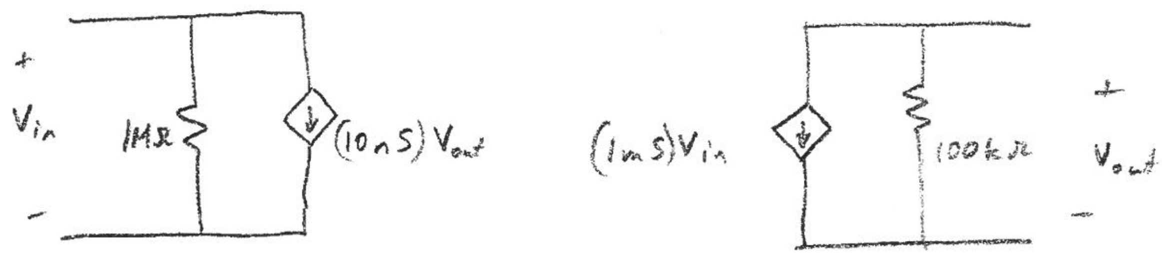
Draw the two-port amplifier model that is described below

- Forward transconductance = 1mS
- Reverse transconductance = 10nS
- Input impedance = 1MΩ
- Output impedance = 100kΩ

Determine the forward voltage gain of this amplifier.

Two-Port Model

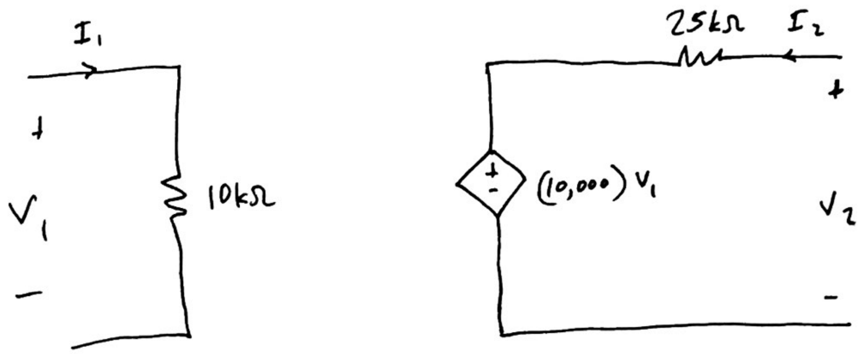


$$\frac{V_{out}}{V_{in}} = -(1mS)(100k\Omega) = -100$$

Draw the two-port amplifier model that is described below

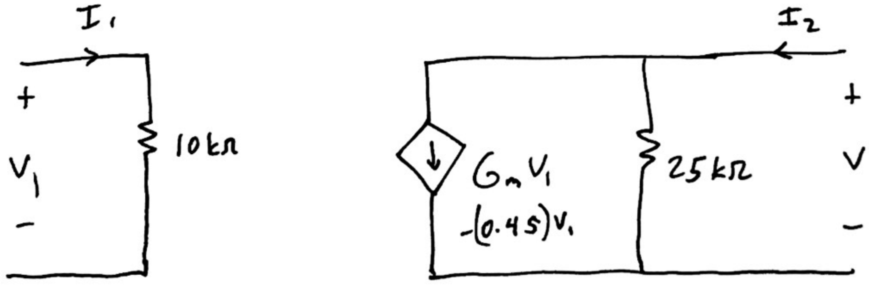
- a_v = 10,000
- R_{in} = 10kΩ
- R_{out} = 25kΩ

Determine the unloaded gain of this amplifier. Also, redraw this two-port model with a Norton output.
Determine the forward voltage gain of this amplifier.



