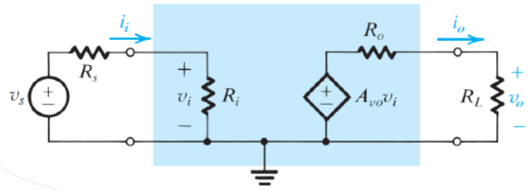
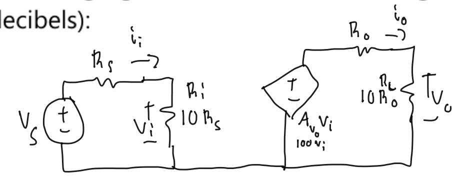
A1. For the circuit below where A_{vo}=100 V/V , calculate voltage gain, v_o/v_s, for the following three conditions (express your answers both directly and in decibels):

(a) $R_i=10R_s$, $R_L=10R_o$
(b) $R_i=R_s$, $R_L=R_o$
(c) $R_i=R_s/10$, $R_L=R_o/10$



a)



$$\frac{V_o}{V_s} = 100\left(\frac{10R_s}{R_s+10R_s}\right)\left(\frac{10R_o}{R_o+10R_o}\right)$$

$$\frac{V_o}{V_s} = 100\left(\frac{10}{11}\right)\left(\frac{10}{11}\right)$$

$$\boxed{\frac{V_o}{V_s} = 82.64 = 38.34\ [dB]}$$

$$V_i = V_s\left(\frac{R_i}{R_s+R_i}\right)$$

$$V_o = A_{v_o}V_i\left(\frac{R_L}{R_o+R_L}\right)$$

$$V_o = A_{v_o}V_s\left(\frac{R_i}{R_s+R_i}\right)\left(\frac{R_L}{R_o+R_L}\right)$$

$$\frac{V_o}{V_s} = A_{v_o}\left(\frac{R_i}{R_s+R_i}\right)\left(\frac{R_L}{R_o+R_L}\right)$$

$$\frac{V_o}{V_s} = 100\left(\frac{R_i}{R_s+R_i}\right)\left(\frac{R_L}{R_o+R_L}\right)$$

b) $$\frac{V_o}{V_s} = 100\left(\frac{R_i}{R_s+R_i}\right)\left(\frac{R_L}{R_o+R_L}\right)$$

$$\frac{V_o}{V_s} = 100\left(\frac{R_s}{R_s+R_s}\right)\left(\frac{R_o}{R_o+R_o}\right)$$

$$\frac{V_o}{V_s} = 100\left(\frac{1\cancel{R_s}}{2\cancel{R_s}}\right)\left(\frac{1\cancel{R_o}}{2\cancel{R_o}}\right)$$

$$\boxed{\frac{V_o}{V_s} = 25 = 27.96\ [dB]}$$

c) $$\frac{V_o}{V_s} = 100\left(\frac{R_i}{R_s+R_i}\right)\left(\frac{R_L}{R_o+R_L}\right)$$

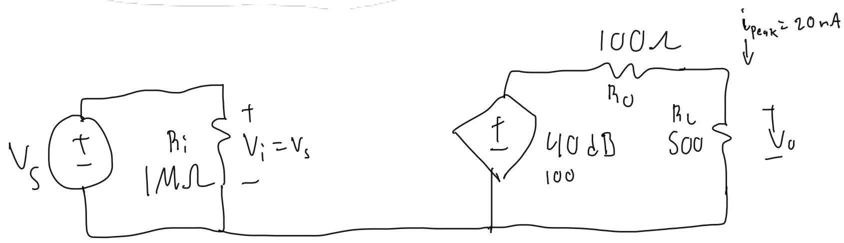
$$\frac{V_o}{V_s} = 100\left(\frac{\frac{R_s}{10}}{R_s+\frac{R_s}{10}}\right)\left(\frac{\frac{R_o}{10}}{R_o+\frac{R_o}{10}}\right)$$

$$\frac{V_o}{V_s} = 100\left(\frac{R_s}{10R_s+R_s}\right)\left(\frac{R_o}{10R_o+R_o}\right)$$

$$\frac{V_o}{V_s} = 100\left(\frac{1\cancel{R_s}}{11\cancel{R_s}}\right)\left(\frac{1\cancel{R_o}}{11\cancel{R_o}}\right)$$

$$\boxed{\frac{V_o}{V_s} = 0.826 = -1.656\ [dB]}$$

A2. An amplifier with 40 dB of small-signal, open-circuit voltage gain, an input resistance of 1 M Ω, and an output resistance of 100 Ω, drives a load of 500 Ω. What voltage and power gains (expressed in dB) would you expect with the load connected? If the amplifier has a peak output-current limitation of 20 mA, what is the rms value of the largest sine-wave input for which an undistorted output is possible? What is the corresponding output power available?



