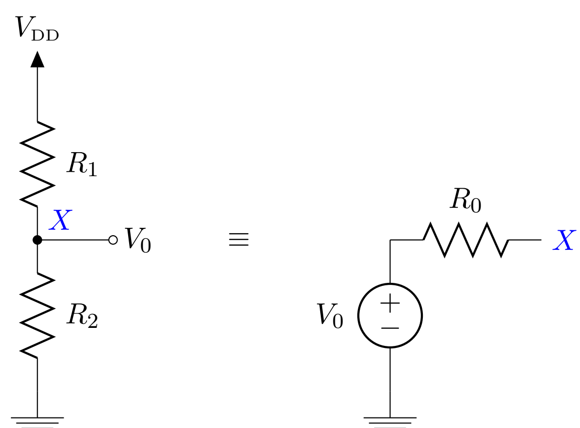
Problem 1. Complete the following review problems on Ohm's law, voltage dividers, current dividers and Thévenin/Norton equivalent circuits.

(A) Measurements taken on various resistors are shown below. For each case, calculate the power dissipated in the resistor and the power rating necessary for safe operation using standard components with power ratings of 1/8 W. 1/4 W, 1/2 W, 1 W or 2 W.

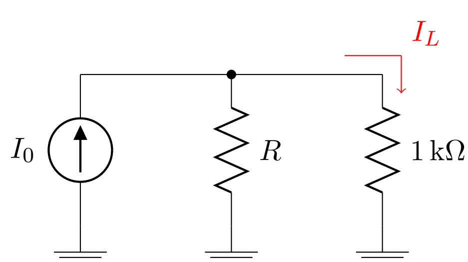
i. 1 kΩ conducting 30 mA
ii. 1 kΩ conducting 40 mA
iii. 10 kΩ conducting 3 mA
iv. 10 kΩ conducting 4 mA
v. 1 kΩ dropping 20 V
vi. 1 kΩ dropping 11 V

(B) You are given three resistors whose values are 10 kΩ, 20 kΩ, and 40 kΩ. How many different resistances can you create using series and parallel combinations of these three? List them in value order, lowest to highest. (*Hint:* In your search, first consider all parallel combinations, then all series combinations, then combined series/parallel combinations of which there are two kinds).

(C) Consider the voltage divider shown below alongside the Thévenin equivalent circuit seen looking into node X. Find expressions for V_0 and R_0.



(D) For the circuit below, choose a value of R to achieve $I_L = 0.2 I_0$.

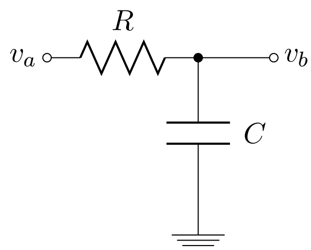


Problem 2. For the two circuits shown below, complete the following analyses:

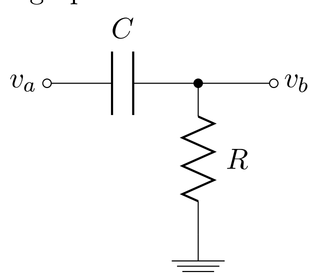
- Derive an expression the Laplace-domain transfer function $H(s)$.
- Solve an expression for the magnitude response $|H(\omega)|^2$.
- If the component values are $R = 1\text{k}\Omega$ and $C = 10\mu\text{F}$, calculate the time constant and the pole freqency.
- Draw a Bode magnitude plot for the signal V_B using the calculated pole frequency, given a constant input magnitude of $V_A = 60\text{dB}$.

Complete these tasks for the high-pass and low-pass circuits shown below.

(A) Low-pass circuit



(B) High-pass circuit



Problem 3. A non-linear one-port device has a voltage v applied across its terminals, and the corresponding current i is some some function of v. The device is said to have a *differential resistance* defined by

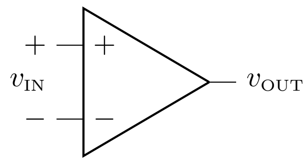
$$r_{\text{eq}} = \frac{\Delta v}{\Delta i},$$

where both Δv and Δi are assumed to be very small so that the i, v relationship is approximately linear. Consider the following scenarios and determine the differential resistance in each case.

(A) Suppose a device has an exponential response $i = (10\,\mu\text{A})\exp(v/0.25\,\text{V})$. If the device's voltage is kept very close to $0.5\,\text{V}$, what is the differential resistance? (*Hint:* apply a first-order Taylor approximation centered at $0.5\,\text{V}$).

