EE538_Sp2021_Midterm

May 7, 2021

Instructor: Jason Silver
Midterm (100 points)
Due Sunday, May 16 (Submit on Canvas as a Jupyter Notebook or PDF)

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Problem 1:Noise figure (25 points)

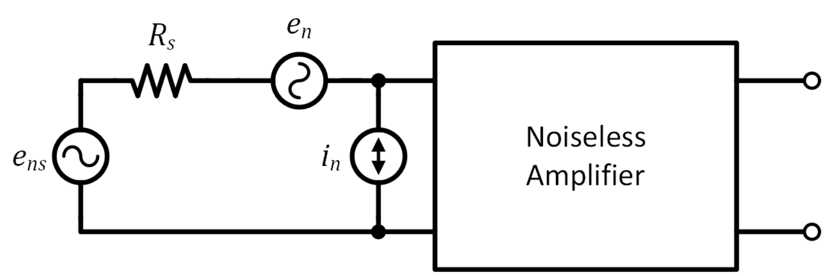

Figure 1. Amplifier noise model

An amplifier datasheet provides noise measurements that show it has a noise figure of $3dB$ for $R_s = 100\Omega$ and $R_s = 10k\Omega$ (same noise figure for both values of R_s) at $T = 300K$ and $f = 10kHz$.

a) Assuming all noise sources are white and e_n and i_n are uncorrelated, determine e_n and i_n at $10kHz$ from the noise figure data. (10 points)

b) What are the optimum source resistance R_{opt} of the amplifier and the corresponding minimum noise figure NF_{min}? (5 points)

c) Upon measuring the output noise of the amplifier with $R_s = 0$, you find that it has a $1/f$ noise corner of $1kHz$. What is the noise figure at $100Hz$ for $R_s = R_{opt}$? (10 points)

Problem 2: Noise in opamp circuits (25 points)

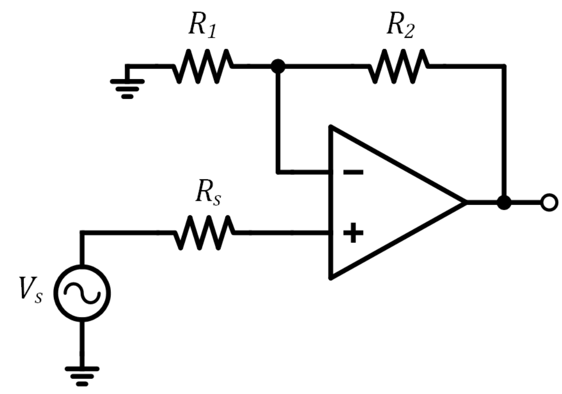

Figure 2. Non-inverting amplifier with source resistance

For the non-inverting amplifier in Fig. 2, suppose you have a choice between two opamps. Opamp A has $e_{na} = 10nV/\sqrt{Hz}$ and $i_{na} = 10pA/\sqrt{Hz}$, while opamp B has $e_{na} = 5nV/\sqrt{Hz}$ and $i_{na} = 0.5pA/\sqrt{Hz}$.

a) What is the optimum source resistance for each opamp and its corresponding minimum noise figure? If $R_s = 1k\Omega$, which opamp should you use to minimize noise figure? (10 points)

b) You found an even better opamp with $e_{na} = 2nV/\sqrt{Hz}$ and $i_{na} = 1pA/\sqrt{Hz}$ and decided to use it instead of the first two. What is the noise figure of the amplifier if $R_1 = 500\Omega$ and $R_2 = 4.5k\Omega$? (7.5 points)

c) If the transit frequency of the opamp is $10MHz$ and its $1/f$ corner is $10kHz$, what is the signal-to-noise ratio for an input signal given by $v_{in} = v_a \cdot \sin(\omega_0 t)$, where $v_a = 1mV$ and $\omega_0 = 2\pi \cdot 1kHz$? (7.5 points)

Problem 3: Low-noise amplifier design (25 points)