$$P = V^2 I = \frac{V^2}{R} = I^2 R$$

power gain: $$\underbrace{\frac{P_o}{P_i}}_{A_p} = \frac{\frac{V_o^2}{R_L}}{\frac{V_i^2}{R_i}} = \frac{V_o^2 R_i}{V_i^2 R_L}$$

$$\frac{V_o}{V_s} = \frac{V_o}{V_i} = 100\left(\frac{R_L}{R_o + R_L}\right)$$

$$\frac{V_o}{V_i} = 100\left(\frac{500}{100+500}\right)$$

$$\frac{V_o}{V_i} = 100\left(\frac{5}{6}\right)$$

$$A_v = \boxed{\frac{V_o}{V_i} = 83.\overline{33} = 38.42\ [dB]}$$

$$A_p = \left(\frac{V_o}{V_i}\right)^2 \frac{R_i}{R_L}$$

$$A_p = (83.\overline{33})^2 \frac{1M}{500}$$

$$\boxed{A_p = 13.\overline{88}\ \underset{(10^4)}{M} = 71.43\ [dB]}$$

$$V_{o,peak} = i_{peak} \cdot R_L$$
$$= (20m) \cdot 500$$
$$V_{o,peak} = 10\ [V]$$

$$\frac{V_{o,peak}}{V_{i,peak}} = A_{v,peak}$$

$$V_{i,peak} = \frac{V_{o,peak}}{A_{v,peak}}$$

$$V_{i,peak} = \frac{10}{83.\overline{33}}$$

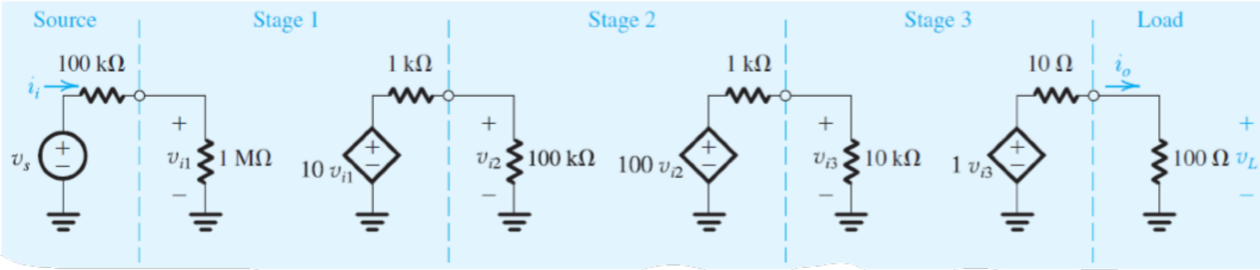
$$V_{i,peak} = 120\ [mV]$$

$$V_{i,peak\ RMS} = \frac{V_{i,peak}}{\sqrt{2}}$$
$$= \frac{120m}{\sqrt{2}}$$
$$\boxed{= 84.85\ [mV]}$$

$$V_{o,peak\ RMS} = \frac{10}{\sqrt{2}}$$

$$P_{V_{o,peak\ RMS}} = \frac{V_{o,peak\ RMS}^2}{R_L}$$
$$= \frac{\left(\frac{10}{\sqrt{2}}\right)^2}{500}$$
$$= \frac{\frac{100}{2}}{500}$$
$$\boxed{= 0.1\ [W]}$$

A3. Find the overall voltage gain v_o/v_s and compare to the overall voltage gain obtained when the first and second stages are interchanged.



