EE230-02 RFIC II
Fall 2018

Lecture 9: LNA4

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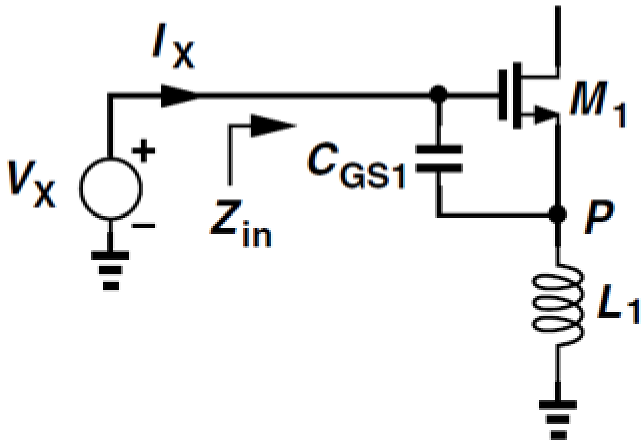
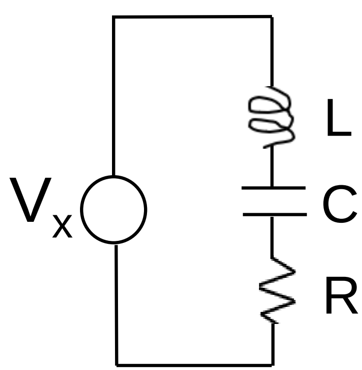
ENG-259

Series Resonance



$$\frac{V_X}{I_X} = \underbrace{\boxed{\frac{1}{C_{GS1}s} + L_1 s}}_{\text{Resonate}} + \underbrace{\boxed{\frac{g_m L_1}{C_{GS1}}}}_{50\ \Omega}$$



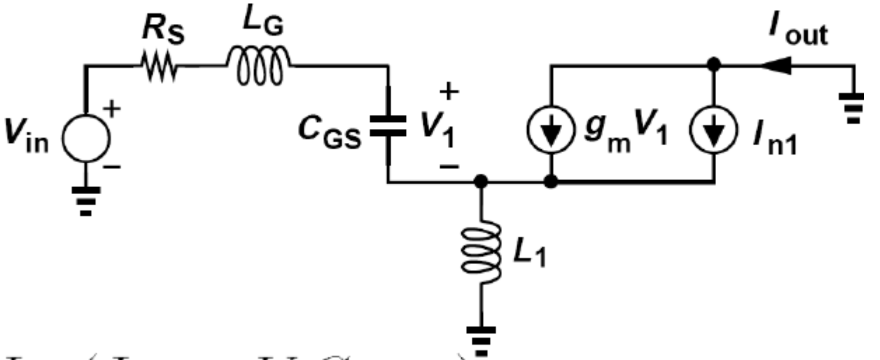
$$Z(\omega_0) = R$$

$$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 C R}$$

$$|V_L| = |V_C| = Q \cdot |V_x|$$

NF Calculation

Excluding the effect of channel-length modulation, body effect, C_{GD} and C_{pad} for simplicity



$$I_{out} = g_m V_1 + I_{n1}$$

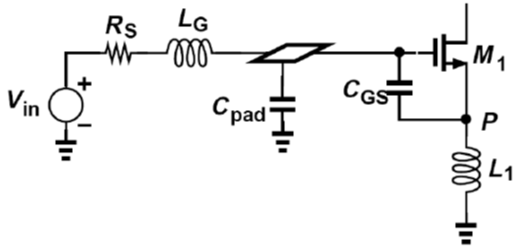
KVL around the input loop yields:

$$V_{in} = (R_S + L_G s)V_1 C_{GS1} s + V_1 + L_1 s(I_{out} + V_1 C_{GS1} s)$$

$$V_{in} = I_{out} L_1 s + \frac{(L_1 + L_G)C_{GS1}s^2 + 1 + R_S C_{GS1} s}{g_m}(I_{out} - I_{n1})$$

$$V_{in} = I_{out}\left(jL_1\omega_0 + \frac{jR_S C_{GS1}\omega_0}{g_m}\right) - I_{n1}\frac{jR_S C_{GS1}\omega_0}{g_m}$$

The coefficient of I_{out} represents the transconductance gain of the circuit:



$$\left|\frac{I_{out}}{V_{in}}\right| = \frac{1}{\omega_0\left(L_1 + \frac{R_S C_{GS1}}{g_m}\right)}$$

NF Calculation

For input matching, $\frac{g_m L_1}{C_{GS1}} = R_S \Longrightarrow L_1 = \frac{R_s C_{GS1}}{g_m}$

$$\left|\frac{I_{out}}{V_{in}}\right| = \frac{1}{\omega_0\left(L_1 + \frac{R_S C_{GS1}}{g_m}\right)} = \frac{g_m}{2\omega_0 R_s C_{GS1}} = \frac{\omega_T}{2\omega_0 R_s} = \frac{Q g_m}{2}$$

Interestingly, the transconductance of the circuit remains independent of L_1, L_G, and g_m so long as the input is matched.

