Problem 1 – (20 points) An amplifier has the following transfer function:

\[ A(s) = \frac{10s}{(s/10 + 1)(s/1000 + 1)(s/100000 + 1)} \cdot \frac{V}{V} = \frac{\frac{10}{s} \cdot \frac{1}{s+1}}{(1+\frac{10}{s})(\frac{s}{1000} + 1)(\frac{s}{10000} + 1)} \]

(b) What is \( \beta \) for \( A_f = 20 \text{dB} \)?

(c) What is the lowest closed-loop gain \( A_f \) for which this amplifier has acceptable stability (having a phase margin of at least 45°)?

\[ A_f = \frac{0.7 V/V}{V/V} = \frac{0.7}{1+100(\beta)} \quad \Rightarrow \quad \beta(100) = \frac{100}{10} - 1 = 0.09 \]

\[ f = 100k \quad \text{for} \quad \text{pm} = 45° \quad \Rightarrow \quad |A \cdot \beta| = 1 = \frac{100 \cdot 0.09}{\sqrt{1^2 + (\frac{10}{100})^2}} \cdot \frac{\frac{100k}{(1k)^2 + 1^2}}{\sqrt{2}} \]
Problem 2 - (20 points) What type of feedback topology is shown below (e.g., series-series, shunt-series,...)?

**shunt-shunt**

Draw three pictures showing the circuit configurations used for measuring $\beta$, $R_{11}$, and $R_{22}$ for the feedback network shown, and find values for $\beta$, $R_{11}$, and $R_{22}$.

\[ R_s = 1 \, \text{k}\Omega \]
\[ 2 \, \text{k}\Omega \]
\[ 4.3 \, \text{k}\Omega \]
\[ -5 \, \text{V} \]
\[ +5 \, \text{V} \]
\[ R_L = 2 \, \text{k}\Omega \]
\[ 100\, \text{k}\Omega \]
\[ 20\, \text{k}\Omega \]

**$R_n$**
\[ \frac{2\, \text{k}}{100\, \text{k}} \]
\[ \frac{20\, \text{k}}{20\, \text{k}} \]

**$R_{22}$**
\[ \frac{2\, \text{k}}{100\, \text{k}} \]
\[ \frac{20\, \text{k}}{20\, \text{k}} \]

\[ R_{11} = 2\, \text{k} + (20\, \text{k}) \| 100\, \text{k} \approx 18.7\, \text{k}\Omega \]
\[ R_{22} = 100\, \text{k} + (2\, \text{k}) \| 20\, \text{k} \approx 102\, \text{k}\Omega \]

\[ \beta = \frac{I_f}{I_f} = -\frac{0.02}{2\, \text{k}} = -10\, \mu \]

\[ V_i = V_0 \frac{(2\, \text{k}) \| 20\, \text{k}}{(2\, \text{k}) \| 20\, \text{k} + 100\, \text{k}} \]

\[ V_i = 0.02V_0 \]
\[ 0.02V_0 = -I_f (2\, \text{k}) \]
**Problem 3** - (30 points) Assume that the amplifier below is biased at $I_D=1\, \text{mA}$, $V_{GS}=2\, \text{V}$, $V_{T}=1\, \text{V}$. Ignore $\lambda$.

The feedback network consists of the two highlighted $3\, \text{k}\Omega$ resistors. $R_{11}=6\, \text{k}\Omega$, $R_{22}=1.5\, \text{k}\Omega$, $\beta=-1/2$.

(a) What is $A$? (Note that $v_i \neq 0$)

(b) What is the closed-loop gain, $v_o/v_{sig}$ or $A_f$ of the feedback amplifier?