$$V_L = V_o = V_{i3}\left(\frac{100}{110}\right)$$

$$V_o = 818.26\, V_s\left(\frac{100}{110}\right)$$

$$\boxed{\frac{V_o}{V_s} = 743.876}$$

$$V_{i1} = V_s\left(\frac{1M}{100K+1M}\right)$$

$$V_{i2} = 10\, V_{i1}\left(\frac{100K}{1K+100K}\right)$$

$$V_{i2} = 10\, V_s\left(\frac{1M}{100K+1M}\right)\left(\frac{100K}{1K+100K}\right)$$

$$V_{i3} = 100\, v_{i2}\left(\frac{10K}{1K+10K}\right)$$

$$V_{i3} = 100\cdot 10\, V_s\left(\frac{1M}{100K+1M}\right)\left(\frac{100K}{1K+100K}\right)\left(\frac{10K}{1K+10K}\right)$$

$$= 818.26\, V_s$$

If stage 1 ⟷ stage 2:

$$V_{i2} = V_s\left(\frac{100K}{200K}\right) = \frac{1}{2}V_s$$

$$V_{i1} = 100\, v_{i2}\left(\frac{1M}{1K+1M}\right)$$

$$V_{i1} = 50\, V_s\left(\frac{1M}{1K+1M}\right)$$

$$V_{i3} = 10\, v_{i1}\left(\frac{10K}{11K}\right)$$

$$V_{i3} = \frac{5000}{11}\left(\frac{1M}{1K+1M}\right)V_s$$

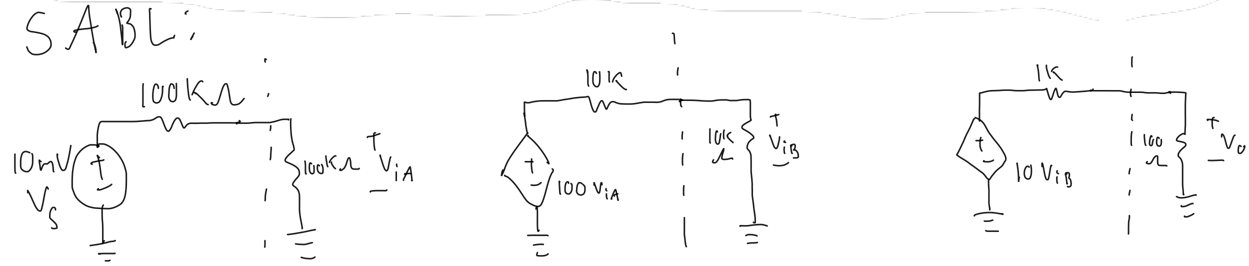
$$V_L = V_o = V_{i3}\left(\frac{100}{110}\right)$$

$$V_o = \frac{5000}{11}\left(\frac{1M}{1K+1M}\right)V_s\left(\frac{10}{11}\right)$$

$$\boxed{\frac{V_o}{V_s} = 412.81}$$

A4. You are given two amplifiers, A and B, to connect in cascade between a 10-mV, 100-kΩ source and a 100- Ω load. The amplifiers have voltage gain, input resistance, and output resistance as follows: for A, 100 V/V, 100 kΩ, 10 kΩ, respectively; for B, 10 V/V, 10 kΩ, 1 kΩ, respectively. Your problem is to decide how the amplifiers should be connected. To proceed, evaluate the two possible connections between source S and load L, namely, SABL and SBAL. Find the voltage gain for each both as a ratio and in decibels. Which amplifier arrangement is best?

SABL:



$V_{iA} = V_S\left(\frac{100\,K}{200\,K}\right)$

$= \frac{1}{2}V_S$

$V_{iB} = 100\,V_{iA}\left(\frac{10K}{20K}\right)$

$V_{iB} = 100\left(\frac{1}{2}V_S\right)\left(\frac{1}{2}\right)$

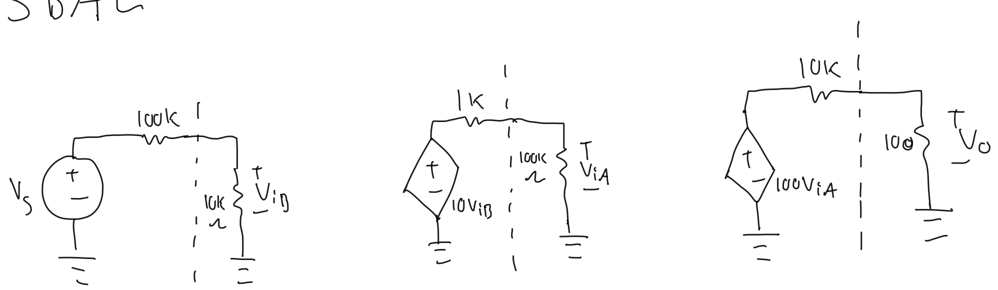
$V_{iB} = 25\,V_S$

$V_o = 10\,V_{iB}\left(\frac{100}{1100}\right)$

$V_o = \frac{10}{11}\left(25V_S\right)$

$A_{SABL} = \frac{V_o}{V_S} = \frac{250}{11} = 22.7\overline{2} = 27.13$ [dB]

SBAL



$V_{iB} = V_S\left(\frac{10K}{110K}\right)$

$= \frac{1}{11}V_S$

$V_{iA} = 10\,V_{iB}\left(\frac{100K}{101K}\right)$

$= \frac{1000}{101}\cdot\frac{1}{11}V_S$

$V_o = 100\,V_{iA}\left(\frac{100}{10K+100}\right)$

$= 100\left(\frac{1}{11}\cdot\frac{1000}{101}V_S\right)\left(\frac{100}{10K+100}\right)$

$\frac{V_o}{V_S} = 0.891 = -1$ [dB]

Clearly, SABL is the better amplifier arrangement since SBAL actually attenuates the signal

A5. Design an amplifier that provides 0.5W of signal power to a 100Ω load resistance. The signal source provides a 30-mV rms signal and has a resistance of 0.5MΩ. Three types of voltage-amplifier stages are available:

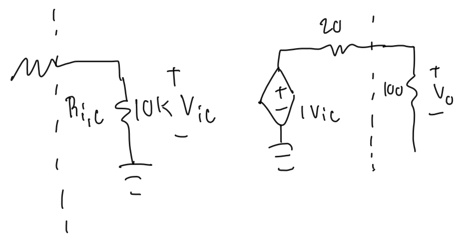
(a) A high-input-resistance type with R_i=1 MΩ, A_{vo}= 10, and R_o= 10 kΩ
(b) A high-gain type with R_i=10 kΩ, A_{vo}=100, and R_o=1 kΩ
(c) A low-output-resistance type with R_i= 10 kΩ, A_{vo}= 1, and R_o= 20Ω

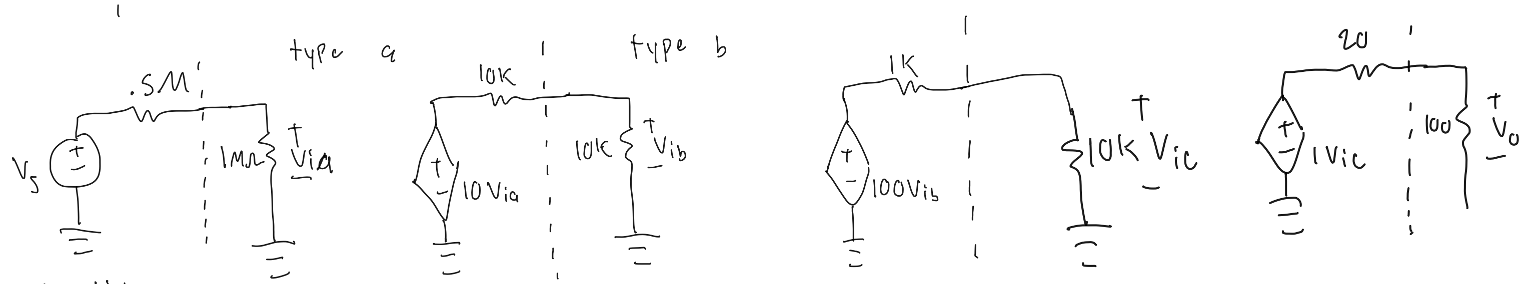
Design a suitable amplifier using a combination of these stages. Your design should utilize the minimum number of stages and should ensure that the signal level is not reduced below 10 mV at any point in the amplifier chain. Find the load voltage and power output realized.