Let Vin = 0, and find total output noise current:

$$|I_{n,out}|_{M1} = |I_{n1}|\frac{R_S C_{GS1}}{g_m L_1 + R_S C_{GS1}}$$

For $g_m L_1 / C_{GS1} = R_S$

$$|I_{n,out}|_{M1} = \frac{|I_{n1}|}{2} \qquad \overline{I^2_{n,out}}|_{M1} = kT\gamma g_m$$

Rewrite this in terms of Q

We arrive at the noise figure of the circuit:

$$\mathrm{NF} = 1 + g_m R_S \gamma \left(\frac{\omega_0}{\omega_T}\right)^2 = 1 + \frac{\gamma}{Q^2 g_m R_S}$$

- **It is important to bear in mind that this result holds only at the input resonance frequency and if the input is matched.**

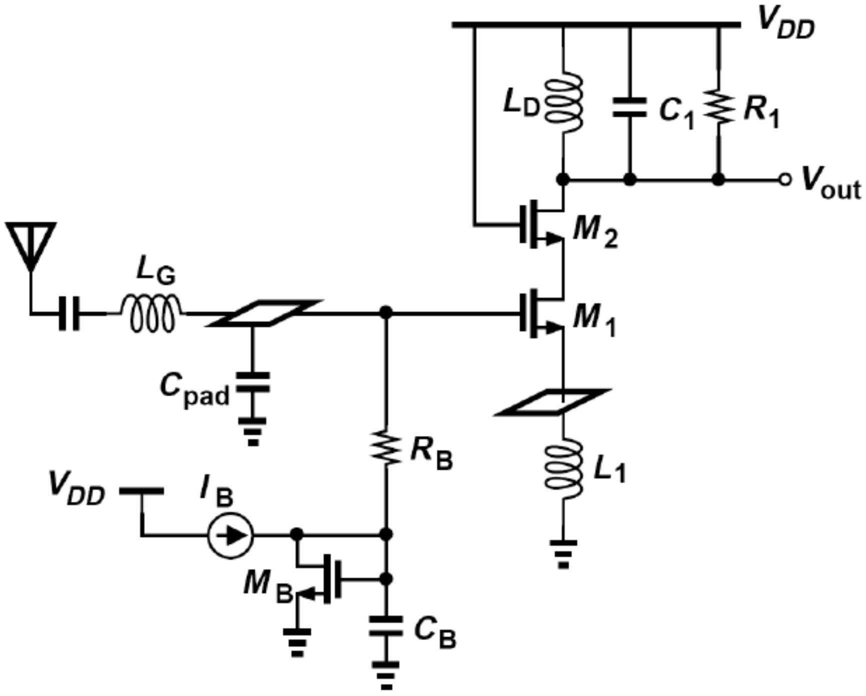
Design Procedure

The design procedure can begin with known values for NF and *L_1* and the following two equations:

$$\mathrm{NF} = 1 + g_{m1} R_S \gamma \left(\frac{\omega_0}{\omega_T}\right)^2$$

$$R_S = \left(\frac{C_{GS1}}{C_{GS1} + C_{pad}}\right)^2 L_1 \omega_T$$

The overall LNA appears as shown on right:

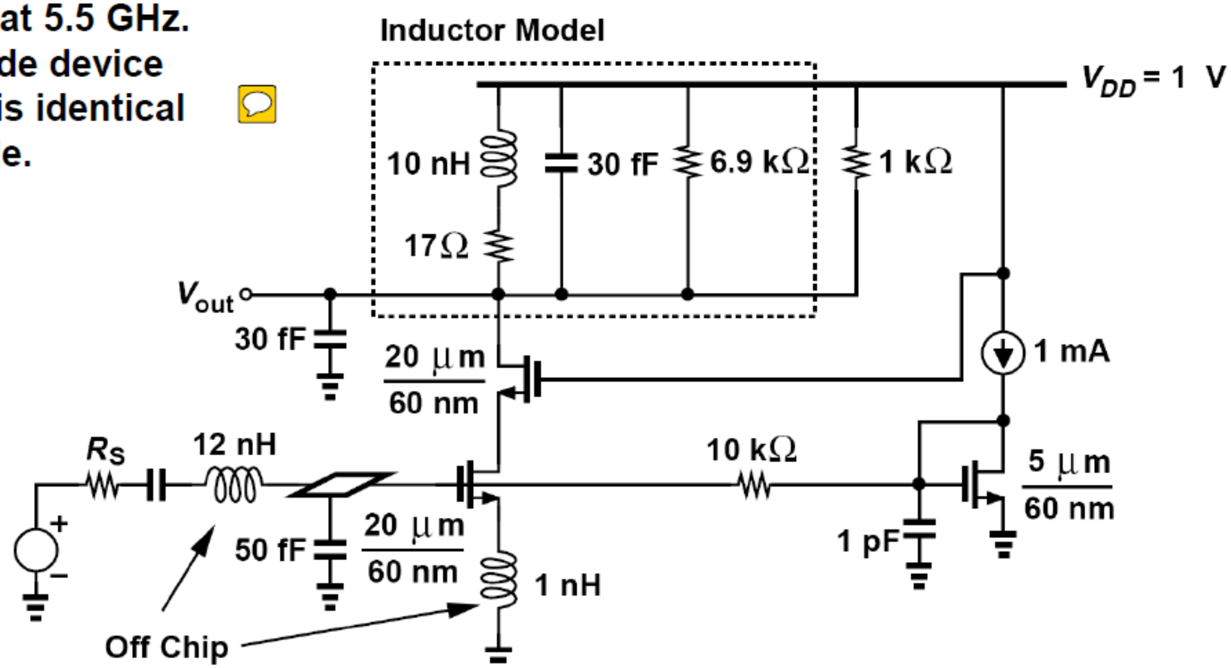


Design Procedure

Design a cascode CS LNA for a center frequency of 5.5 GHz in 65-nm CMOS technology.

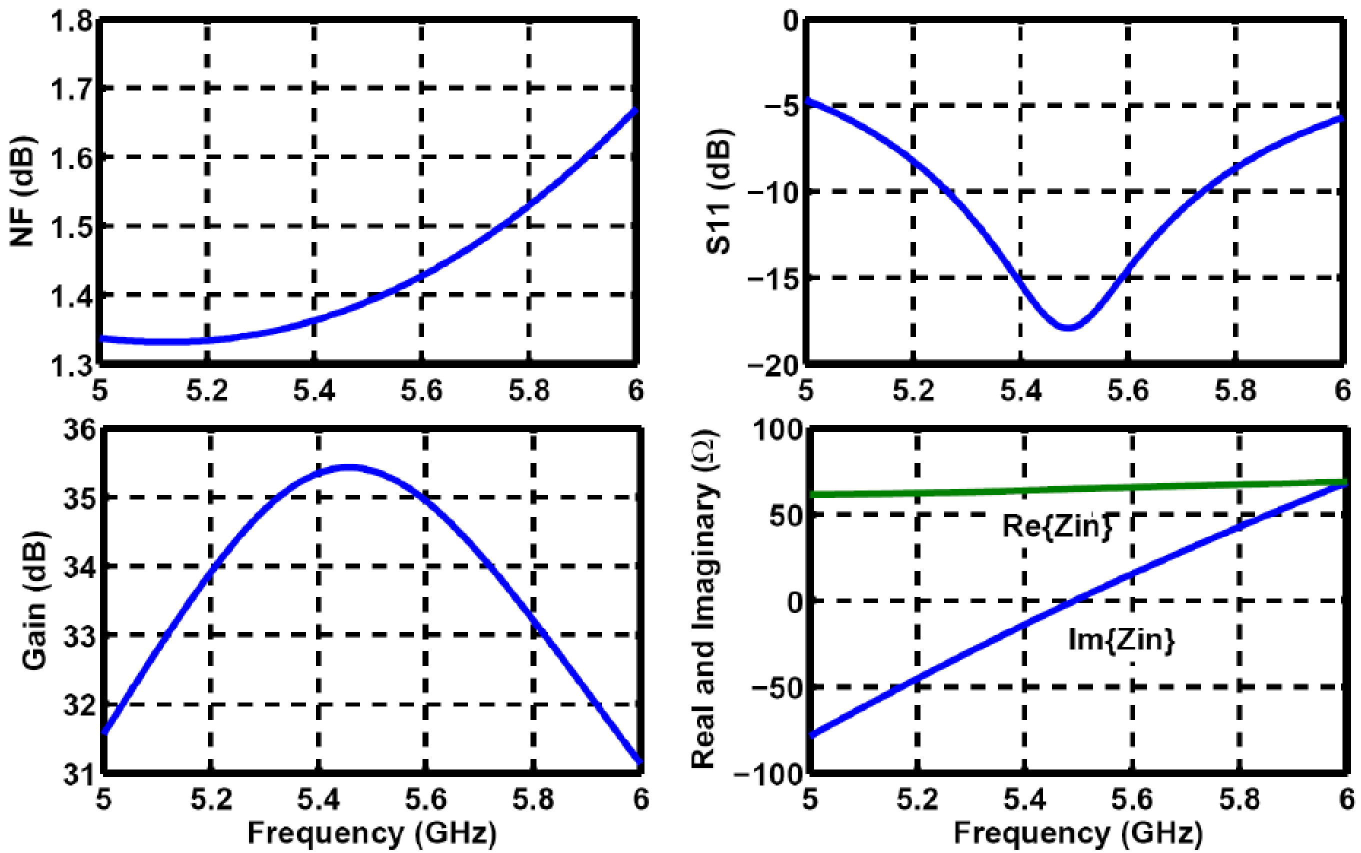
We begin with a degeneration inductance of 1 nH and the same input transistor as that in the CG stage in previous example. Interestingly, with a pad capacitance of 50 fF, the input resistance happens to be around 60Ω. (Without the pad capacitance, $Re\{Z_{in}\}$ is in the vicinity of 600 Ω.) We thus simply add enough inductance in series with the gate (L_G = 12 nH) to null the reactive component at 5.5 GHz.

