EE230-02 RFIC II
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Lecture 7: LNA2

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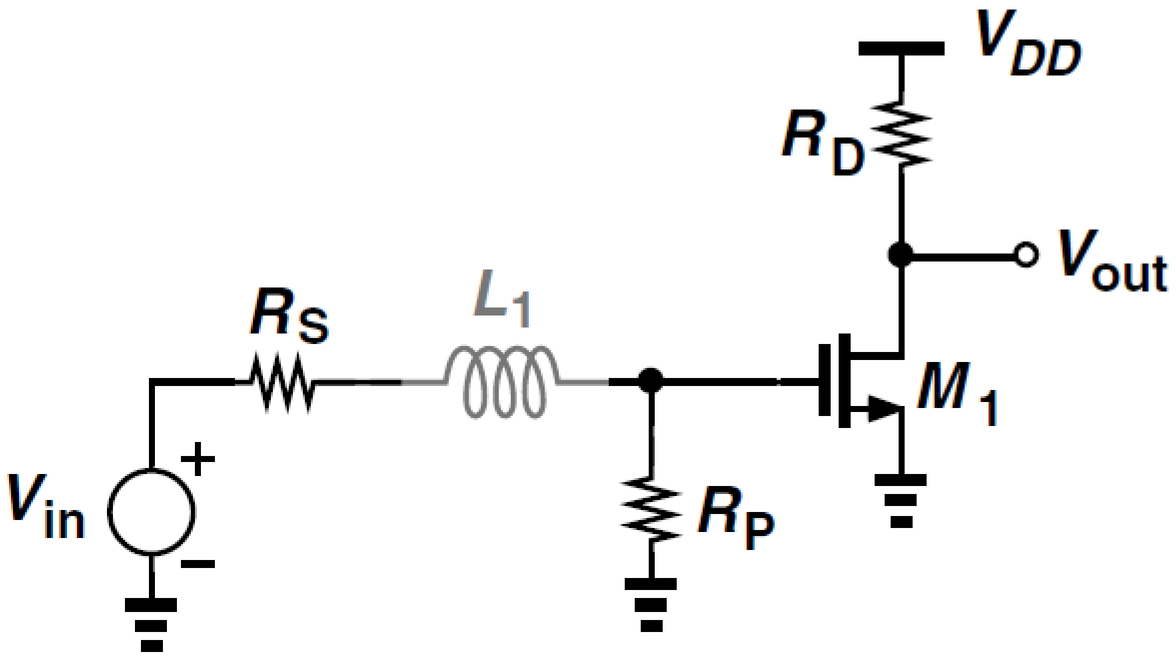
LNA Topologies

Common–Source Stage with	Common–Gate Stage with	Broadband Topologies
■ Inductive Load ■ Resistive Feedback ■ Cascode, Inductive Load, Inductive Degeneration	■ Inductive Load ■ Feedback ■ Feedforward ■ Cascode and Inductive Load	■ Noise–Cancelling LNAs ■ Reactance–Cancelling LNAs

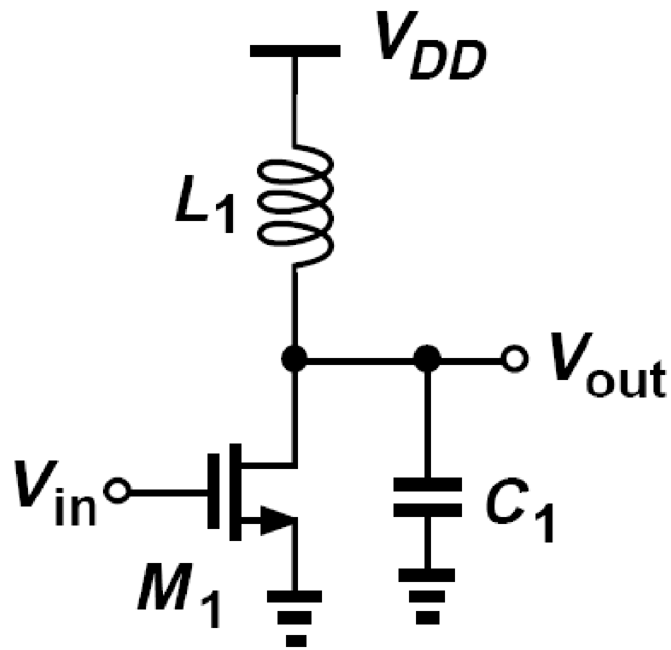
Resistor Input Matching



For $R_P \approx R_S$, the NF exceeds 3 dB—perhaps substantially.

