Methods for noise calculation of active devices

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12th III-V Semiconductor
Device Simulation Workshop

October 10-11, 2000

Duisburg

Overview

- Simulation of noisy n-ports
- Separation of the noise sources
- FET example
- Application example
- Conclusion

Noisy 2-ports

Transformation matrix

$$[T]^{(y \to a)} = \begin{bmatrix} 0 & -\dfrac{1}{\underline{y}_{21}} \\ 1 & -\dfrac{\underline{y}_{11}}{\underline{y}_{21}} \end{bmatrix}$$

Noise matrix

input
output

$$\begin{bmatrix} v_i^{(a)} \\ i_o^{(a)} \end{bmatrix} = [T]^{(y \to a)} \begin{bmatrix} i_i^{(y)} \\ i_o^{(y)} \end{bmatrix}$$

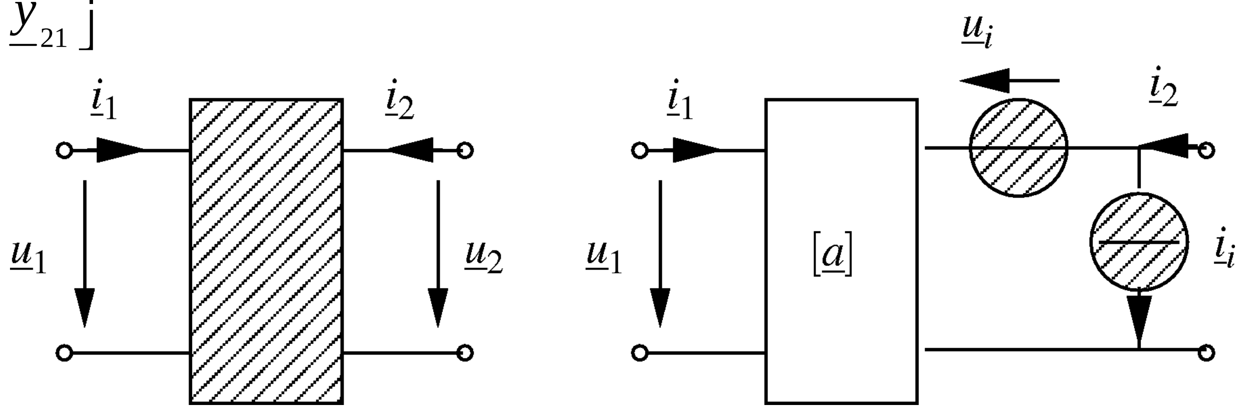

Fig.: Transformation of noise sources.

Correlation matrix, calculation of noise power

$$[\underline{C}]^{(a)} = \frac{1}{4kT\Delta f}\left(\begin{bmatrix} \underline{v}_i \\ \underline{i}_i \end{bmatrix}\begin{bmatrix} \underline{v}_i^* & \underline{i}_i^* \end{bmatrix}\right)$$

Separation of noise sources

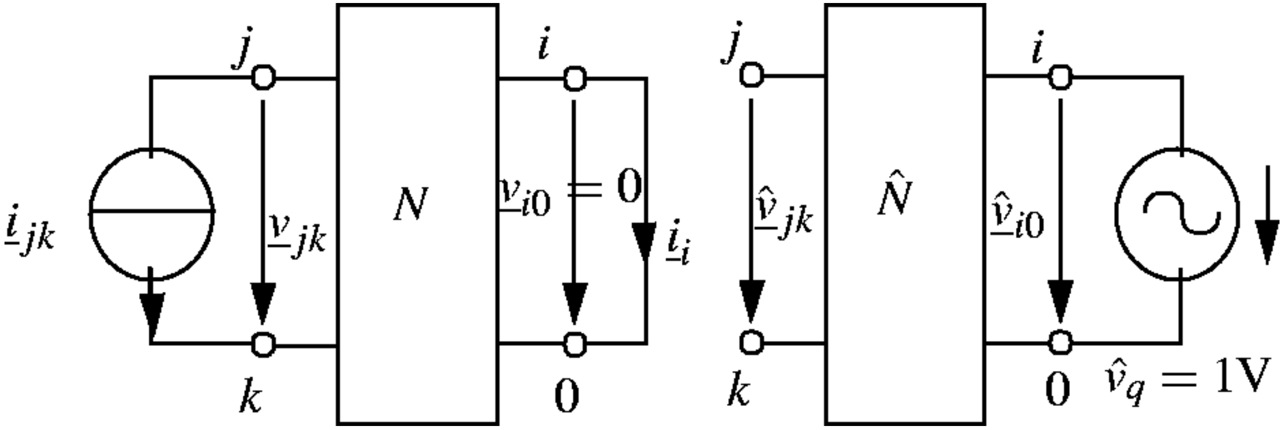

Fig.: Calculation of transformation functions.

