1. General Considerations:

1. Low noise: NF
2. Gain, linearity, and DR.
3. Impedance matching: $\begin{align*}
\text{input:} & \quad 5\Omega \\
\text{output:} & \quad 50\Omega
\end{align*}$
4. Stability:

   - Ssrn stability factor: $k = \frac{|1 + \Delta|}{1 + \Delta} \leq 1 / |\Delta| \leq 1$

   - $a = \Delta_{v1} = -\Delta_{v2}$

   - If $k > 1$ and $\Delta < 1$, unconditional stability

   - $|a| \rightarrow k^a$

5. In summary: $\begin{align*}
NF_{tot} &= NF_{lca} + \frac{NF_{other}}{G_{lca}} \\
1 & \leq \frac{1}{\frac{1}{ZP_2} - \frac{1}{ZP_3}} \leq \frac{1}{2ZP_1} \\
& \leq \frac{G_{lca}}{ZP_3}
\end{align*}$

   - NF and gain of LCA decide $NF_{tot}

   - High $ZP_3$ of LCA reduces in-band IM distortion

   - Total $ZP_3$ is not decided by LCA performance

   - Matching provides for overall signal performance in front-end.

2. Input Stage:

1. Common Source Stage.

   - $Z_{in} = \frac{2m}{1 + \frac{L}{2m}}$

   - $R_P$ is added to match the source resistance $R_s$

   - Drawback: Input is attenuated. For the attenuator: $NF = 1 + \frac{R_s}{Z_P} = 2$

   - $NF_{lca} > 3$ dB

   - This input stage is not attractive!
If \( g_m \ll 1 \) and \( C_{eq} \rightarrow 0 \) for \( \omega \gg \frac{1}{RC} \), the noiseless conductance would provide nice matching, but amplifier gain for \( K_F \) becomes poor.

2. Common gate stage.

Resistance matching possible by \( I_{ss} \).

However \( NF = 1 + \frac{1}{2} \gg 3 \sim 4 \). \( \Rightarrow \) not very useful!

3. Shunt-series feedback:

Create another low resistance path.

Simple implementation

Drawbacks:

- \( M_2 \) may introduce substantial noise from the output \( \rightarrow \) raise the \( NF \)
- Total phase shift around the loop may create instability.
- Higher power dissipation.


Series in provides negative feedback.

\[ V_{in} = V_{gs} + V_{gs} = j \omega L_s \left( g_m V_{gs} + j \omega C_{gs} V_{gs} \right) + V_{gs} \]

\[ Z_{in} = \frac{V_{in}}{\omega C_{gs} V_{gs}} = \frac{g_m L_s}{\omega C_{gs} + \frac{1}{j \omega C_{gs}}} \]

\( \Rightarrow \) cancelled for \( \omega = \omega_c \)

Noiseless matching resistance.
Refinement of the ckt:

\[ Z_{in} = \frac{g_m L_s}{C_{gs}} + j \left[ \omega (L_s + L_d) - \frac{1}{\omega C_{gs}} \right] \]

Matching criteria:

\[
\begin{align*}
C_{gs} &= \frac{1}{L_s + L_d} \\
R_s &= \frac{g_m L_s}{C_{gs}}
\end{align*}
\]

LNA Analysis:

\[ NF = \frac{S_{in}/V_{in}}{S_{out}/V_{out}} = \frac{S_{in}}{S_{out}} \frac{N_{dev, out} + G \cdot N_{in}}{N_{in}} = \frac{N_{dev, out} + G \cdot N_{in}}{G \cdot N_{in}} + 1. \]

At resonant freq., \( Z_{in} = R_s \) \( \rightarrow \) \( V_{in, in} = \frac{V_{gs}}{2} \) \( \therefore \) \( I_{in, in} = \frac{V_{gs}}{2R_s} \)

Next, calculate gain: \( G_m = \frac{I_{out}}{V_{in, in}} \) \( \therefore G_m^2 = G \)

\[ V_{gs} = \frac{I_{in, in}}{(j\omega C_{gs})} \] \( \therefore I_{out} = g_m \cdot V_{gs} \)

\[ G_m = \frac{g_m \cdot I_{in, in} / (j\omega C_{gs})}{V_{in, in}} = \left. \frac{g_m}{R_s \cdot j\omega C_{gs}} \right|_{w = w_0} = \frac{g_m}{j} \]

\[ NF = \frac{N_{dev, out}}{|g_m|^2 \cdot N_{in}} + 1 = \frac{4kT \cdot \mu \cdot g_m}{g_m^2 \cdot \alpha^2 (4kT R_s) / 4} + 1 = 1 + \frac{4 \cdot \mu}{g_m \cdot \alpha^2 \cdot R_s} \]

\[ g_m \cdot \alpha^2 \cdot R_s = \left. \frac{g_m \cdot R_s}{(R_s \cdot \omega C_{gs})^2} \right|_{R_s = \frac{g_m L_s}{C_{gs}}} = \frac{1}{L_s \cdot \omega^2 \cdot C_{gs}} \left|_{\omega = \frac{1}{L_s \cdot \omega C_{gs}}} \right. = \frac{1}{L_s \cdot \omega^2 \cdot C_{gs}} \]

\[ \Rightarrow NF = 1 + \frac{4 \cdot \mu}{1 + \frac{L_s}{L_s}} \]

\[ W_{\text{opt}} = \frac{1}{3W_t C_{ox} R_i} \quad \text{and} \quad F_{\text{min}} \approx 1 + 2.3 \left( \frac{W_t}{W_r} \right) \]

\[ \frac{g_m L_s}{C_{gs}} = 50 \rightarrow L_s = \frac{50 C_{gs}}{g_m} \]

\[ W_o^2 = \frac{1}{C_{gs} (L_s + g)} \rightarrow I_g = \frac{1}{W_o^2 C_{gs} L_s} \quad \text{use SP and RF simulation to optimize} \]

5. Differential LNA Design.

Avoid parasitic
Double gain
Better linearity for same output level
Double power losses
Double area
Higher NF!

6. IP3 and Power.

\[ \text{IP}_3 = \frac{4V_r^2}{R_s} \left| \frac{g_v}{g_r + g_v - 2g_i} \right| \]

Power dissipation:

\[ P \propto \frac{L^2}{R_t} \frac{W_s^2}{w_s} \cdot \frac{1}{L_s^3 (1 + L_s / L_0)} \]

standard RT circuit parameters