

Transconductance g_m and Feedback Capacitance C_{gd} Extraction Accuracy

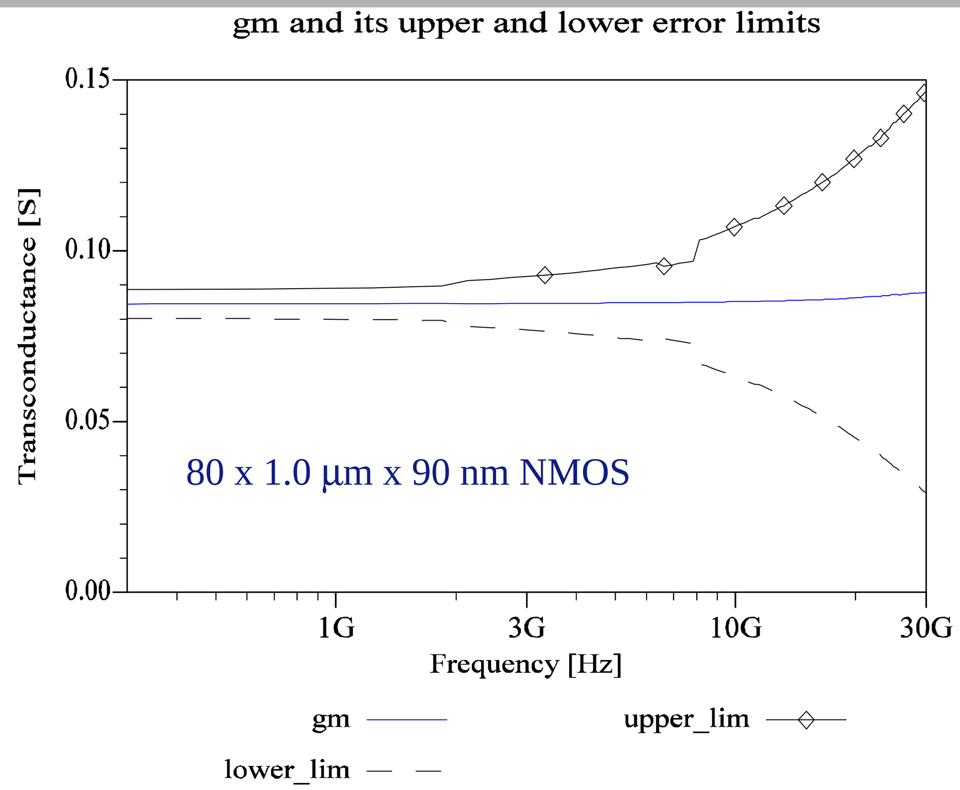
Transconductance calculation

$$g_m = \mathrm{Re}\{Y_{21}\}$$

$$Y_{21} = \frac{-2S_{21}}{((1+S_{11})(1+S_{22})-S_{12}S_{21})Z_0} \approx \frac{-2S_{21}}{(1+S_{11})(1+S_{22})Z_0}$$

$$\Delta g_m = \left|\frac{\partial g_m}{\partial S_{11m}}\right|\Delta S_{11} + \left|\frac{\partial g_m}{\partial \theta_{11m}}\right|\Delta\theta_{11} + \left|\frac{\partial g_m}{\partial S_{22m}}\right|\Delta S_{22} + \left|\frac{\partial g_m}{\partial \theta_{22m}}\right|\Delta\theta_{22} + \left|\frac{\partial g_m}{\partial S_{21m}}\right|\Delta S_{21} + \left|\frac{\partial g_m}{\partial \theta_{21m}}\right|\Delta\theta_{21}$$

gm and its upper and lower error limits



→ Errors in a few % range at lower frequencies.

Approximation valid below 5 GHz in this case.