Network N	Adjuncted network
Y-matrix	Transposed Y-matrix

Current transformation function

$$\alpha_{i,jk} = \frac{i_i}{i_{jk}} = -\frac{\hat{v}_{jk}}{\hat{v}_q}$$

FET example

TOPAS

$$i_{6,3} = \sqrt{\frac{1}{R_G}} \qquad i_{7,4} = \sqrt{\frac{1}{R_D}}$$

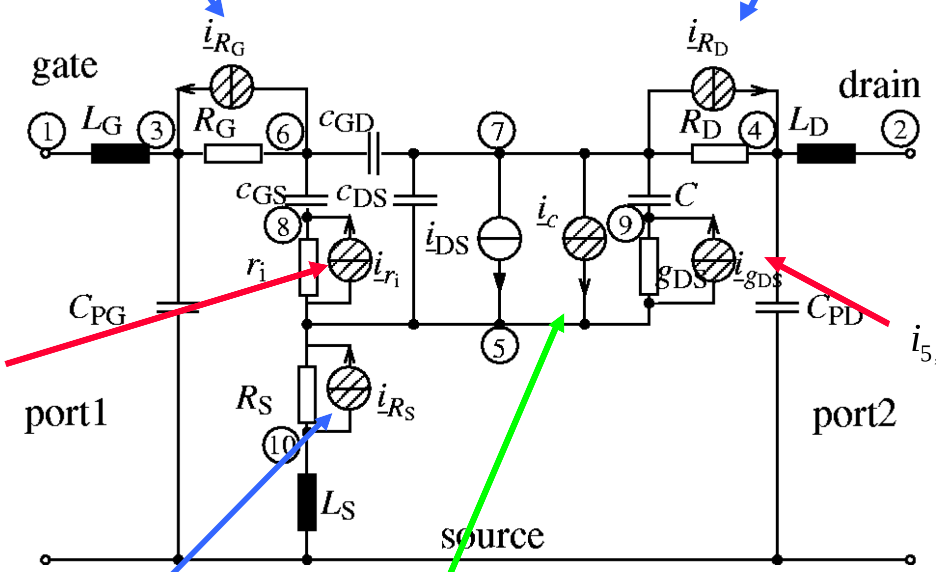

Fig.: TOPAS equivalent circuit.

$$i_{5,8} = \sqrt{\frac{1}{r_i}} \qquad i_{5,9} = \sqrt{g_{DS}}$$

$$i_{10,5} = \sqrt{\frac{1}{R_S}} \qquad i_{7,5} = \sqrt{g_{i_C}}$$

Noise current matrix

$$[i_N] = \sqrt{4kT\Delta f} \cdot \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & i_{5,8} & i_{5,9} & 0 \\ 0 & 0 & i_{6,3} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & i_{7,4} & i_{7,5} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & i_{10,5} & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Channel noise

1/f-noise

$$g_{i_C} = \frac{T_{sim}}{T_0}\frac{2}{3}g_m + k_f \frac{I_c^{af}}{f^b \, 4kT_0}$$

