Noise and Feedback

- Ideal feedback:
  - No increase of input referred noise
  - No decrease of SNR at output

- Practical feedback: increased noise
  - Noise from feedback network
  - Noise gain from elements outside feedback loop
Ideal Feedback and Noise

- Ideal (noiseless) feedback network:
  - Noise doesn't change

- Real feedback elements have noise though…

Real Feedback

- Conceptually identical to standard two port calculations
  - Use $R_s = 0$ to find $v_{leq}^2$
  - $R_s = \infty$ to find $i_{leq}^2$

- Calculations get tedious…
Practical Feedback Analysis

- Quick approximation method:
  - Consider loading of feedback network on the input
  - Add a noise source associated with this element.
- Example: shunt feedback
  - Loading at input is $R_F \Rightarrow i_i^2 = i_n^2 + 4kT\Delta f/R_F$

Example #2: Series-Shunt Feedback

- Loading is $R_F \parallel R_E$
- So, noise voltage becomes:
  - $v_i^2 = v_n^2 + 4kT(R_F \parallel R_E)\Delta f$
Implications: Non-Inverting Amp

- Minimum power from feedback $\rightarrow$ large $R_1+R_2$
- Example:
  - $A_v = 10$, $R_2 = 100k\Omega$, $R_1 = R_2(A_v - 1) = 900k\Omega$
  - $v_{nfb}^2 = 40nV/\sqrt{Hz}$ (very high)
- Only way to lower noise is increase power…

Example: Inverting Amplifier

- Ignoring noise from $R_1$, $R_2$:
  \[
  v_i = -v_j \frac{R_2}{R_1} + v_n \frac{R_1 + R_2}{R_1} \]
  \[
  v_{eq}^2 = v_i^2 \left( \frac{R_1 + R_2}{R_1} \right)^2 = v_n^2 \left( \frac{R_1 + R_2}{R_2} \right)^2 = v_n^2 \left( 1 + \frac{1}{|A_v|} \right)^2
  \]
- “Ideal” feedback, why is $v_{i,eq}^2 > v_n^2$?
“Complete” Noise Example

- Effect of cascode device noise on common-source feedback amplifier

- Simplified model:
  - Lump parasitic caps
  - Neglect $r_0$

Example (cont.)

- Calculate noise TF to amplifier output:

\[
\begin{align*}
  v_o : & \quad s \left( C_L + FC_{tot} \right) v_o = g_{m2} v_x + i_{n2} \\
  v_i : & \quad s C_s v_i + g_{m1} v_i + g_{m2} v_x + i_{n_2} = 0 \\
  v_g : & \quad v_g = F v_o \\
\end{align*}
\]

with \( F = \frac{C_F}{C_F + C_{tot}} \)
Example (cont.)

- **Low frequency:**
  - $i_{n2}$ doesn’t reach output

- **High frequency:**
  - $C_x$ acts as a short

\[
\begin{align*}
V_o &= \frac{1}{F_g(s)} \left( \frac{sC_x}{g_m2} \right) i_{n2} \\
y_m &= \frac{1}{F_g(s)} \left( \frac{s}{\omega_p} \right) \frac{1}{s^2} i_{n2}
\end{align*}
\]

Example (cont.)

- **Total noise:**

\[
\begin{align*}
\sigma_v^2 &= \frac{1}{F_g(s)} \left( \frac{\alpha_0 R}{4} \right) (4kTg_m2) \\
\sigma_v^2 &= \frac{1}{F_g(s)} \left( \frac{F_g(s)C_x}{g_m2} \right) \left( \frac{F_g(s)C_L}{C_L + FC_{tot}} \right) (kTg_{m2}) \\
\sigma_v^2 &= \frac{kT}{(C_L + FC_{tot})} \left( \frac{C_x}{C_L + FC_{tot}} \right)
\end{align*}
\]