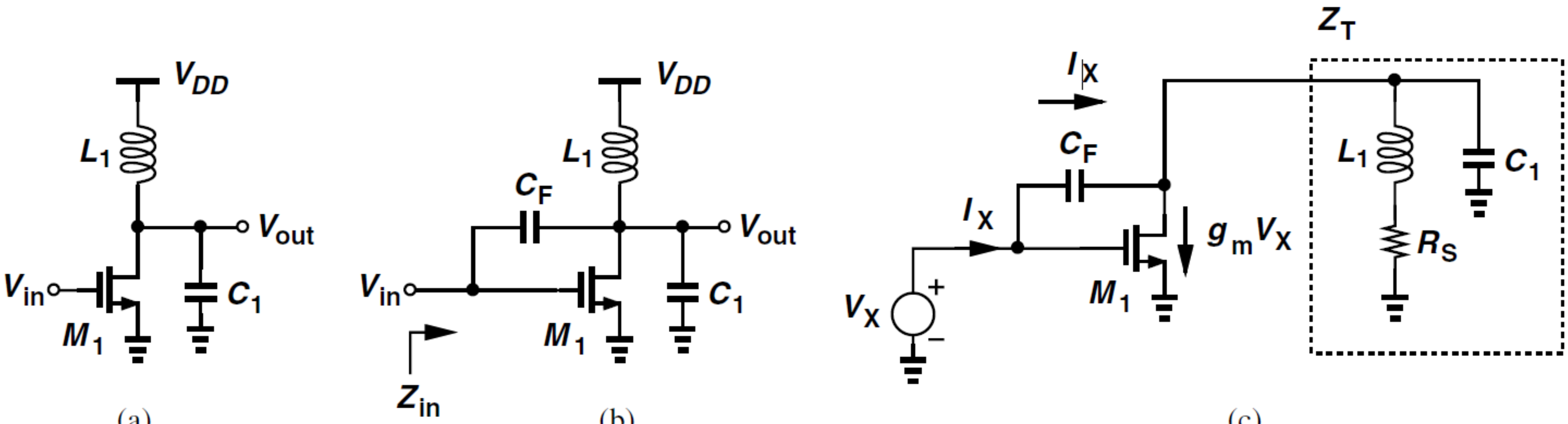
Common Source with Inductive Load

- Can operate with very low supply voltages
- L_1 resonates with the total capacitance at the output node, affording a much higher operation frequency than does the resistively-loaded counterpart



How about the input matching?