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Tellegen Theorem 1

Y-matrix → Z-matrix → Y_{2x2}-matrix → $[\underline{y}_T] = [\underline{y}]^T$

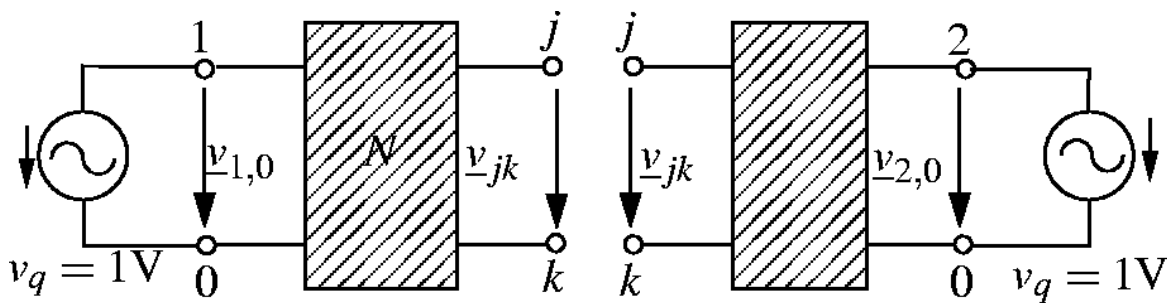


Fig.: Tellegen theorem for noisy circuits.

Adjuncted network for calculating transformation functions

$$i_{Q_1} = \frac{v_q}{\underline{y}_{T,2\times 2_{1,1}}} \quad \text{and} \quad i_{Q_2} = \frac{v_q}{\underline{y}_{T,2\times 2_{2,2}}}$$

Tellegen Theorem 2

$$\begin{bmatrix} i_{Q1} \\ \vdots \\ i_{Q10} \end{bmatrix} = \begin{bmatrix} y_{T_{1,1}} & \cdots & y_{T_{1,10}} \\ \vdots & \ddots & \vdots \\ y_{T_{10,1}} & \cdots & y_{T_{10,10}} \end{bmatrix} \begin{bmatrix} v_1 \\ \vdots \\ v_{10} \end{bmatrix}$$

Solve equation system for the voltages using Gauss algorithm

Voltage transformation factor

One single noise source at input, one single at output

$$[T]^{(y \to a)} = \begin{bmatrix} 0 & -\frac{1}{\underline{y}_{2\times2_{21}}} \\ 1 & -\frac{\underline{y}_{2\times2_{11}}}{\underline{y}_{2\times2_{21}}} \end{bmatrix}$$

1 current, 1 voltage source at output

Correlation matrix

$$F = 1 - \frac{T_{\text{sim}}}{T_o} \frac{\left|\underline{y}_G\right|^2 C_{11}^{(a)} + C_{22}^{(a)} + 2\Re\left\{\underline{y}_G \underline{C}_{12}^{a}\right\}}{g_G}$$

$$R_n = \frac{T_{\text{sim}}}{T_0} C_{11}^{a}$$

Correlation matrix

$$\left[\underline{C}\right]^{(a)} = \left[T\right]^{(y\to a)} \left[\underline{C}\right]^{(y)} \left[T\right]^{(y\to a)+}$$

$$V_{NF}\left[\text{dBm}/\sqrt{\text{Hz}}\right] = 20\log\left(\sqrt{\frac{T_{\text{sim}}}{T_0} \cdot i_0 i_0^* \frac{50\Omega}{50\Omega\Re\left(\underline{y}_{2\times2_{22}}\right)+1}} \cdot 1000\right)$$

$$\Gamma_{G_{\text{opt}}} = \frac{1 - \underline{y}_{G_{\text{opt}}} Z_0}{1 + \underline{y}_{G_{\text{opt}}} Z_0}$$