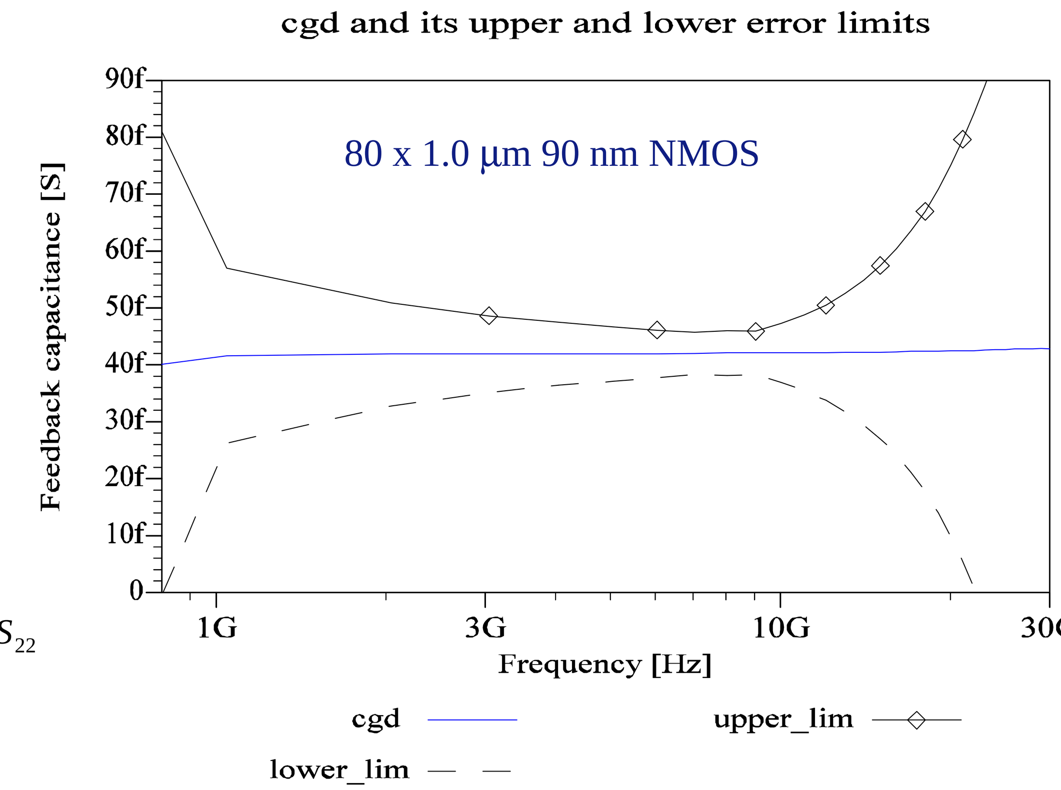
Feedback capacitance calculation

$$C_{gd} = -\frac{\mathrm{Im}\{Y_{12}\}}{\omega}$$

$$Y_{12} = \frac{-2S_{12}}{((1+S_{11})(1+S_{22})-S_{12}S_{21})Z_0} \approx \frac{-2S_{12}}{(1+S_{11})(1+S_{22})Z_0}$$

$$\Delta C_{gd} = \left|\frac{\partial C_{gd}}{\partial S_{11m}}\right|\Delta S_{11} + \left|\frac{\partial C_{gd}}{\partial \theta_{11m}}\right|\Delta\theta_{11} + \left|\frac{\partial C_{gd}}{\partial S_{22m}}\right|\Delta S_{22} + \left|\frac{\partial C_{gd}}{\partial \theta_{22m}}\right|\Delta\theta_{22} + \left|\frac{\partial C_{gd}}{\partial S_{12m}}\right|\Delta S_{12} + \left|\frac{\partial C_{gd}}{\partial \theta_{12m}}\right|\Delta\theta_{12}$$

cgd and its upper and lower error limits

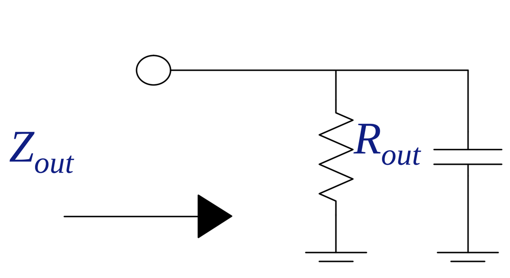


→ Errors in tens of % range at optimum extraction frequencies.