The design of the cascode device and the output network is identical to that of the CG example.

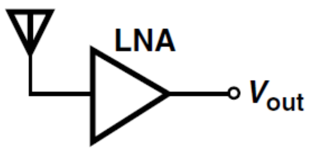


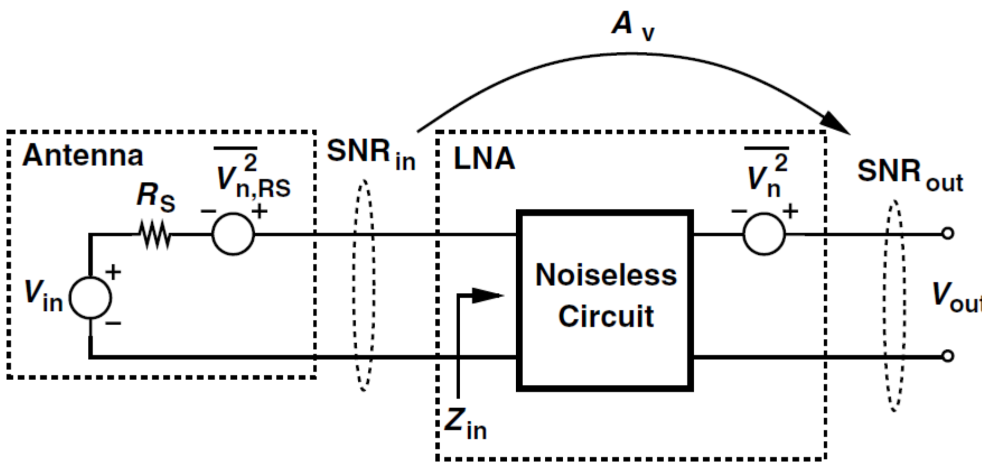
Design Procedure

Figure below shows the simulated characteristics. We observe that the CS stage has a higher gain, a lower noise figure, and a narrower bandwidth than the CG stage in previous example.