Verification 1

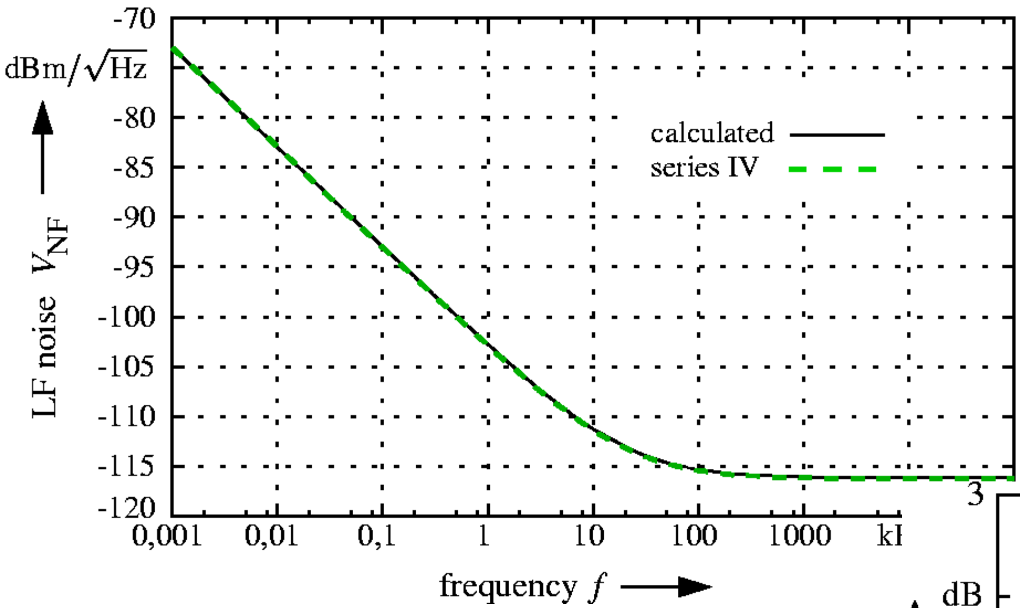
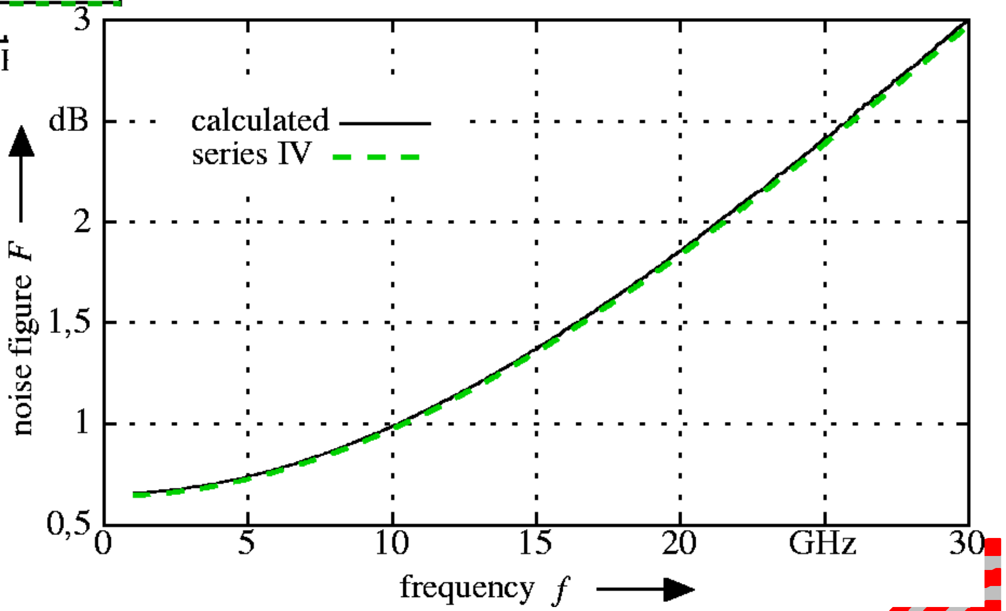


Fig.: Calculation for 1/f-noise. Comparison of proposed algorithm versus series IV simulation.

Fig.: Calculation of noise figure F. Comparison of proposed algorithm versus series IV simulation.



