ECE 6416 Quiz 2

November 16, 2009

Professor Leach Name______________________________

Instructions. Print your name in the space above and at the top of all other pages in your quiz. Place a box around each answer. Express each numerical answer as a decimal number. Numerical values are $4kT_0 = 1.6 \times 10^{-20}$ J, $q = 1.6 \times 10^{-19}$ C, and $V_T = 25\,\text{mV}$. **Honor Code:** *I have neither given nor received help on this quiz.* Initials ____________

1. An amplifier has a voltage gain of 300 and an input resistance of $5\,\text{k}\Omega$. A white noise source with an output resistance $R_S = 2\,\text{k}\Omega$ is connected to the amplifier input. With the source voltage zeroed, the rms amplifier noise output voltage is $0.470\,\text{mV}$. With the rms spot noise output voltage of the source set to $v_s = 0.1\,\mu\text{V}/\sqrt{\text{Hz}}$, the rms amplifier output voltage is $4.82\,\text{mV}$. Solve for the noise factor and the noise figure of the amplifier.

$$v_{no1}^2 = \left(\frac{AR_i}{R_S + R_i}\right)^2 4kTR_SB_n \times F \qquad v_{no2}^2 = \left(\frac{AR_i}{R_S + R_i}\right)^2 (S_vB_n + 4kTR_SB_n \times F)$$

Take ratios and solve for F.

$$F = \frac{S_v}{\left(\dfrac{v_{no2}^2}{v_{no1}^2} - 1\right) 4kTR_S} = \frac{\left(0.1 \times 10^{-6}\right)^2}{\left[\dfrac{\left(4.82 \times 10^{-3}\right)^2}{\left(0.470 \times 10^{-3}\right)^2} - 1\right] \times 1.6 \times 10^{-20} \times 2000} = 3$$

$$NF = 10\log(F) = 4.77$$

2. An amplifier has $v_n = 3\,\text{nV}/\sqrt{\text{Hz}}$, $i_n = 6\,\text{pA}/\sqrt{\text{Hz}}$, and $\rho = 0.15$. The amplifier is driven from a voltage source with an output resistance $R_S = 1\,\text{k}\Omega$. Assume the noise bandwidth $B_n = 1\,\text{Hz}$.

(a) Calculate the noise factor F and noise figure NF.

$$F = \frac{4kTR_S + v_n^2 + 2v_ni_nR_S\rho + i_n^2R_S^2}{4kTR_S} = 4.15 \qquad NF = 10\log(F) = 6.18$$

(b) Calculate the optimum source resistance R_{so}.

$$R_{so} = \frac{v_n}{i_n} = 500\,\Omega$$

(c) A resistor is added in parallel with the amplifier input to make the source resistance seen by the amplifier equal to R_{so}. What is the required value of the resistor?

$$R_p = \frac{R_SR_{so}}{R_S - R_{so}} = 1000\,\Omega$$

(d) What are the new noise figure and noise factor?

$$V_{i(oc)} = \frac{R_p}{R_S + R_p}V_s + V_{tso} + V_n + I_nR_{so} = \frac{R_p}{R_S + R_p}\left[V_s + \frac{R_S + R_p}{R_p}\left(V_{tso} + V_n + I_nR_{so}\right)\right]$$

$$V_{ni} = \frac{R_S + R_p}{R_p}\left(V_{tso} + V_n + I_nR_{so}\right)$$

$$F = \frac{\left(\dfrac{R_S + R_p}{R_p}\right)^2 \left(4kTR_{so} + v_n^2 + 2v_ni_nR_{so}\rho + i_n^2R_{so}^2\right)}{4kTR_S} = 7.18 \qquad NF = 10\log(F) = 8.56$$

3. The figure shows the ac signal circuit of a common-base amplifier. The BJT has the parameters $\beta = 150$, $r_x = 50\ \Omega$, and $r_0 = \infty$. It is given that $R_s = 50\,\Omega$ and $R_C = 30\,\mathrm{k}\Omega$.
(a) If flicker noise is neglected, calculate the optimum bias current $I_{C(opt)}$ and the rms equivalent noise voltage in series with V_s for the band $0\,\mathrm{Hz} \le f \le 50\,\mathrm{kHz}$.

$$I_{C(opt)} = \frac{V_T}{R_s + r_x} \frac{\beta}{\sqrt{1+\beta}} = 3.05\,\mathrm{mA}$$

$$v_{ni}^2 = 4kT\left(R_s + r_x\right) B_n \frac{\sqrt{1+\beta}}{\sqrt{1+\beta} - 1} = 8.71 \times 10^{-14}\,\mathrm{V}^2 \qquad v_{ni} = 2.95 \times 10^{-7}\,\mathrm{V}$$

(b) What is the noise factor and noise figure for the band $0\,\mathrm{Hz} \le f \le 50\,\mathrm{kHz}$?

$$F = \frac{v_{ni}^2}{4kTR_sB_n} = 2.18 \qquad NF = 10\log(F) = 3.38$$

(c) What is the rms noise voltage at the amplifier output for the band $0\,\mathrm{Hz} \le f \le 50\,\mathrm{kHz}$?

$$A_v = \frac{i_e'}{v_s}\frac{i_c'}{i_e'}\frac{v_o}{i_c'} = \left(-\frac{1}{r_e' + R_s}\right)\alpha\left(-R_C\right) = +510 \qquad v_{no} = A_v v_{ni} = 0.150\,\mathrm{mV}$$