(B) A temperature sensor is specified to provide $2\,\text{mV}/°\text{C}$. When the sensor is connected to a load resistance of $10\,\text{k}\Omega$, and the temperature is changed by $10\,°\text{C}$, the output voltage is observed to change by $10\,\text{mV}$. What is the sensor's differential resistance?

Problem 4. The differential voltage amplifier shown below has a non-linear transfer characteristic described by a non-linear equation:



$$v_{\text{OUT}} = V_R \left(\frac{\exp(Av_{\text{IN}})-1}{\exp(Av_{\text{IN}})+1} \right)$$

In this equation, V_R is interpreted as the *rail voltage*, i.e. the power supplies are at $+V_R$ and $-V_R$. The constant A is related to the amplifier's gain.

When dealing with a non-linear amplifier such as this, we usually *approximate* the device using a first-order Taylor expansion, so that it looks like a linear amplifier:

$$v_{\text{out}} \approx A v_{\text{in}},$$
$$\text{where } A = \left| \frac{dv_{\text{OUT}}}{dv_{\text{IN}}} \right|_{v_{\text{IN}}=0}$$

In this problem, we will take a closer look at this approximation.

Please perform the following tasks:

(A) Using Matlab, Octave or other software, plot the transfer characteristic (v_{out} on the vertical axis and v_{in} on the horizontal axis) over the domain $v_{\text{in}} \in (-2\text{V}, +2\text{V})$ in steps of 0.01V, using the parameter values $V_R = 10\text{V}$ and $A = 10\text{V}^{-1}$.

(B) Notice that the *slope* is steepest near $v_{\text{IN}} = 0$. In your plotting software, zoom into the domain $v_{\text{in}} \in (-0.1\text{V}, +0.1\text{V})$. Ideally, an amplifier's transfer characteristic should be a *straight line*. Comment on the straightness of the zoomed characteristic, and how it might affect amplifier function.

(C) In your zoomed plot, measure the slope $\Delta v_{\text{OUT}}/\Delta v_{\text{IN}}$ for the transfer characteristic near the point where $v_{\text{IN}} = 0$.

(D) Now find the amplifier's *gain* by solving an expression for the derivative $dv_{\text{OUT}}/dv_{\text{IN}}$, and evaluate the derivative at the point $v_{\text{IN}} = 0$. Give your answer as an equation in terms of V_R and A.

(E) Finally, evaluate your gain equation using the values specified in part (a). How closely does it match to the numerical measure you made in part (c)?

Problem 5. An amplifier has the following small-signal characteristics:

$$
\begin{aligned}
A_v(\text{dB}) &= 40\text{dB} \\
R_{\text{in}} &= 1\text{M}\Omega \\
R_{\text{out}} &= 10\Omega
\end{aligned}
$$

This amplifier is used to drive a load of $R_L = 100\Omega$. The signal source is an ideal voltage source with no series resistance (i.e. $R_{\text{sig}} = 0$).

(A) What is the *voltage gain* with the signal-source connected, but with no load connected?

(B) What is the *voltage gain* with both the signal source connected and the load connected?

(C) What is the *power gain* of the amplifier, when source and load are connected?

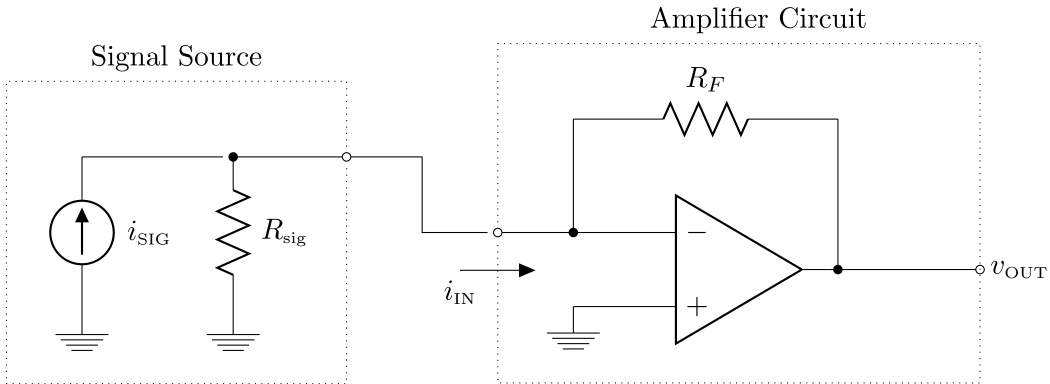
Problem 6. A current amplifier has the following characteristics:

$$
\begin{aligned}
R_{\text{in}} &= 1\text{k}\Omega \\
R_{\text{out}} &= 10\text{k}\Omega \\
A_i &= 100\text{A/ A}
\end{aligned}
$$