Verification 2

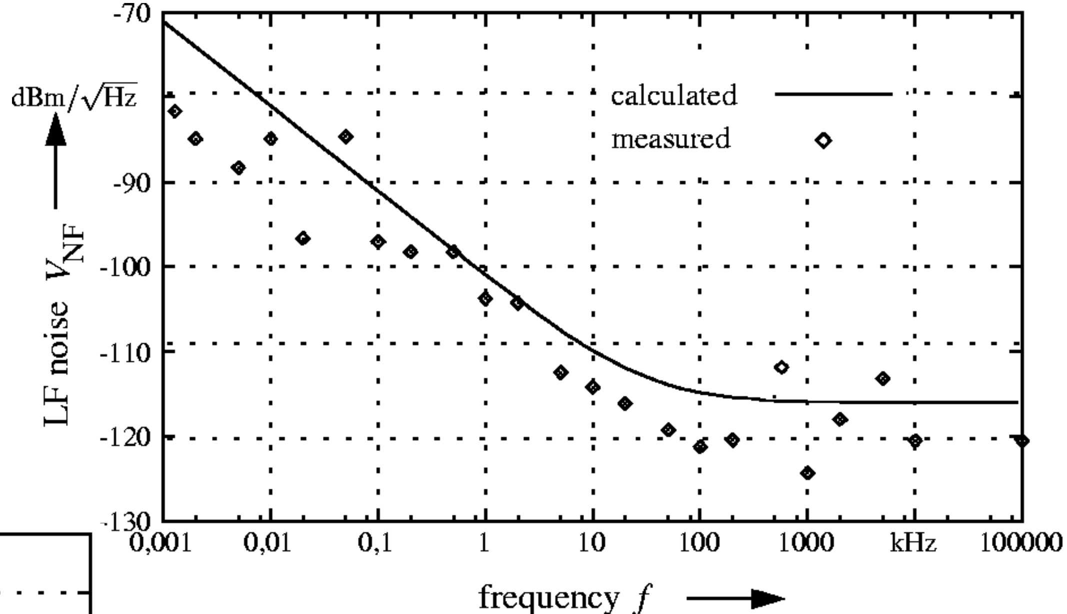
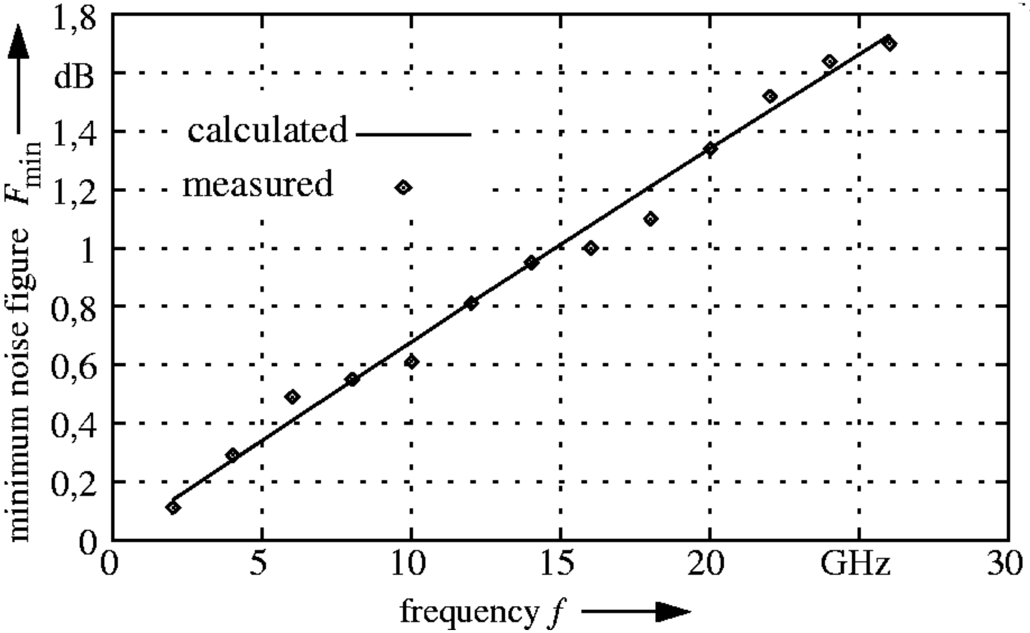


Fig.: Simulation and measurement of 1/f-noise.

Fig.: Simulation and measurement of minimum noise figure.