Unloaded gain = a_v = 10,000

Equivalent circuit with a Norton-style output



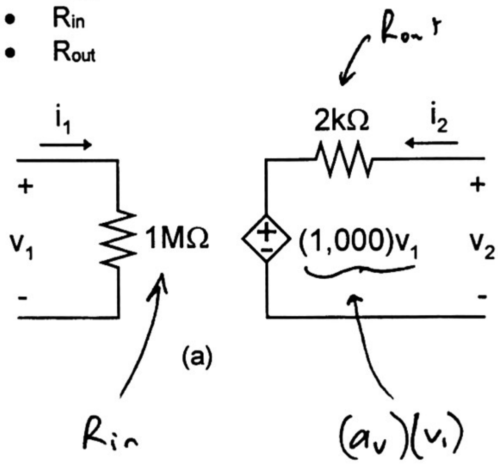
Find G_m

Remember $a_v = -G_m R_{out}$

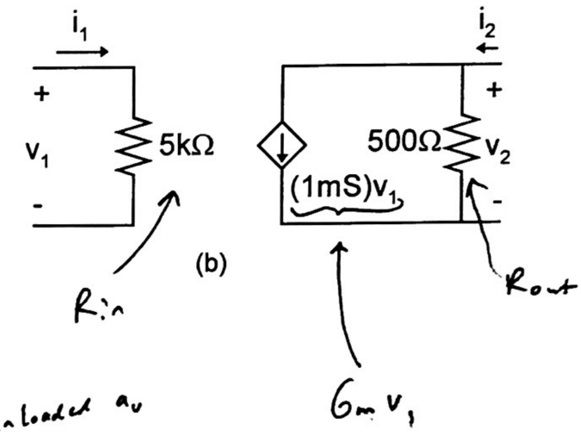
$$\therefore\ G_m = \frac{-a_v}{R_{out}} = \frac{-10{,}000}{25k\Omega} = -0.4\ S$$

For the following two-port models, determine the following information.

- $a_{v,unloaded}$
- R_{in}
- R_{out}



(a)



(b)

$\therefore\quad a_{v,unloaded} = a_v = 1{,}000$

$R_{in} = 1M\Omega$

$R_{out} = 2k\Omega$

unloaded a_v

$a_v = -G_m R_{out} = (1mS)(500\Omega)$

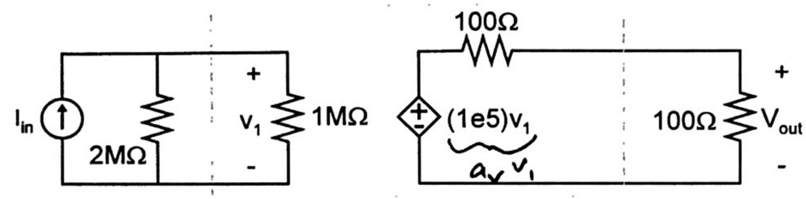
$\therefore\quad a_v = -0.5$

$R_{in} = 5k\Omega$

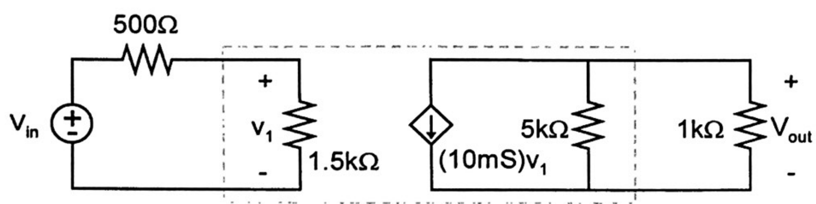
$R_{out} = 500\Omega$

For each circuit below, the amplifier is drawn within the dotted lines. Determine the following information for each circuit.

- Unloaded gain
- Overall gain (output/input), including loading effects



(a)



(b)

a) Unloaded gain (2-port network only)

$$\boxed{a_v = 100{,}000}$$

Overall gain

$$\frac{V_{out}}{I_{in}} = \frac{v_1}{I_{in}} \cdot \frac{V_{out}}{v_1}$$

$$v_1 = (I_{in})\,(2\,M\Omega \,//\, 1\,M\Omega) = (I_{in})\,(667\,k\Omega)$$

$$V_{out} = \underbrace{(a_v v_1)}_{a_v = 100{,}000}\ \underbrace{\frac{100\,\Omega}{100\,\Omega + 100\,\Omega}}_{\text{voltage divider}} = 50{,}000\ v_1$$

$$\therefore\ \frac{V_{out}}{I_{in}} = \frac{(667\,k\Omega)(I_{in})}{(I_{in})} \cdot \frac{(50{,}000)(v_1)}{v_1} = \boxed{3.335 \times 10^{10}\ \Omega}$$

b) Unloaded gain (2-port network only) $\Rightarrow$ $a_v = -G_m R_{out}$

$$a_v = -(10\,mS)(5\,k\Omega) = \boxed{-50}$$

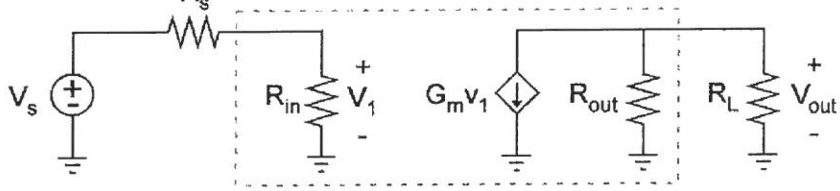
Overall Gain

$$\frac{V_{out}}{V_{in}} = \frac{v_1}{V_{in}} \cdot \frac{V_{out}}{v_1} = \left(\frac{1.5\,k\Omega}{1.5\,k\Omega + 500\,\Omega}\right)\left((-10\,mS)(5\,k\Omega \,//\, 1\,k\Omega)\right) = \boxed{-6.25}$$