Common Source with Inductive Load

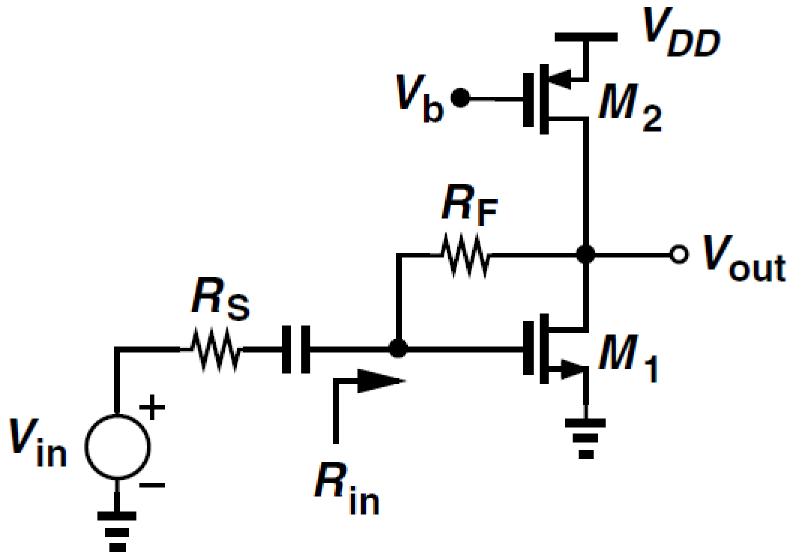


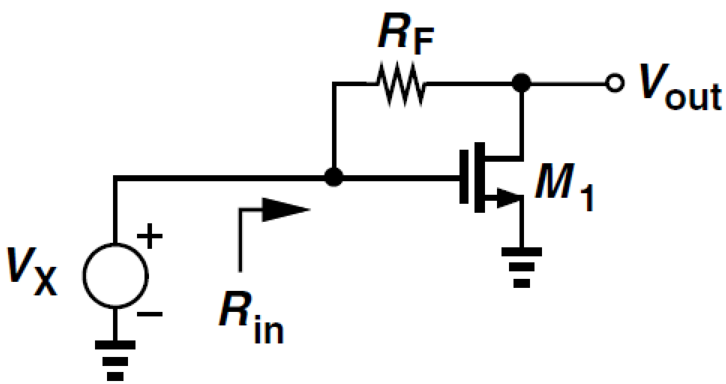
(a) (b) (c)

$$Z_{in}(s) = \frac{V_X}{I_X} = \frac{L_1(C_1 + C_F)s^2 + R_S(C_1 + C_F)s + 1}{[L_1C_1s^2 + (R_SC_1 + g_mL_1)s + 1 + g_mR_S]C_Fs}$$

While providing the possibility of $\mathrm{Re}\{Z_{in}\} = 50\ \Omega$ at the frequency of interest, the feedback capacitance C_F gives rise to a negative input resistance at other frequencies, potentially causing instability.

Common Source with Resistive Feedback

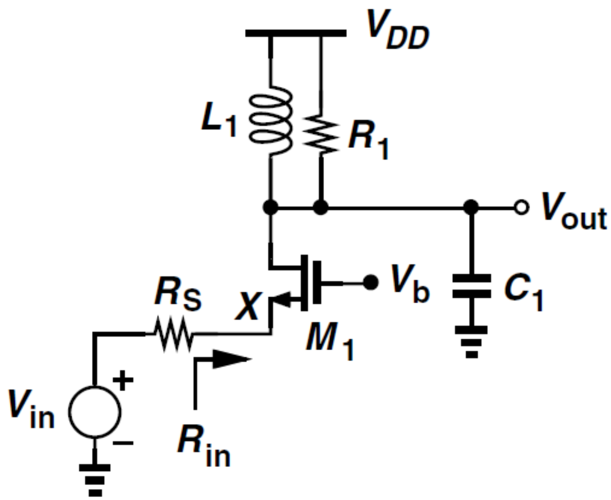




$$\mathrm{NF} \approx 1 + \frac{4R_S}{R_F} + \gamma + \gamma g_{m2} R_S$$

For $\gamma \approx 1$, the NF exceeds 3 dB even if $4R_S/R_F + \gamma g_{m2} R_S \ll 1$.