Verification 2

1/f-noise parameter extraction

$$i_f^2 = k_f \frac{I^{af}}{f^b} \Delta f$$

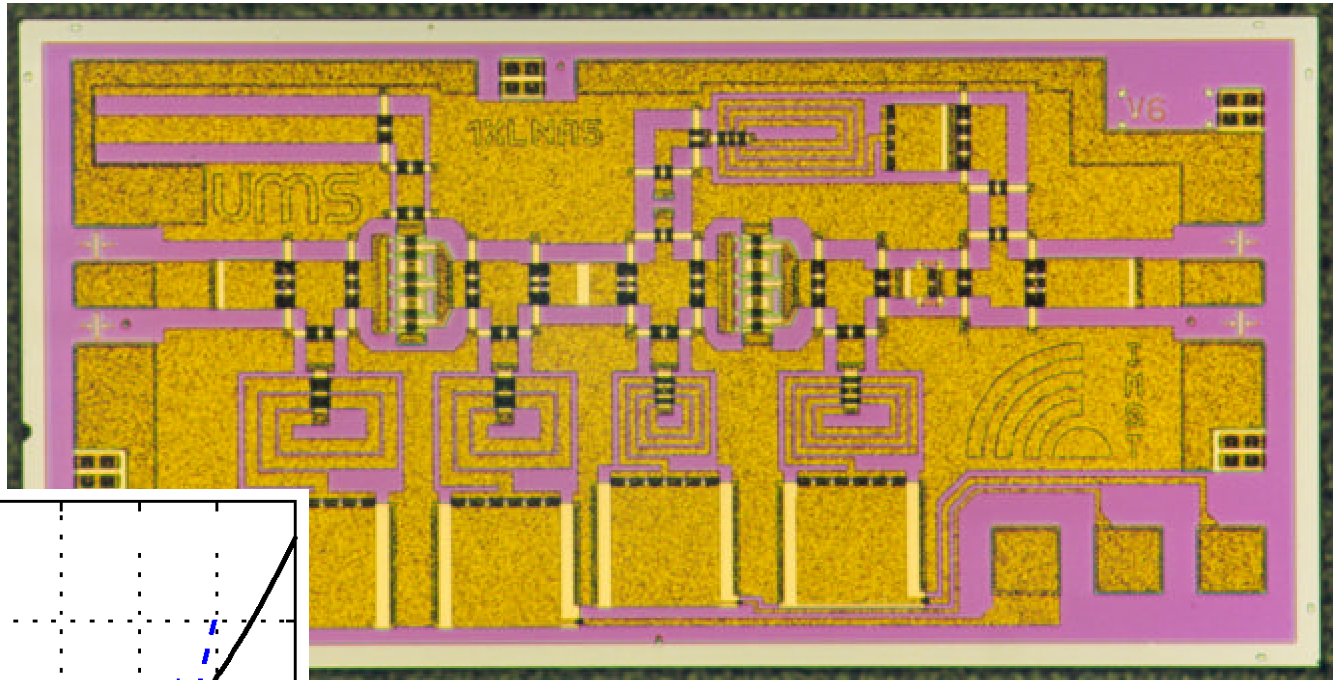


Fig.: Chip photography of the X-band LNA.

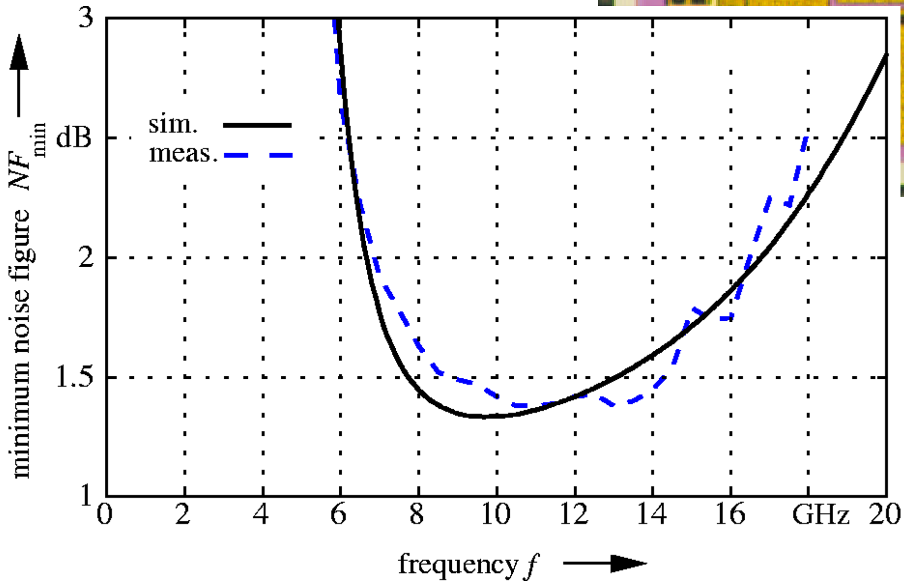


Fig.: Minimum noise figure. Measurement versus simulation.

Conclusion

- Fast noise calculation method
- Excellent comparison to commercial available methods (ADS)
- Allows simulation as well as extraction
- LF and RF noise behaviour

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