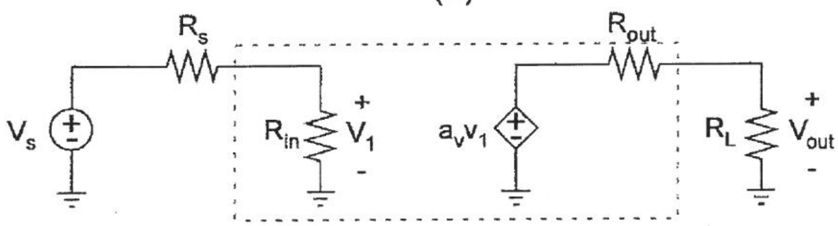
Significantly less than the unloaded case

For each circuit below, the amplifier is drawn within the dotted lines. Perform the following.

- Determine the unloaded voltage gain of the amplifier (i.e. ideal voltage source and load impedance)
- Determine the actual voltage gain of the amplifier (i.e. using the circuit shown below)
- Assuming we have control over the input/output impedances of the amplifier, but not the source and load, how can we design the amplifier to maximize the voltage gain
- Convert the amplifier of Part a to a voltage output (i.e. Thevenin). Convert the amplifier of Part b to a current output (i.e. Norton)



(a)



(b)

a) Unloaded gain → $\frac{V_{out}}{V_{in}} = -G_m R_{out}$

Loaded gain → $\frac{V_{out}}{V_s} = \frac{V_1}{V_s} \cdot \frac{V_{out}}{V_1} = \left(\frac{R_{in}}{R_{in}+R_s}\frac{\cancel{V_s}}{\cancel{V_s}}\right)\left(\frac{-G_m\cancel{V_1}\; R_{out}/\!/R_L}{\cancel{V_1}}\right) =$

$$= \left(\frac{R_{in}}{R_{in}+R_s}\right)\left(-G_m\, R_{out}/\!/R_L\right) =$$

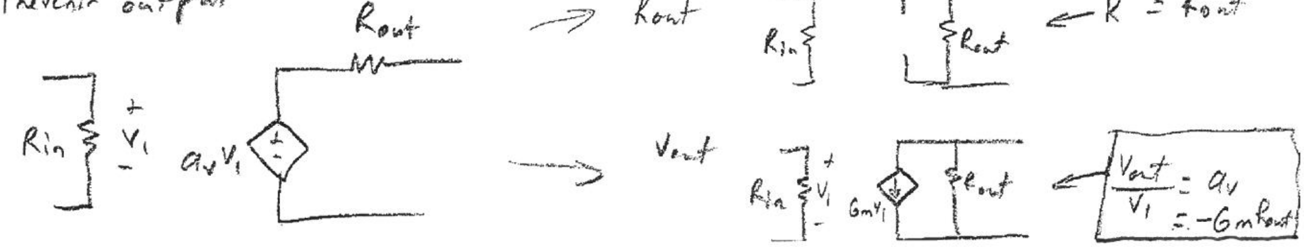
$$= \left(\frac{R_{in}}{R_{in}+R_s}\right)\left(-G_m\frac{R_{out}R_L}{R_{out}+R_L}\right)$$

We can maximize the voltage gain if

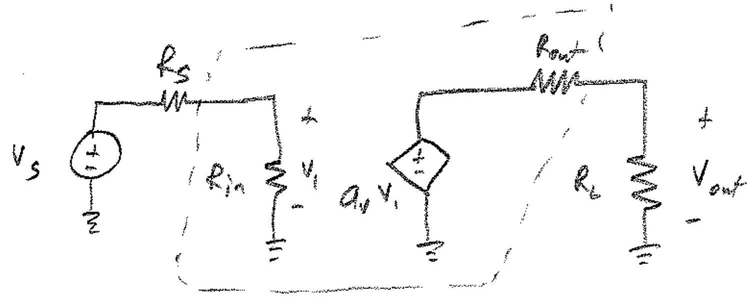
$\left(\frac{R_{in}}{R_{in}+R_s}\right) \to 1 \Rightarrow \therefore \boxed{R_{in} \to \infty}$

$-G_m\left(R_{out}/\!/R_L\right) \to -G_m R_L$ if $\boxed{R_{out} \to \infty}$, Also $\boxed{\text{increase } G_m}$

