

# Radio-Frequency IC Design

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## Lecture 6: Low Noise Amplifier

ELEC 404

Acknowledgement: *The Design of CMOS Radio-Frequency Integrated Circuits.* T. Lee



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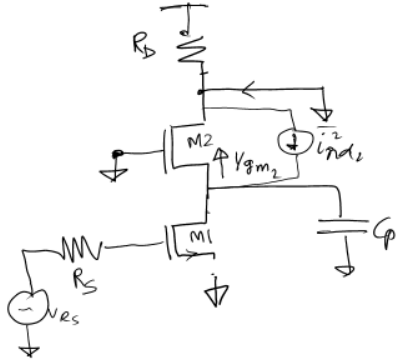
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# Noise Factor, KCL & KVL

- For  $F$ , calculate the o/p noise current due to different noise sources
- Apply KVL and KCL, and remember correlations
- For simplicity, ignore channel length mod

$$F = \frac{\overline{V_{no, Total}^2}}{\overline{V_{n, o, R_S}^2}}$$

$$= \frac{\overline{i_{n, o, Total}^2}}{\overline{i_{n, o, R_S}^2}}$$



①  $\overline{V_{R_S}^2} = 4KTR_S \Delta f$

$$\overline{i_{n, o, R_S}^2} = g_{m1}^2 \overline{V_{R_S}^2} \frac{\left(\frac{1}{\omega C_p}\right)^2}{\left(\frac{1}{g_{m2}}\right)^2 + \left(\frac{1}{\omega C_p}\right)^2} \quad \text{--- ①}$$

②  $\overline{i_{R_D}^2} = \frac{4KT}{R_D} \Delta f$        $\overline{i_{n, o, R_D}^2} = \overline{i_{R_D}^2}$  --- ②

③  $\overline{i_{nd,1}^2} = 4KT \gamma g_{m2} \Delta f = 4KT \gamma \frac{g_{m1}}{\alpha} \Delta f$

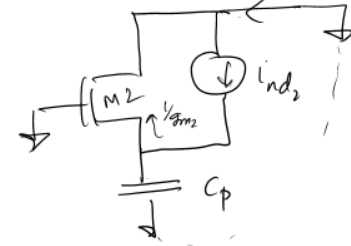
$$\alpha = \begin{cases} 1 & \text{long-channel device} \\ \frac{g_m}{g_{m0}} \approx \frac{1}{1.8} & \text{short-channel} \end{cases}$$

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$$\overline{i_{n, o, d_1}^2} = \overline{i_{nd,1}^2} \frac{g_{m1}^2}{g_{m2}^2 + \omega^2 C_p^2} \quad \text{--- ③}$$

④

$$\overline{i_{n, o, d_2}^2} = \overline{i_{nd,2}^2} \frac{\omega^2 C_p^2}{g_{m1}^2 + \omega^2 C_p^2}$$



④

where  $\overline{i_{nd,2}^2} = 4KT \frac{\gamma}{2} g_{m2} \Delta f$

$$F = \frac{\text{①} + \text{②} + \text{③} + \text{④}}{\text{①}}$$

$$= 1 + \frac{\gamma}{\alpha} \left( \frac{1}{g_{m1} R_S} + \frac{\omega^2 C_p^2}{g_{m1}^2 g_{m2} R_S} \right)$$

$$+ \frac{1}{g_{m1}^2 R_S R_D} \left( 1 + \frac{\omega^2 C_p^2}{g_{m2}^2} \right)$$

# Low Noise Amplifier

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- **Noise Figure (NF)**
- **Gain**
  - **Voltage ( $A_v$ ) when output is connected directly to the gate of the mixer**
  - **$S_{21}$  (input/output impedances matched)**
- **Input Matching:  $S_{11}$**
- **Power Consumption**
- **Linearity (IIP3, 1dB compression point)**
- **-3dB BW**
  - **Narrowband/Broadband**

# **R-CSLNA: Input Match/NF**

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- **Resistor-matched Common-Source (CS)**
  - **Input match to  $R_s$**
  - **Broadband match**
  - **Attenuates signal**
  - **Adds noise**

# **CGLNA: Input Match / NF / $A_v$**

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- **Common-Gate (CG) stage**

- **Input match to  $\sim 1/g_m$**
- **Broadband match**
- **No input signal attenuation**
- **No extra 'matching' noise**
- **Limited gain and noise performance**

# **Z-Degenerated CSLNA: Input Match**

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- **Impedance-degenerated CS**

# **L-degenerated CSLNA: Input Match**

- **Inductor-degenerated CS**

- **Series RLC tank**

# **L-degenerated CSLNA: $G_m$**

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- **Effective transconductance ( $G_m$ ) and available transconductance ( $G_{ma}$ )**

# L-degenerated CSLNA: NF

$$\overline{|X + Y|^2} = \overline{(X + Y)(X + Y)^*} = \overline{|X|^2 + |Y|^2 + XY^* + YX^*} = \overline{|X|^2} + \overline{|Y|^2} + \overline{2Re(XY^*)}$$

$$F = 1 + \frac{\omega_0 \gamma}{\omega_T \alpha} \frac{1}{2Q} \left[ 1 + (4Q^2 + 1) \frac{\delta \alpha^2}{5\gamma} - 2|c| \sqrt{\frac{\delta \alpha^2}{5\gamma}} \right] = 1 + \frac{\omega_0}{\omega_T} S_N$$

# **L-degenerated CSLNA: $A_v$**

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- **“Power-matched” design**
- **Ignore  $C_{gd}$  and  $r_0$  for now (Use Cascode)**