Noise Figure Revisit





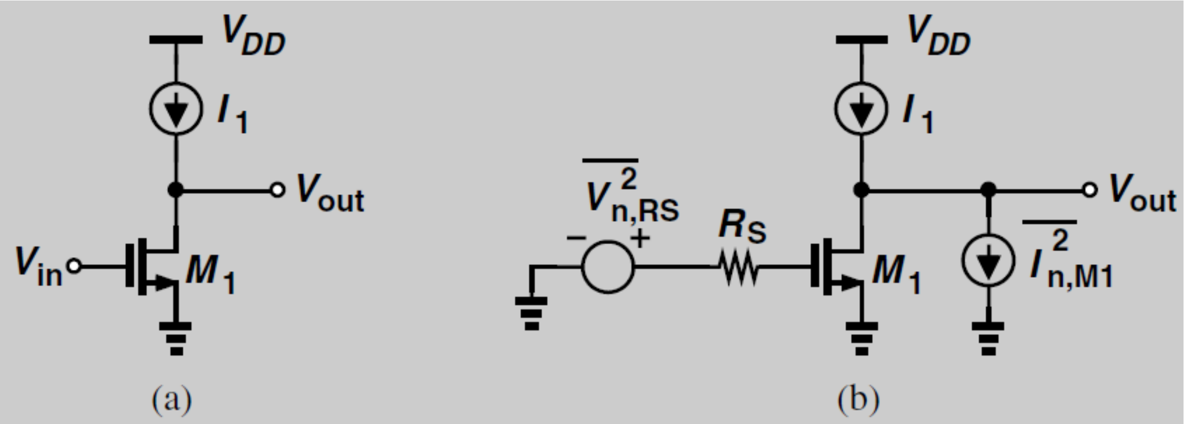
$$\mathrm{NF} = \frac{SNR_{in}}{SNR_{out}} \qquad SNR_{in} = \frac{|\alpha|^2 V_{in}^2}{|\alpha|^2 \overline{V_{RS}^2}} \qquad SNR_{out} = \frac{V_{in}^2 |\alpha|^2 A_v^2}{\overline{V_{RS}^2}|\alpha|^2 A_v^2 + \overline{V_n^2}}$$

$$\mathrm{NF} = \frac{V_{in}^2}{4kTR_S} \cdot \frac{\overline{V_{RS}^2}|\alpha|^2 A_v^2 + \overline{V_n^2}}{V_{in}^2 |\alpha|^2 A_v^2} = \frac{1}{4kTR_S} \cdot \frac{\overline{V_{n,out}^2}}{A_0^2} = \frac{\textit{Total Output Noise}}{\textit{Output Noise due to Source}}$$

$$= \frac{\textit{Noise due to Source} + \textit{Noise due to Circuit}}{\textit{Noise due to Source}} = 1 + \frac{\textit{Noise due to Circuit}}{\textit{Noise due to Source}}$$

Noise Figure Example Revisit

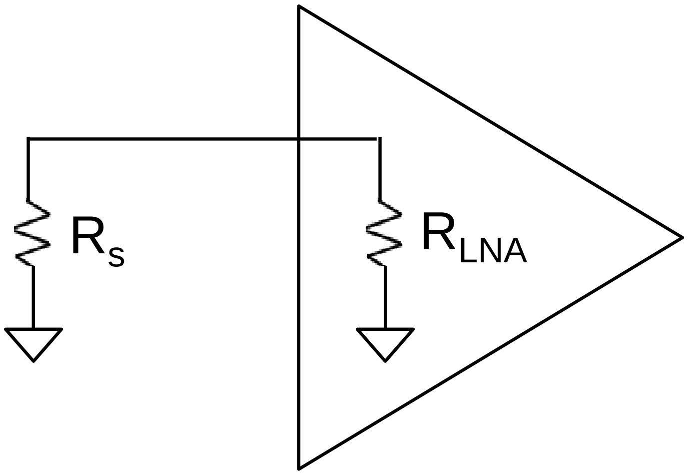
Determine the noise figure of the common-source stage shown below with a source impedance R_S. Neglect the capacitances and flicker noise of M1 and assume I_1 is ideal.



$$NF = \frac{Total\ Output\ Noise}{Output\ Noise\ due\ to\ Source}$$

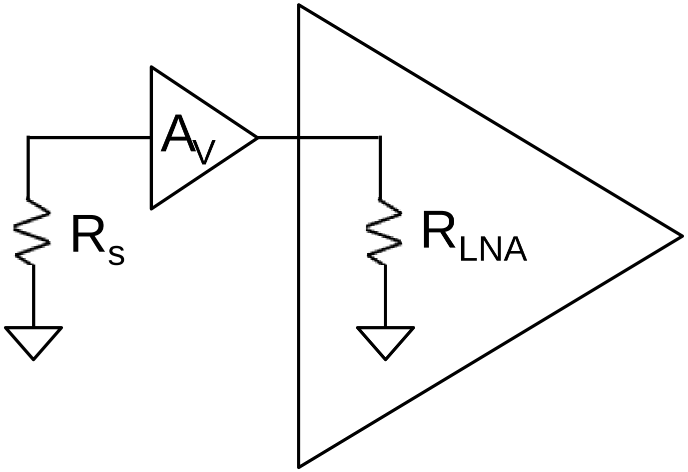
$$= \frac{(4kT\gamma g_m)r_o^2 + 4kTR_s(g_m r_o)^2}{4kTR_s(g_m r_o)^2} \quad = 1 + \frac{\gamma}{g_m R_s}$$