Approximation valid below 5 GHz in this case.

Output Related Extraction Uncertainty

Analysis flowgraph



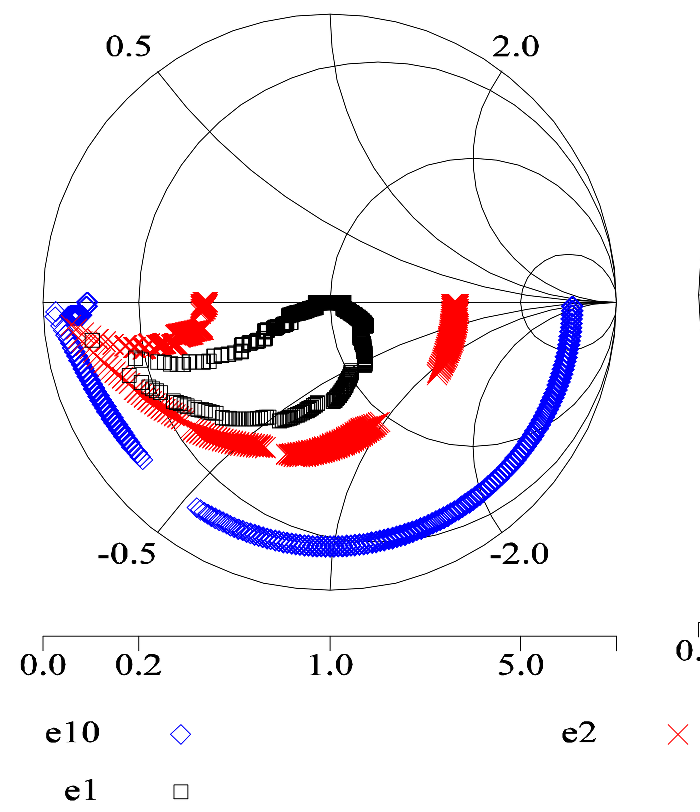
Simplified output equivalent circuit in this study

Calculate S_{22} parameter

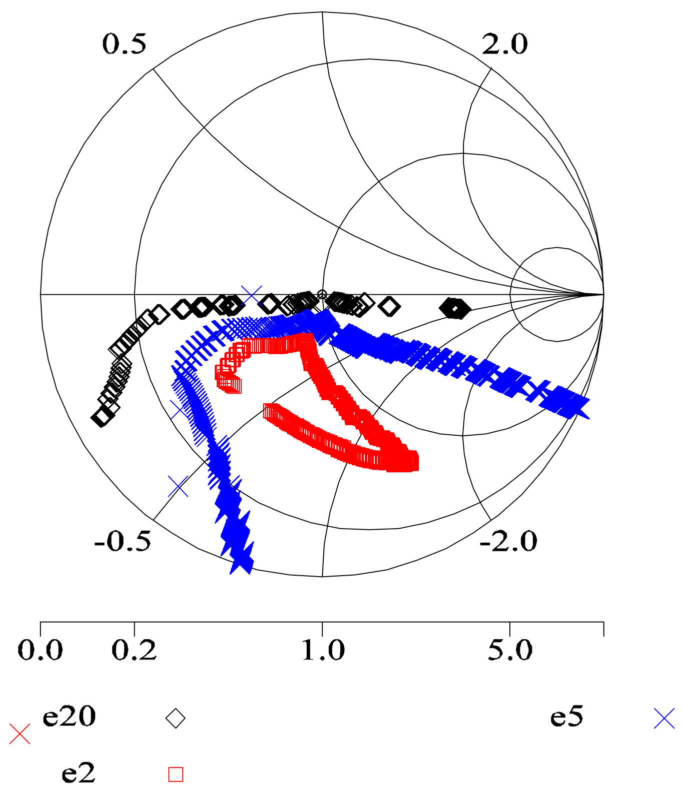
$S_{22m}(R_{out},C_{out})$ and $\theta_{22}(R_{out},C_{out})$

