Architecture of Radio Receivers and Transmitters (BE2M37ART)

Sensitivity Analysis, Distributed Amplifier, MMIC

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2 Algorithm in General

A parametric system of the circuit linear equations can be written in the form

$$\boldsymbol{A}(p)\,\boldsymbol{x}(p) = \boldsymbol{b}(p),$$

where p is one of the circuit parameters on which the sensitivities are requested.

The vector of the derivatives with respect to this parameter $\partial\boldsymbol{x}(p)/\partial p$ marked by $\boldsymbol{x}'(p)$ can be obtained by differentiating

$$\boldsymbol{A}'(p)\,\boldsymbol{x}(p) + \boldsymbol{A}(p)\,\boldsymbol{x}'(p) = \boldsymbol{b}'(p),$$

which gives the basic system of the complex linear equations

$$\boldsymbol{A}(p)\,\boldsymbol{x}'(p) = \boldsymbol{b}'(p) - \boldsymbol{A}'(p)\,\boldsymbol{x}(p).$$

3 Standard Sensitivity Analysis

The circuit contains an independent input source and no other internal sources in this case. Therefore, the first part of the right side is equal to zero and the system is simpler

$$\boldsymbol{A}(p)\,\boldsymbol{x}'(p) = -\boldsymbol{A}'(p)\,\boldsymbol{x}(p).$$

If simulator procedures are unable to determine the parametric derivatives $\partial A_{\dots}/\partial p$ in a symbolic way, they must be computed numerically. For example, the simplest approximation of the derivatives

$$\boldsymbol{A}'(p) \approx \frac{\boldsymbol{A}(p+\Delta p) - \boldsymbol{A}(p)}{\Delta p}$$

can be used, and using this formula gives the final system

$$\boldsymbol{A}(p)\,\boldsymbol{x}'(p) = \frac{\boldsymbol{b}(p) - \boldsymbol{A}(p+\Delta p)\,\boldsymbol{x}(p)}{\Delta p}.$$

4 Noise Sensitivity Analysis

The circuit contains n_n internal noise sources and no independent input source in this case. A j^{th} output of the noise analysis is determined by solving the system

$$\boldsymbol{A}(p)\,{}_j\boldsymbol{x}(p) = {}_j\boldsymbol{b}(p),\ j = 1,\ldots,n_n,$$

which is of the same type as that in the standard analysis. Therefore, the complex LU factorization of $\boldsymbol{A}$ must be executed only once $\forall f$.

Similarly, the sensitivity of the j^{th} output is determined by solving

$$\boldsymbol{A}(p)\,{}_j\boldsymbol{x}'(p) = {}_j\boldsymbol{b}'(p) - \boldsymbol{A}'(p)\,{}_j\boldsymbol{x}(p).$$

If the procedure is unable to compute the parametric derivatives $\partial A_{\ldots}/\partial p$ in a symbolical way, they must be determined numerically using above approximation of $\boldsymbol{A}'(p)$ and the analogy is used

$${}_j\boldsymbol{b}'(p) \approx \frac{{}_j\boldsymbol{b}(p+\Delta p) - {}_j\boldsymbol{b}(p)}{\Delta p},\ j = 1,\ldots,n_n,$$

which gives the final system

$$\boldsymbol{A}(p)\,{}_j\boldsymbol{x}'(p) = \frac{{}_j\boldsymbol{b}(p+\Delta p) - \boldsymbol{A}(p+\Delta p)\,{}_j\boldsymbol{x}(p)}{\Delta p},\ j = 1,\ldots,n_n.$$

5 Noise-Figure Sensitivity Analysis

General formulae for computing the noise factor F_n and the noise figure F_n^{dB} are the following[1]

$$F_n = \frac{V_n^2 - V_{n,R_{\mathrm{load}}}^2}{A_V^2 4kT_0 R_{\mathrm{source}}}, \quad F_n^{\mathrm{dB}} = 10 \log\left(F_n\right),$$

where V_n, A_V, k, R_{source}, and T_0 are the spectral density of the total output noise voltage, voltage gain, Boltzman constant, internal resistance of the input source, and standard temperature ($T_0 = 290$ K).