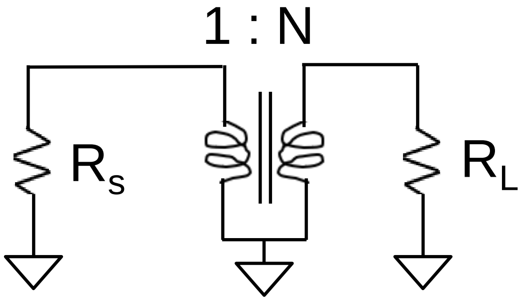
Noise Figure on Circuit Resistor

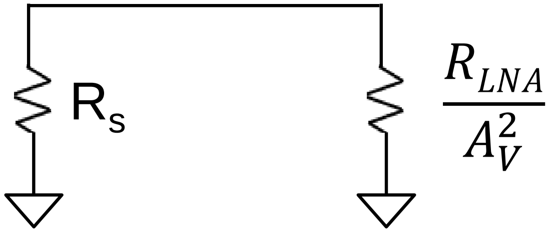


$$NF = 1 + \frac{4kTR_{LNA}}{4kTR_S}$$
$$= 1 + \frac{R_{LNA}}{R_S}$$

Noise Figure with Gain

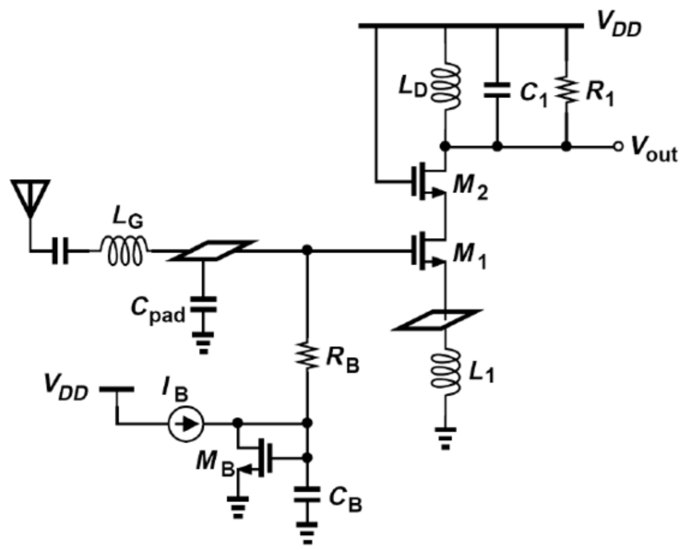


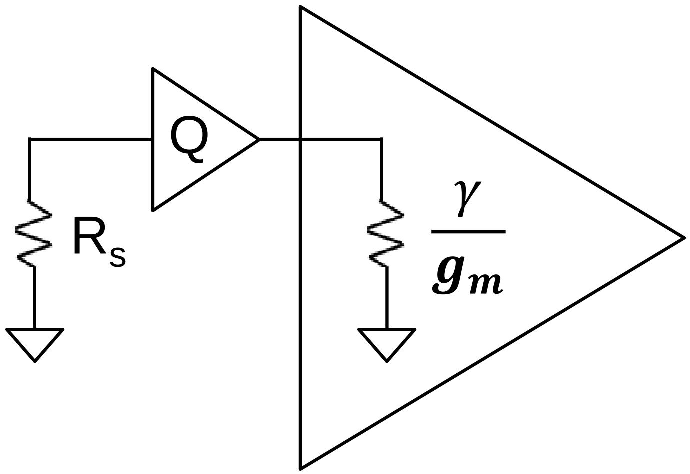




$$\boldsymbol{NF = 1 + \frac{R_{LNA}}{A_V^2 R_S}}$$

Noise Figure of CS LNA with Inductive Degeneration





$$NF = 1 + \frac{\gamma}{Q^2 g_m R_S}$$