(c) What is the feedback amplifier’s input resistance including $R_s$, $R_f$?

\[
A = \frac{I_o}{I_i} \quad \text{and} \quad g_m = \frac{2I_D}{V_{OL}} - \frac{2(1\, \text{mA})}{2-1} = 2\, \text{mA/V}
\]

\[
I_o = g_m V_{gs}
\]

\[
V_g = I_i (100\, \text{\Omega}) \quad \text{and} \quad V_{gs} = I_i (5650)
\]

\[
V_{gs} = I_i (5650) - g_m (1.5k) V_{gs} \Rightarrow V_{gs} = \frac{I_i (5650)}{1 + g_m (1.5k)} = 1412.5 I_i
\]

\[
\frac{I_o}{I_i} = g_m (1412.5) = 2.825\, \text{A/A}
\]
#3 6. \[ A_f = \frac{A}{1 + A/B} = \frac{2.825}{1 + (2.825)^{-\frac{1}{2}}} = -6.85 \, \frac{A}{A} \]

\[ A_f = \frac{I_o}{I_{sig}} \]

\[ I_{sig} = \frac{V_{sig}}{100k} \]

\[ V_o = -I_o \left(\frac{7.5k}{2}\right) \Rightarrow I_o = -267u \, V_o \]

\[ A_f = \frac{I_o}{I_{sig}} = \frac{-267u \cdot V_o \cdot 100k}{V_{sig}} = -6.85 \]

\[ \frac{V_o}{V_{sig}} = 0.3 \, \frac{V}{V} \]

C. \[ R_i = (100k || 6k || 5u || 10u) = 5650 \]

\[ R_{if} = \frac{5650}{1 + A/B} = 13.6k \]
**Problem 4** – (15 points)
The datasheet of the PN2222A bipolar transistor contains the following information:

- Maximum allowable junction temperature $T_{j,max} = 150^\circ C$
- Maximum power dissipation $P_{d,max} = 1.5 \ W$ at case temperature $T_c = 25.5^\circ C$
- Junction-to-case thermal resistance $\theta_{jc} = 83 \ ^\circ C/W$
- Junction-to-ambient thermal resistance $\theta_{ja} = 200 \ ^\circ C/W$

(a) What is the maximum ambient temperature to ensure safe operation at 0.5W? (Note that we are not using a heat sink in this problem.)

(b) Find the case-to-ambient thermal resistance $\theta_{ca}$.

(c) Assuming an ambient temperature of 25$^\circ C$, what is the case temperature $T_c$ when the transistor dissipates 100mW?

\[ T_A = T_J - \theta_{JA} (0.5W) = 150 - 200 (0.5) \]
\[ T_A = 50^\circ C \]

\[ (\theta_{CA} + \theta_{JC}) = \theta_{JA} \rightarrow \theta_{CA} = \theta_{JA} - \theta_{JC} = 200 - 83 = 117^\circ C/W \]

\[ T_c = T_A + \theta_{CA} (100mW) = 25 + (117^\circ C)(100m) \]
\[ T_c = 36.7^\circ C \]
Problem 5 – (15 points)
(a) The following output stage has an input, $v_i$, shown below. Assume the transistors are biased for the correct operation. $V_{cc} = 3\, \text{V}$, $V_{BE} = 0.5\, \text{V}(\text{constant})$, and $V_{CESAR} = 0.5\, \text{V}$ What is the output $v_o$?

(b) (i) Which analog converter below is the fastest?

(ii) Which analog converter below is the slowest?

(iii) Which analog converter below is the most accurate?
(c) An analog signal in the range of 0 to +5V is to be digitized. If the circuit shown below is used, what is the resolution of the conversion? If $V_{in} = 3V$, what is the binary output?

![Diagram of an analog-to-digital converter with comparators and binary output.]

Resolution: $\frac{5}{8}$

$V_{in} = 3 \Rightarrow 11100000 \Rightarrow 100$

$\frac{3}{5/8} = 4.8$

(d) The rail voltages for the op amp shown below are ±2V. Sketch the output seen for the input below. Assume $R_1 = R_2$.

![Diagram of an op amp with rail voltages and input signal.]

$V_t = \frac{V_0(R_1)}{R_1 + R_2} = V_0 \left(\frac{1}{2}\right)$

$V_{TH} = 1V$

$V_{TL} = -1V$