$\Delta R_{out}(R_{out},C_{out},\Delta S_{22m},\Delta\theta_{22})$ and $\Delta C_{out}(R_{out},C_{out},\Delta S_{22m},\Delta\theta_{22})$

Output resistance extraction accuracy as a function of output impedance at 500 MHz. Impedance curves are shown where the output resistance can be extracted with 1%, 2% and 10% accuracy.



Output capacitance extraction accuracy as a function of output impedance at 500 MHz. Impedance curves are shown where the output capacitance can be extracted with 2%, 5% and 20% accuracy.

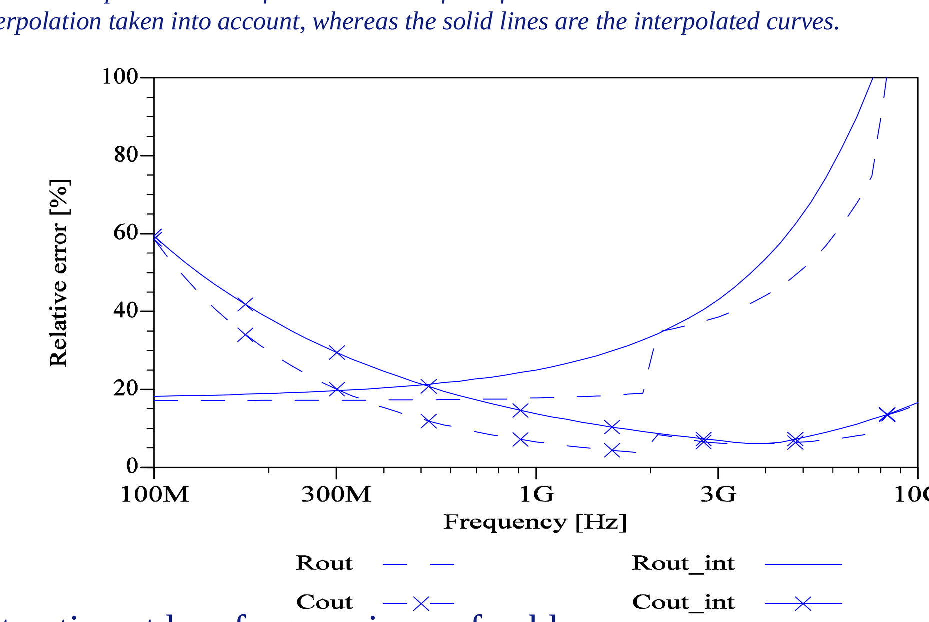


→ Practical output resistance and capacitance extraction accuracy is in the range of tens of %.

Output resistance extraction is more accurate the smaller the capacitance in parallel is.

Output capacitance extraction is more accurate the larger the capacitance is with a real part as close to 50Ω as possible.

Relative Rout and Cout errors as a function of frequency for a MOSFET output with Rout of 1kΩ and Cout of 500 fF. The dashed lines are lines with no interpolation taken into account, whereas the solid lines are the interpolated curves.



R_{out} extraction at low frequencies preferable

C_{out} extraction has an optimum frequency depending on device size and bias point.

References:

1. J. Saijets, *MOSFET RF Characterization Using Bulk and SOI CMOS Technologies*, Doctoral Thesis, May 2007.

Applying these results in practice:

- The results of this measurement error study are especially applicable to AC parameter extraction as conditioning numbers.
- The measured accuracy of input and output-related small signal parameters can be used as guidelines for the design of the optimum AC device extraction set, as well as the bias region.