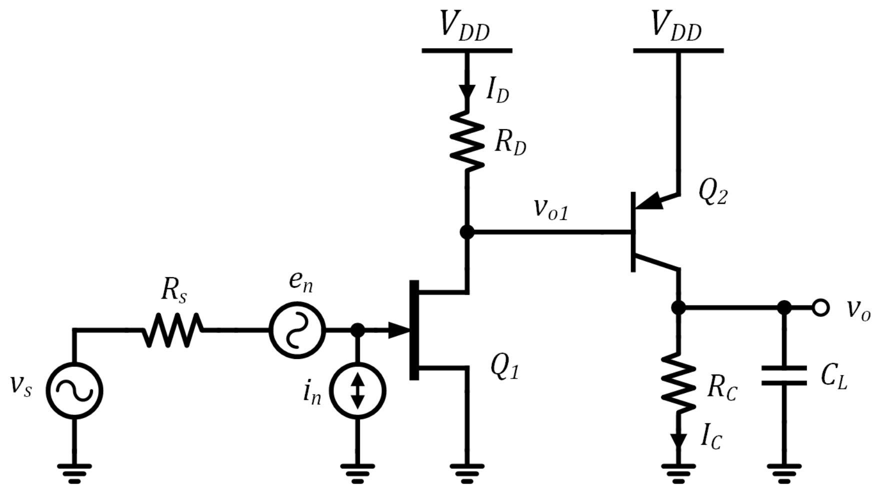

Figure 3. CS-CE Amplifier

As shown in Fig. 3, a common-source amplifier can be combined with a common-emitter amplifier for high input impedance and high gain (biasing circuitry not shown).

Unless otherwise specified, assume only drain current thermal noise for Q_1 and base/collector shot noise for Q_2 (i.e. ignore $1/f$ noise and assume $i_n = 0$ for Q_1 and $r_b = 0$ for Q_2). Ignore all capacitances except C_L.

For both transistors, assume $r_o \to \infty$.

Use $\gamma = 2/3$, $T = 300K$, and $\beta = I_C/I_B = 200$ for Q_2 for your calculations.

a) Noise measurements of Q_1 reveal that $e_n = 3nV/\sqrt{Hz}$ for $I_D = 100\mu A$. What is the corresponding transconductance efficiency, g_m/I_D? (5 points)

b) Assuming the g_m/I_D value determined in part **a)**, determine values for I_D and R_D that give an input-referred voltage noise density of the common-source stage to be $e_{n1} = 1nV/\sqrt{Hz}$ and a voltage gain of $20dB$. (10 points)

c) Design the common-emitter stage (i.e. determine I_C and R_C) for a gain of $20dB$ and such that with the addition of the second stage the total input-referred *voltage* noise is only 1% higher than the $1nV/\sqrt{Hz}$ target. (10 points)

Problem 4: DC-coupled differential amplifier (25 points)

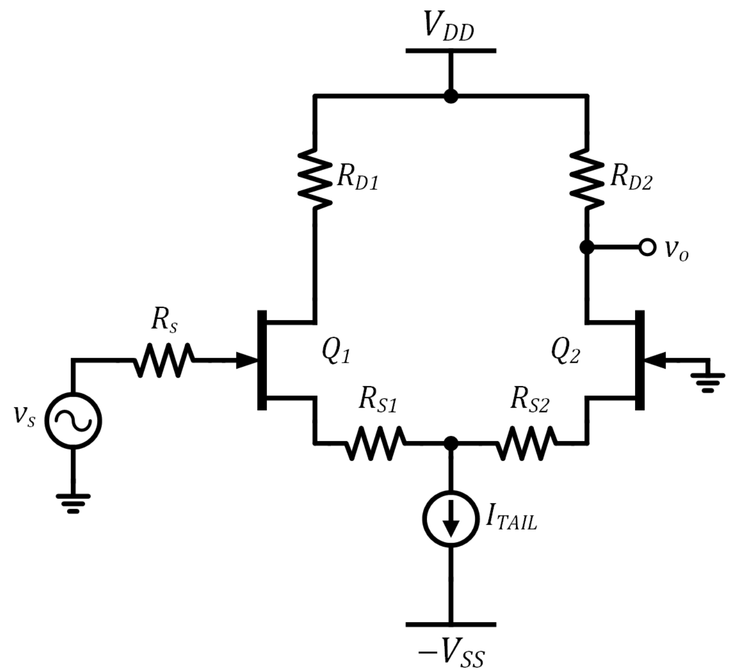

Figure 4. DC-coupled differential amplifier

The JFET differential pair in Fig. 4 is to be used for a DC-coupled sensor application.

I_{TAIL} is an ideal current source with $R_{out} \to \infty$.

Unless otherwise specified, assume only drain current thermal noise for Q_1 and Q_2 (i.e. ignore $1/f$ noise and assume $i_{ng} = 0$ for Q_1 and Q_2). Ignore all capacitances.

For both transistors, assume $r_o \to \infty$, $\gamma = 2/3$, and $g_m/I_D = 10S/A$. $T = 300K$.

a) Determine an expression for the input-referred voltage noise density of the amplifier, e_n, in terms of R_D, R_{S1}, R_{S2}, I_{TAIL}, γ, and kT. Do NOT assume balanced operation for noise analysis. (15 points)

b) Calculate the input-referred noise density if $I_{tail} = 1mA$, $R_D = 10k\Omega$, and $R_{S1} = R_{S2} = 1k\Omega$. (10 points)