IV. (40 pts): A voltage amplifier (A-amplifier) has an open-circuit voltage gain $A_{v0}$ of 100V/V, an input resistance $R_i$ of 250 k$\Omega$ and an output resistance $R_o$ of 1 k$\Omega$. It is connected in a negative feedback loop with a series-shunt topology.

When port 1 of the feedback network is open-circuited, the feedback network (looking from side 2) has an input resistance of 2 k$\Omega$.

When port 2 is short-circuited, the feedback network (looking from side 1) has an input resistance of 5 k$\Omega$.

The feedback factor is 0.1 V/V.

The amplifier is fed with a voltage source with a resistance $R_s$ of 5 k$\Omega$ and is feeding a load resistance $R_L$ of 2 k$\Omega$.

- Which small parameters should you use to model the feedback network?
- Draw the full circuit diagram including source resistance, voltage amplifier, its feedback network, and the load resistance.
- Draw the $A'$ amplifier and calculate its gain. Specify the units.
- Calculate the input resistance $R_i'$ and output resistance $R_o'$ of the $A'$-amplifier.
- Finally, calculate the input resistance $R_{if}$ and output resistance $R_{of}$ of the amplifier with feedback.

\[
\begin{align*}
R_i' &= R_s + R_i + h_{11} = R_s + R_i + R_1 = 2.5 \\
R_o' (V_s = 0) &= [R_L \| h_{22}^{-1} \| R_L] = [R_L \| R_2 \| R_L] = 500 \Omega
\end{align*}
\]
\[ V_i = \frac{R_i}{R_i + R_2 + R_1} \]

\[ V_o' = A_{V0} V_i \frac{R_L || R_2}{(R_L || R_2) + R_0} \]

\[ A' = \frac{V_o'}{V_i'} \]

\[ A' = 100 \frac{100}{100 + 100} \left( \frac{250}{260} \right) = 48 \]

\[ 1 + R_2^2 A' = 1 + 0.1 \times 48 = 5.8 \]

\[ R_{i_f} = R_i \left( 1 + A' \frac{R_2}{R_1} \right) \]

\[ R_{o_f} = R_o \left( 1 + A' \frac{R_2}{R_1} \right) \]
Consider the following feedback configuration.

Circle the feedback network.
Calculate the h-parameters for the feedback network.
Show how to build the A1 amplifier.
Calculate the gain of the A1 amplifier.
Calculate the gain $A_f = \frac{V_o}{V_s}$.
Determine the input and output resistances of the A1 amplifier.
Calculate the input ($R_{if}$) and output ($R_{of}$) resistances of the amplifier with feedback.

Use the following values in the calculations above:

$R_{id} = 100 \text{ kΩ}$
$M = 10^4$
$R_o = 1 \text{ kΩ}$
$R_L = 2 \text{ kΩ}$

$R_1 = 1 \text{ kΩ}$
$R_2 = 1 \text{ MΩ}$
$R_3 = 10 \text{ kΩ}$
Find a gain of a circuit - Series-Shunt

Extra example

Feedback network

A' circuit using h-parameters for feedback network.

\( R_{22} = R_1 + R_2 \)

\( h_{11} \) & \( h_{22} = h_{22}^{-1} = R_1 + R_2 \) from h-parameters analysis.

\( h_{-} \text{-parameters} \)

\( h_{11} \) & \( h_{22} \)

Voltage divider

\( B_f = \frac{V_{f2}}{V_{f1}} = \frac{R_1}{R_1 + R_2} \)

\[
\begin{bmatrix}
U_1 \\
U_2 \\
I_2
\end{bmatrix} =
\begin{bmatrix}
h_{11} & h_{12} \\
h_{21} & h_{22}
\end{bmatrix}
\begin{bmatrix}
I_1 \\
V_2
\end{bmatrix}
\]
Gain of A' circuit is \( \frac{V_o}{V_i} \)

\[
A' = \frac{M \left( \frac{R_L}{R_{22}} \right)}{\left( \frac{R_L}{R_{22}} \right) + 2 \beta} \cdot \frac{R_{id}}{[R_{id} + R_s + R_{11}]} 
\]

\[
R_{id} = 400 \text{ k}\Omega \\
\beta = 10^4 \\
R_0 = 1 \text{ k}\Omega \\
R_L = 2 \text{ k}\Omega \\
R_s = 10 \text{ k}\Omega \\
R_s = 1 \text{ M}\Omega
\]

\[
P_o = \frac{R_1}{R_1 + R_2} \approx 10^{-3} \text{ V/V}
\]

Voltage gain with feedback is given by

\[
A_f = \frac{V_o}{V_i} = \frac{A'}{1 + \beta R_s} = \frac{6000}{1} = 85 \text{ V/V}
\]

Output resistance with feedback

\[
R_{of} = R_s (1 + A' \beta)
\]

where \( R_s \) is the input resistance of A' circuit.

From previous page, we get

\[
R_s = R_{id} + R_{11} = R_s + R_{id} + \left( \frac{R_1}{R_2} \right) \approx 11 \text{ k}\Omega
\]

\[
R_{of} \approx 777 \text{ k}\Omega
\]
But $\text{R}_{\text{in}} + R_s = \text{R}_{\text{if}}$

$\Rightarrow \text{R}_{\text{in}} = \text{R}_{\text{if}} - R_s = 739 \Omega$

$\text{R}_{\text{eff}} = \frac{\text{R}_0'}{1 + \text{A}_f \text{R}_{\text{L}}}$ where $\text{R}_0'$ is output resistance of A' circuit

$\text{R}_0' = \text{R}_0 \parallel \text{R}_L \parallel (\text{R}_1 + \text{R}_2) \approx 664 \Omega$

$\Rightarrow \text{R}_{\text{eff}} = \frac{\text{R}_0'}{1 + \text{A}_f \text{R}_{\text{L}}} = \frac{664}{1} \approx 95.3 \Omega$

Fault $\text{R}_{\text{eff}} = (\text{R}_L \parallel \text{R}_{\text{out}})$

$\Rightarrow \text{R}_{\text{out}} \approx 100 \Omega$

See how it is defined on diagram.