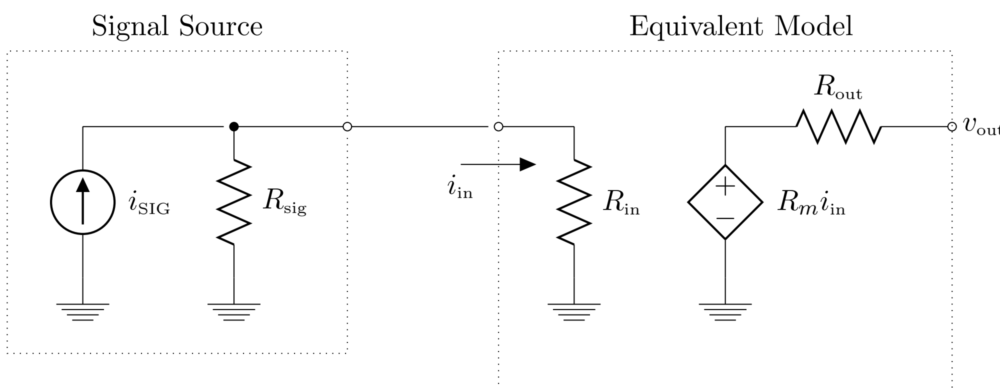
The amplifier's signal source is a sinusoid with amplitude $I_{\text{sig}} = 1\text{mA}$ and parallel resistance of $100\text{k}\Omega$. The amplifier also drives a load resistance of $R_L = 100\Omega$.

What are the values of the current gain, the voltage gain and the power gain for this circuit?

Problem 7. The circuit shown below is a *transresistance amplifier* used to convert a small current signal into a voltage signal.

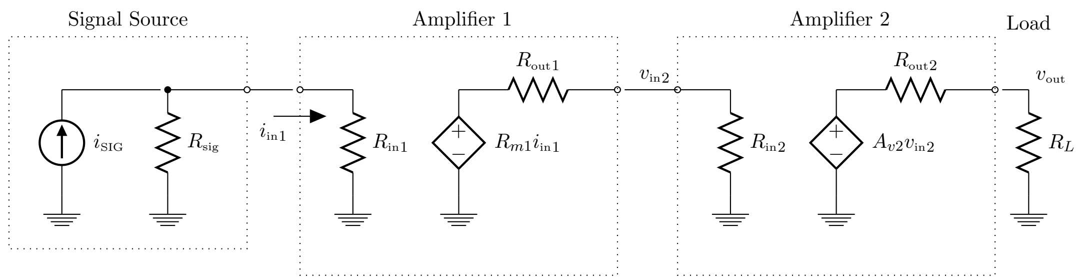


By solving for R_{in}, R_{out} and R_m, you obtain the equivalent circuit model:



If the op amp is ideal, obtain expressions for the amplifier circuit's input resistance, the output resistance and the transconductance gain $R_m = v_{\mathrm{OUT}}/i_{\mathrm{IN}}$.

Problem 8. Two amplifiers are to cascaded between a signal source and load, as shown below.



$$
\begin{aligned}
i_{\mathrm{sig}} &= (10\mu\mathrm{A}) \sin(2\pi f t) \\
R_{\mathrm{sig}} &= 10\mathrm{k}\Omega \\
R_{\mathrm{in}1} &= 100\mathrm{k}\Omega \\
R_{m1} &= 10\mathrm{V}/\ \mu\mathrm{A} \\
R_{\mathrm{out}1} &= 10\mathrm{k}\Omega \\
R_{\mathrm{in}2} &= 1\mathrm{k}\Omega \\
A_{v2} &= 10\mathrm{V}/\ \mathrm{V} \\
R_{\mathrm{out}2} &= 100\Omega \\
R_L &= 10\Omega
\end{aligned}
$$

(A) Accounting for all coupling effects, give an expression for the circuit's overall trasresistance gain, $R_{\mathrm{tot}} = v_{\mathrm{out}}/i_{\mathrm{sig}}$. Calculate the value for this gain.

(B) Calculate the amplitudes of $i_{\mathrm{in}1}$, $v_{\mathrm{in}2}$ and v_{out}.

(C) If the amplifiers' input and output resistances could be modified, describe the changes that would be required to maximize the total transresistance gain. State the value of the maximum gain that can be achieved under these modifications.