However, the procedure should be improved in the following ways:

- The circuit must be matched in advance because the Friis definition of the noise factor assumes available signal and noise powers.
- The subtraction is performed manually for each frequency in the original work. However, if the load resistor is created artificially as a current source controlled by its voltage, then the noise of the load resistor will not be generated.

[1] J. Ortiz and C. Denig, "Noise figure analysis using Spice," *Microwave Journal*, pp. 89–94, Apr. 1992.

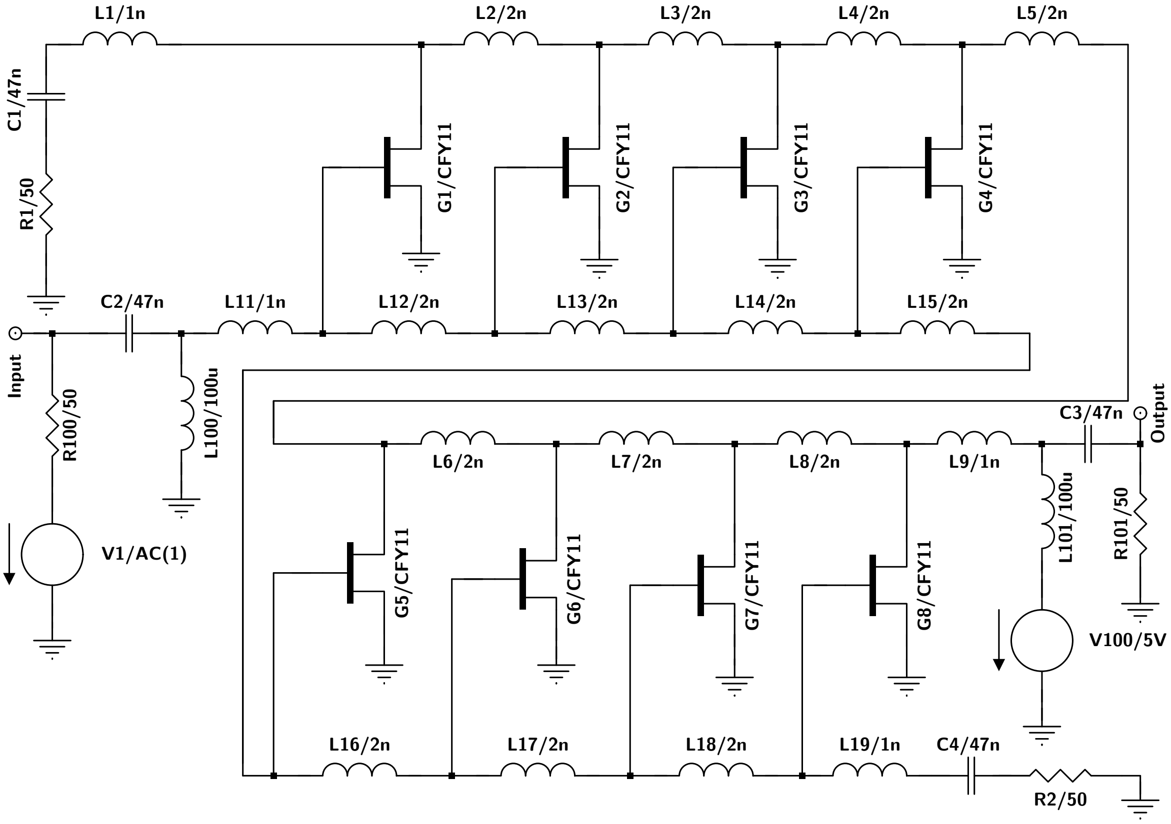
By differentiating, the requested sensitivity of F_n^{dB} on the parameter p marked $F_n^{\mathrm{dB}\,\prime}$ can be obtained:

$$F_n^{\mathrm{dB}\,\prime}\Big|_{V_{n,R_{\mathrm{load}}}=0} = \frac{10}{\ln(10)} \frac{1}{\dfrac{V_n^2}{A_V^2 4kT_0 R_{\mathrm{source}}}} \times \frac{2V_n V_n' A_V^2 4kT_0 R_{\mathrm{source}} - 2A_V A_V' 4kT_0 R_{\mathrm{source}} V_n^2}{(A_V^2 4kT_0 R_{\mathrm{source}})^2}$$

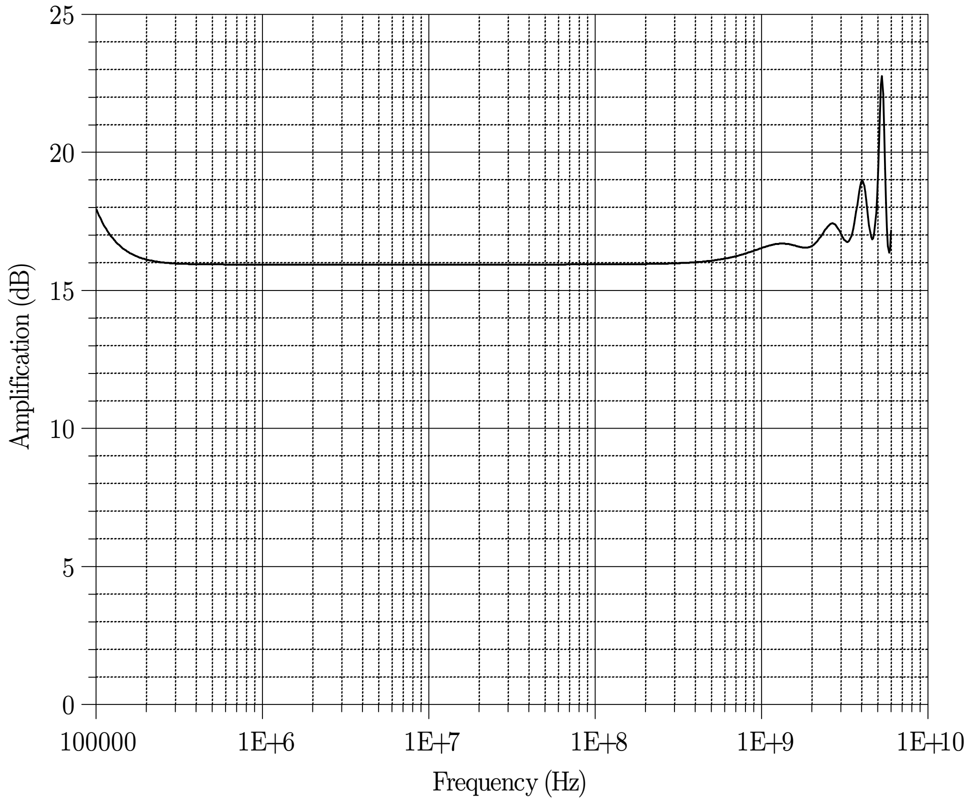
$$= \frac{20}{\ln(10)} \left(\frac{V_n'}{V_n} - \frac{A_V'}{A_V} \right).$$

Let us emphasize that the resulting formula is unusual—most of the CAD tools are not able to determine the sensitivity V_n' and therefore $F_n^{\mathrm{dB}\,\prime}$, too.