Common Gate LNA



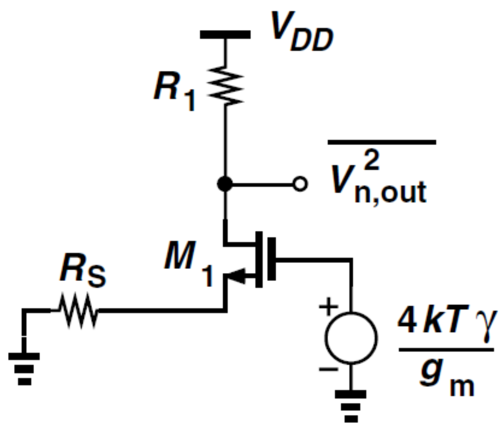
$$R_{in} = 1/g_m$$

$$g_m = 1/R_S = (50\,\Omega)^{-1}$$

$$\frac{V_{out}}{V_X} = g_m R_1 = \frac{R_1}{R_S}$$

$$V_{out}/V_{in} = R_1/(2R_S)$$

Common Gate Noise Figure



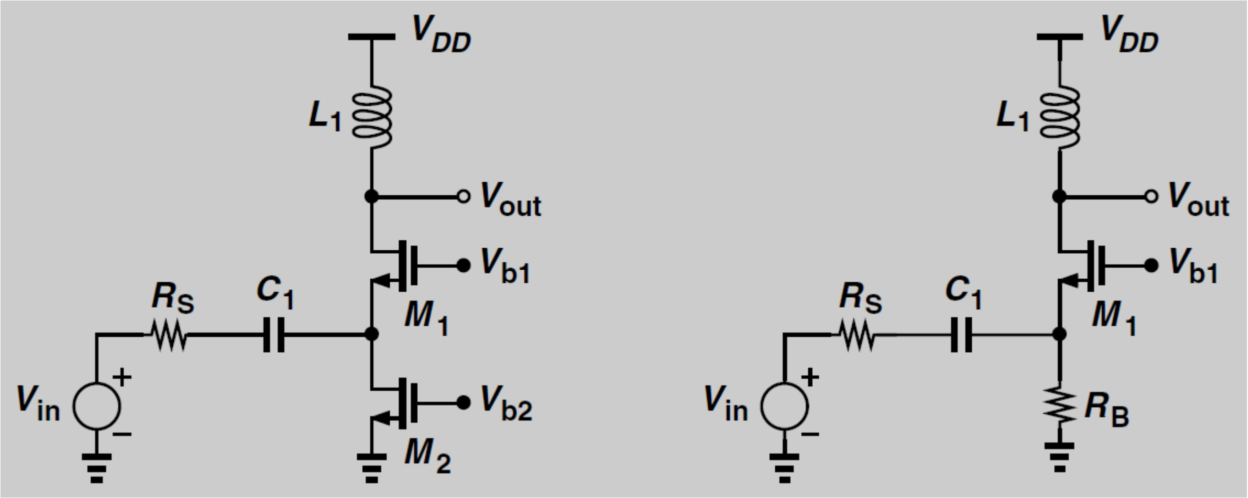
$$\overline{V^2_{n,out}}|_{M1} = \frac{4kT\gamma}{g_m}\left(\frac{R_1}{R_S + \frac{1}{g_m}}\right)^2 = kT\gamma\frac{R_1^2}{R_S}$$

$$NF = \frac{Total\ Output\ Noise}{Output\ Noise\ due\ to\ Source} = 1 + \frac{Noise\ due\ to\ Circuit}{Noise\ due\ to\ Source}$$

$$= 1 + \frac{kT\gamma\frac{R_1^2}{R_S} + 4kTR_1}{4kTR_s(\frac{1}{2}g_mR_1)^2} = 1 + \frac{kT\gamma\frac{R_1^2}{R_S} + 4kTR_1}{kTR_s(\frac{R_1}{R_S})^2} = 1 + \gamma + \frac{4R_S}{R_1}$$

Even if $\frac{4R_S}{R_1}$ << $1 + \gamma$, the NF still reaches 3dB with $\gamma \approx 1$

Common Gate Bias



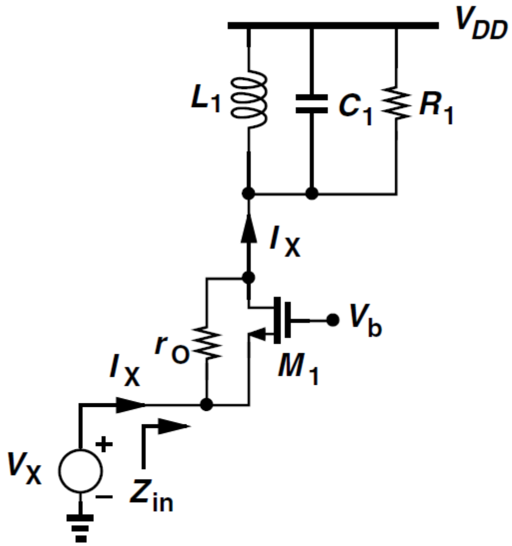
$$V_{DS2} \geq V_{GS2} - V_{TH2}$$

$$\overline{I^2_{n,M2}} = 4kT\gamma g_{m2}$$
$$= 4kT\gamma \frac{2I_D}{V_{GS2} - V_{TH2}}$$

$$\overline{I^2_{n,RB}} = \frac{4kT}{R_B}$$
$$= 4kT\frac{I_D}{V_{RB}}$$

Since $V_{GS2} - V_{TH2} \leq V_{RB}$, the noise contribution of M_2 is about twice that of R_B (for $\gamma \approx 1$). Additionally, M_2 may introduce significant capacitance at the input node.