Thevenin output



b) Unloaded Gain $\rightarrow$



$$\frac{V_{out}}{V_1} = \frac{a_v V_1}{V_1} = a_v$$

Loaded Gain

$$\frac{V_{out}}{V_S} = \frac{V_1}{V_S} \cdot \frac{V_{out}}{V_1} = \left(\frac{R_{in}}{R_{in}+R_S} \frac{V_S}{V_S}\right)\left(\frac{R_L}{R_L+R_{out}} \frac{a_v V_1}{V_1}\right) =$$

$$= \left(\frac{R_{in}}{R_{in}+R_S}\right)\left(\frac{R_L}{R_L+R_{out}} a_v\right)$$

To maximize the gain

$$\left(\frac{R_{in}}{R_{in}+R_S}\right) \rightarrow 1 \qquad \therefore R_{in} \rightarrow \infty$$

$$\frac{R_L}{R_L+R_{out}} a_v \rightarrow \text{large} \qquad \therefore a_v \text{ as large as possible}$$

$$R_{out} \rightarrow 0$$

Norton Output

Looking into the output of the original amplifier

set $V_1 = 0$

$\rightarrow R_N = R_{out}$

short-circuit the output and measure the current

$\rightarrow$

$$i_{sc} = -\frac{a_v V_1}{R_{out}} = G_m V_1$$

$$\therefore G_m = -\frac{a_v}{R_{out}}$$

A signal with a peak amplitude of 100μV needs to be amplified so that the resulting voltage has a peak amplitude of 5V.

a. Determine the voltage gain of an open-loop (i.e. no feedback) amplifier needed to perform this amplification.
b. An amplifier with a gain of a_v = 1,000,000 is used in a negative feedback configuration to achieve the necessary overall amplification. What value of the feedback network is needed to produce the correct gain.

a) Open - Loop

$$a_v = \frac{V_{out}}{V_{in}} = \frac{5V}{100\mu V} = \boxed{50{,}000}$$

b) Still, an overall gain of 50,000 is needed from the closed-loop system

$$\frac{V_{out}}{V_{in}} = \frac{A}{1 + AB}$$

Solve for B

$$(1 + AB)\left(\frac{V_{out}}{V_{in}}\right) = A$$

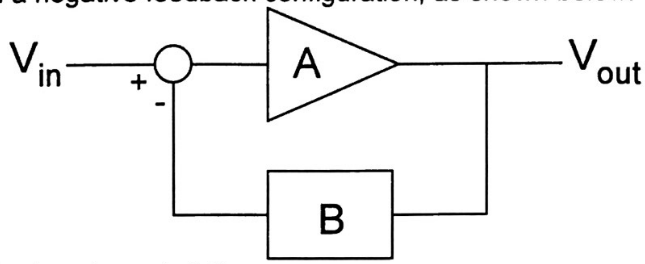
$$B = \frac{\frac{A}{\frac{V_{out}}{V_{in}}} - 1}{A} = \frac{\frac{1\times 10^6}{5\times 10^4} - 1}{1\times 10^6} = 0.000019$$

Sanity Check

For a large value of A, the closed loop gain is approximately $\frac{1}{B}$

$$\frac{1}{B} = 5.26\times 10^4 \approx 5\times 10^4 \checkmark$$

An amplifier, A, is used in a negative feedback configuration, as shown below.



This amplifier has the following characteristics.

- $a_v = 10{,}000$
- $R_{in} = 10k\Omega$
- $R_{out} = 25k\Omega$

If the feedback network, B, has a value of 0.05, determine the following characteristics of the closed-loop system.

a. The "loop gain" of this closed-loop system.
b. The closed-loop gain of this system.
c. The output voltage, if the input voltage is $v_{in} = 0.2\cos(200\pi t)$.
d. The closed-loop input resistance.
e. The closed-loop output resistance.

a) Loop Gain $= AB = (10{,}000)(0.05) = 500$

b) Closed-Loop Gain $= \dfrac{A}{1+AB} = \dfrac{10{,}000}{1+500} = \boxed{19.96}$

This is close to the approximation of $\frac{1}{B} = 20$

c) $V_{out} = (a_v)(V_{in}) = (19.96)(0.2\cos(200\pi t)) = \boxed{3.938\cos(200\pi t)}$

d) $R_{in,cl} = (R_{in,ol})(1+AB) = (10k\Omega)(1+500) = \boxed{5.01\ M\Omega}$

Much bigger, which is good for reducing loading effects

e) $R_{out,cl} = \dfrac{R_{out,ol}}{1+AB} = \dfrac{25k\Omega}{1+500} = \boxed{49.9\Omega}$

Much smaller, which is good for reducing loading effects