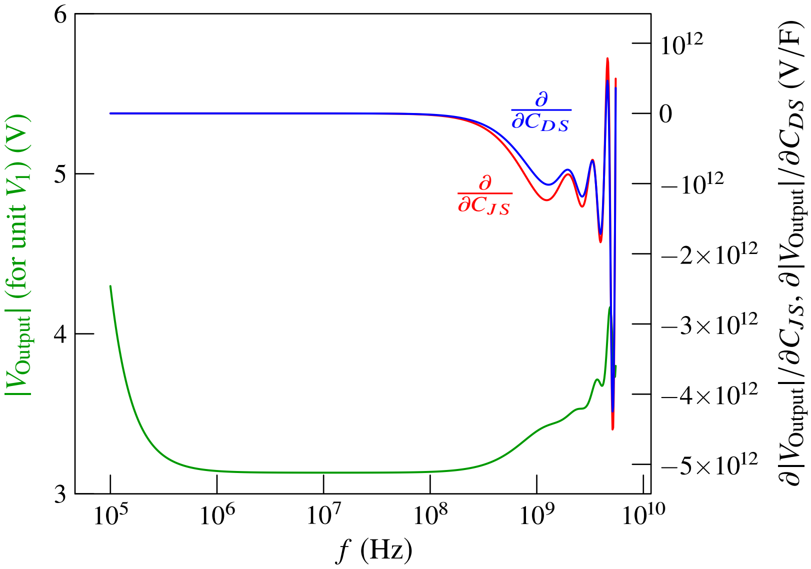
6 Distributed Amplifier



6.1 Frequency Characteristic



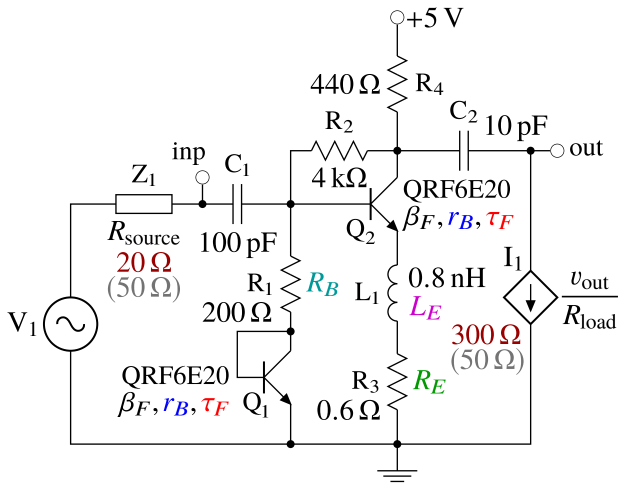
6.2 Sensitivity Analysis



Nominally $C_{JS} = 0.75$ pF, which is the output for $C_{JS} = 0.751$ pF?

- Using the sensitivity analysis: 4.098543 V,
- Using the direct computation: 4.098516 V.

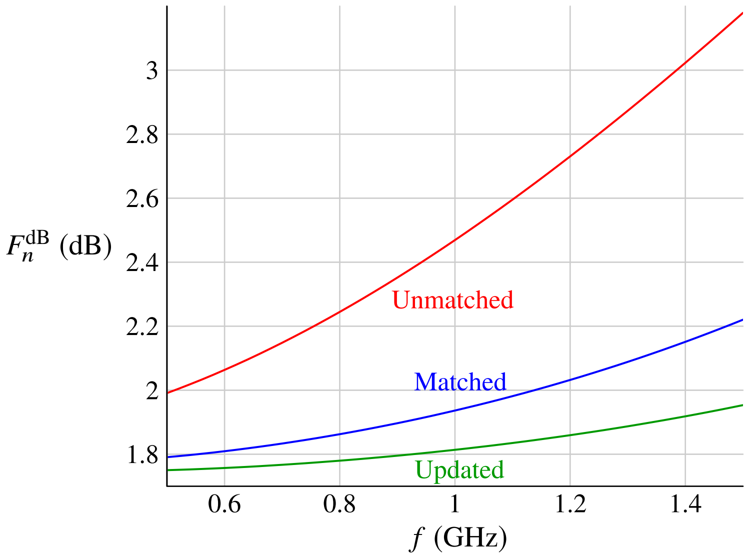
7 Monolithic Microwave Integrated Circuit (MMIC)