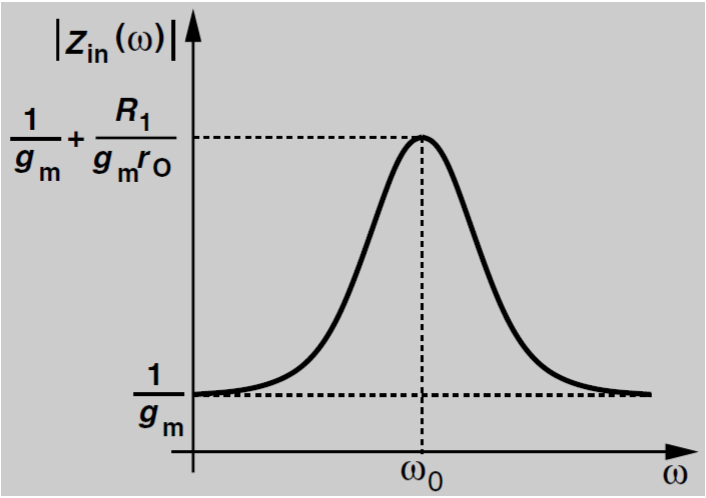
Common Gate Input Impedance



$$V_X = r_O(I_X - g_m V_X) + I_X R_1$$

$$\frac{V_X}{I_X} = \frac{R_1 + r_O}{1 + g_m r_O}$$

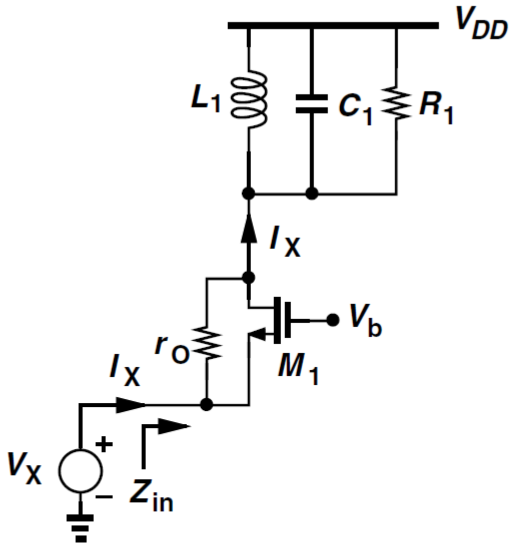
$$\approx 1/g_m + R_1/(g_m r_O)$$



For input matching,

$$R_S = \frac{R_1 + r_O}{1 + g_m r_O}$$

Common Gate Input Impedance



How about voltage gain?

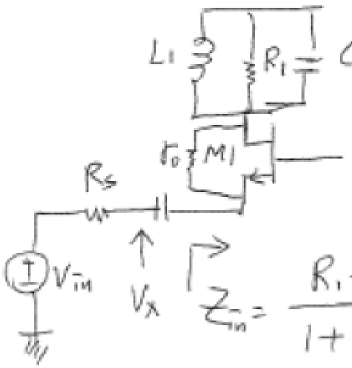
$$\frac{V_{out}}{V_{in}} = \frac{g_m r_O + 1}{r_O + g_m r_O R_S + R_S + R_1} R_1$$

$$R_S = \frac{R_1 + r_O}{1 + g_m r_O}$$

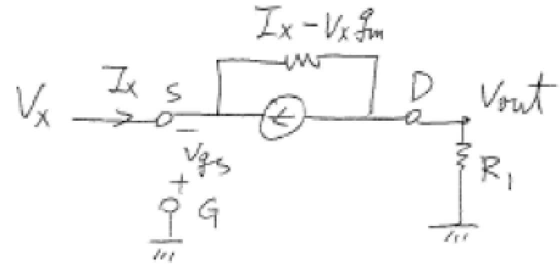
$$\frac{V_{out}}{V_{in}} = \frac{g_m r_O + 1}{2\left(1 + \frac{r_O}{R_1}\right)}$$

This is a disturbing result! If r_O and R_1 are comparable, then the voltage gain is on the order of $g_m r_O/4$, a very low value.