$P_L = .5 = \frac{V_o^2}{R_L} = \frac{V_o^2}{100}$

$V_o = \sqrt{50}$ [V]   low-output for final stage

$i_o = \frac{V_o}{R_L} = 70.71$ [mA]





Due to high signal resistance, need high-input resistance to minimize voltage loss ∴ type a

$V_{ia} = V_s\left(\frac{1M}{1.5M}\right)$

$V_{ia} = \frac{2}{3}V_s$

Check above 10mV: $V_{ia} = \frac{2}{3}(30m) = 20$ [mV] ✓

Due to signal loss in stage a, need to gain voltage back ∴ type b

$V_{ib} = 10V_{ia}\left(\frac{10K}{20K}\right)$
$= 10\left(\frac{2}{3}V_s\right)\left(\frac{1}{2}\right)$

$V_{ib} = \frac{10}{3}V_s$

Check: $\frac{10}{3}(30m) = 100$ [mV] ✓

Try: add c to realize minimum stage before trying more stages unnecessarily.

$V_{ic} = 100V_{ib}\left(\frac{10K}{11K}\right)$
$= 100\left(\frac{10}{3}V_s\right)\left(\frac{10}{11}\right)$

$V_{ic} = \frac{10K}{33}V_s$

Check: $\frac{10K}{33}(30m) = 9.09$ [V] ✓

$V_o = V_{ic}\left(\frac{100}{120}\right)$
$= \frac{10K}{33}V_s\left(\frac{5}{6}\right)$

$V_o = \frac{25K}{99}(30m)$
$= \frac{250}{33}$ [V] $= V_L$

$P_L = \frac{V_L^2}{R_L} = \frac{\left(\frac{250}{33}\right)^2}{100}$

$P_L = 0.574$ [W]

Cant use type b or c as 1st stage since $R_i << R_s$ and wouldn't provide sufficient voltage ∴ add (a) first

If a connected diretly to c, not enough power to drive load

ex. $V_{ic} = 10V_{ia}\left(\frac{10K}{20K}\right)$
$= 5\left(\frac{2}{3}V_s\right)$

check ≥ 10mV: $\frac{10}{3}(30m) = .1V = 100$ mV ✓

$V_o = V_{ic}\left(\frac{100}{120}\right)$
$= \frac{10}{3}V_s\left(\frac{10}{12}\right)$
$= \frac{25}{9}V_s$

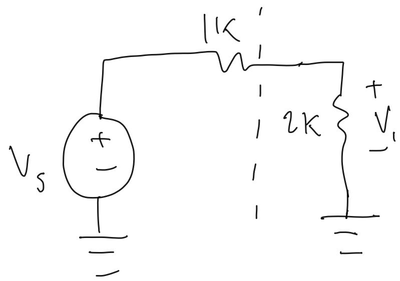
$V_o = 83.\bar{3}$ [mV] $= V_L$

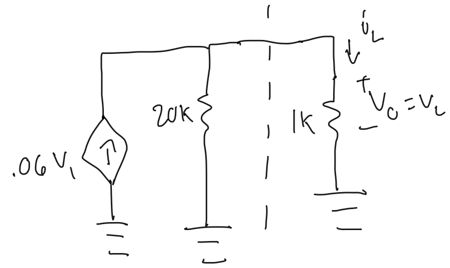
$P_L = \frac{(83.3m)^2}{100} = 69[\mu W] < .5$ [W]

∴ add high gain to connect a to c, thus

Source → a → b → c → load

A6. A transconductance amplifier with R_i= 2 k Ω, G_m = 60 mA/V, and R_o= 20 k Ω is fed with a voltage source having a source resistance of 1 k Ω and is loaded with a 1-k Ω resistance. Find the voltage gain realized.