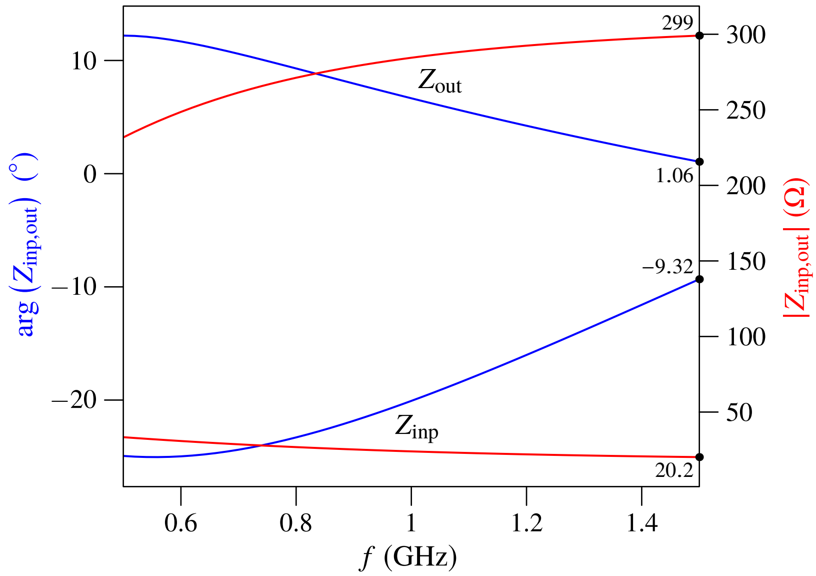
7.1 Optimizing Noise Figure

There are two possible improvements of the noise figure:

1. Matching at the input and output
2. Updating a circuit parameter after the sensitivity analysis

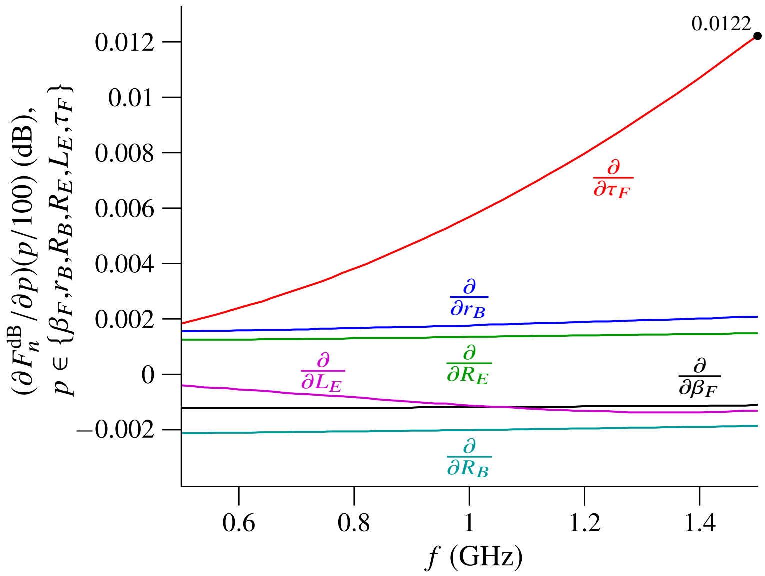


7.1.1 Impedance Matching



As the noise figure is the worst problem at 1.5 GHz, the impedance matching at this frequency was used. (And after that, we obtain "Matched" noise figure.)

7.1.2 Sensitivity Analysis



The transit time τ_F of QRF6E20 was 28 ps. Therefore, it is now possible to use the transistors with $\tau_F = 21$ ps (i.e., − 25 %). (And after that, we obtain "Updated" noise figure.)

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