Common Gate Voltage Gain



$$Z_{in} = \frac{R_1 + r_0}{1 + g_m r_0}$$



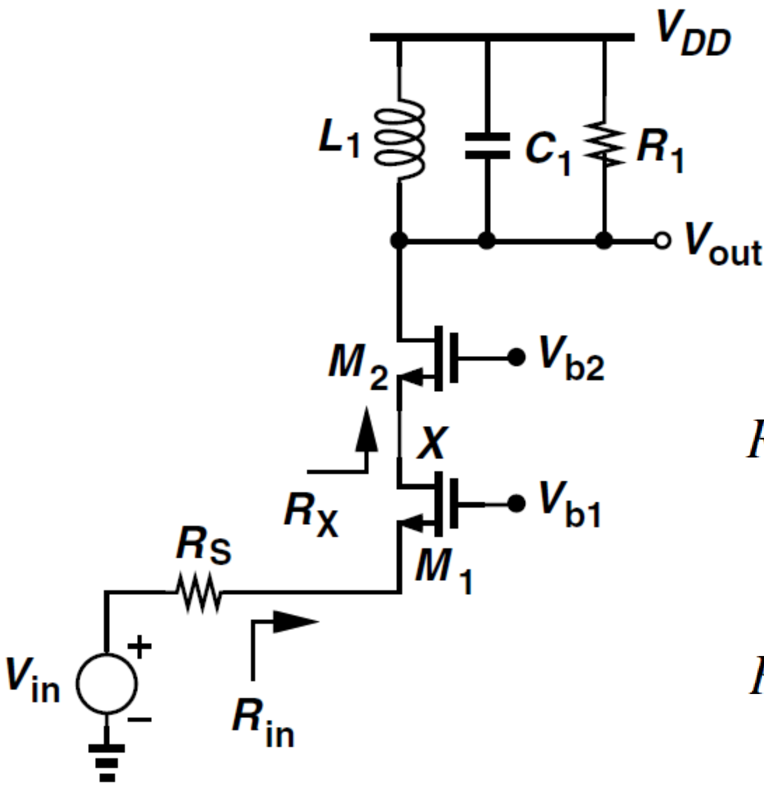
$$\frac{V_{out}}{V_x} = \frac{I_x R_1}{I_x \cdot Z_{in}} = \frac{R_1}{Z_{in}} = \frac{R_1(1+g_m r_0)}{(R_1 + r_0)}$$

$$\frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_x} \cdot \frac{V_x}{V_{in}} = \left[\frac{R_1(1+g_m r_0)}{R_1 + r_0}\right] \cdot \left[\frac{Z_{in}}{R_s + Z_{in}}\right] = \left[\frac{R_1(1+g_m r_0)}{R_1 + r_0}\right] \cdot \left[\frac{\left(\frac{R_1 + r_0}{1+g_m r_0}\right)}{R_s + \left(\frac{R_1 + r_0}{1 + g_m r_0}\right)}\right]$$

$$= \frac{R_1(1+g_m r_0)}{r_0 + g_m r_0 R_s + R_s + R_1} \quad \#$$

when $R_s \simeq \frac{R_1 + r_0}{1 + g_m r_0} \Rightarrow \frac{V_{out}}{V_{in}} \simeq \frac{(1 + g_m r_0)}{2\left(1 + \frac{r_0}{R_1}\right)} \simeq \frac{g_m r_0}{4}$ if $r_0 \simeq R_1$

Cascode Common Gate Stage



$$R_X = \frac{R_1 + r_{O2}}{1 + g_{m2} r_{O2}}$$

$$R_{in} = \left(\frac{R_1 + r_{O1}}{1 + g_{m2} r_{O2}} + r_{O1} \right) \div (1 + g_{m1} r_{O1})$$

$$R_{in} \approx \frac{1}{g_{m1}} + \frac{R_1}{g_{m1} r_{O1} g_{m2} r_{O2}} + \frac{1}{g_{m1} r_{O1} g_{m2}}$$

The addition of the cascode device entails two issues: the noise contribution of M_2 and the voltage headroom limitation due to stacking two transistors.

Noise From M_2