$V_1 = V_S \left(\frac{2K}{3K}\right)$

$V_1 = \frac{2}{3} V_S$

Current divide: $i_L = .06\, V_1 \left(\frac{20K}{21K}\right)$

$= \frac{2}{35}\left(\frac{2}{3} V_S\right)$

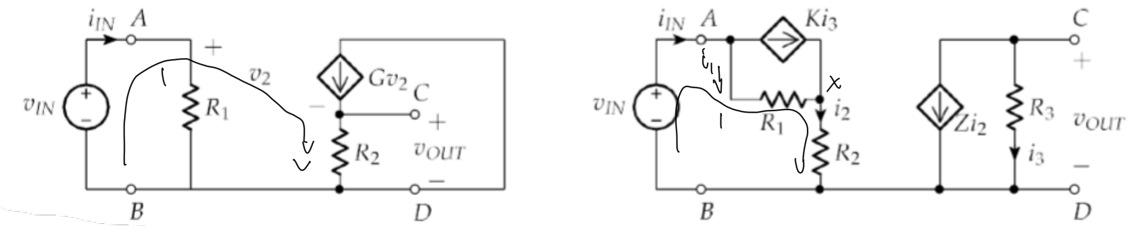
$= \frac{4}{105} V_S$

$V_L = V_o = i_L R_L$

$V_o = \left(\frac{4}{105} V_S\right)(1K)$

$\frac{V_o}{V_S} = 38.095 = 38.1 = 31.62$ [dB]

A7. For the following circuits, find the voltage gain, v_O/v_{IN}, and the input and output resistances.



$G v_2 R_2 = V_{out}$

$V_2 = \frac{V_{out}}{G R_2}$

KVL: $V_{IN} = V_2 + V_{out}$

$V_{IN} = \frac{V_{out}}{G R_2} + V_{out}$

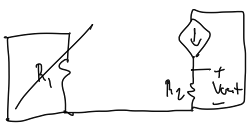
$V_{IN} = V_{out}\left(1 + \frac{1}{G R_2}\right)$

$\frac{V_{out}}{V_{IN}} = \frac{1}{1 + \frac{1}{G R_2}}$

$\frac{V_{out}}{V_{IN}} = \frac{G R_2}{G R_2 + 1}$

$R_{in} = R_1$

R_o:



$R_{out} = R_2$

$i_2 = \frac{V_x}{R_2}$

KCL @ x:

$i_2 = i_1 + K i_3$

$i_2 = \frac{V_{IN} - V_x}{R_1} + K(-Z i_2)$

$i_2(1 + KZ) = \frac{V_{IN} - V_x}{R_1}$

$\frac{V_x}{R_2}(1 + KZ) = \frac{V_{IN} - V_x}{R_1}$

$V_x(1 + KZ) = \frac{R_2}{R_1} V_{IN} - \frac{R_2}{R_1} V_x$

$V_x\left(1 + KZ + \frac{R_2}{R_1}\right) = \frac{R_2}{R_1} V_{IN}$

$V_x = \frac{R_2}{R_1\left(1 + KZ + \frac{R_2}{R_1}\right)} V_{IN}$

$V_x = \frac{R_2}{R_2 + R_1(1 + KZ)} V_{IN}$

$i_3 = -Z i_2$

$\frac{V_{out}}{R_3} = -Z i_2$

$V_{out} = -Z R_3 i_2$

$V_{out} = -Z R_3 \frac{V_x}{R_2}$

$V_{out} = -Z \frac{R_3}{\cancel{R_2}}\left(\frac{\cancel{R_2}}{R_2 + R_1(1+KZ)} V_{IN}\right)$

$\frac{V_{out}}{V_{IN}} = \frac{-Z R_3}{R_2 + R_1(1 + KZ)}$

For R_{in}: since $i_{IN} = i_2$

$i_2(1 + KZ) = \frac{V_{IN} - V_x}{R_1}$

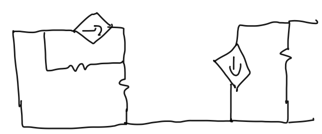
$i_2(1 + KZ) + \frac{R_2 i_2}{R_1} = \frac{V_{IN}}{R_1}$

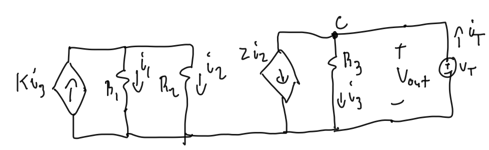
$i_2 R_1(1 + KZ) + R_2 i_2 = V_{IN}$

$i_2(R_1(1 + KZ) + R_2) = V_{IN}$

$\frac{V_{IN}}{i_2} = \frac{V_{IN}}{i_{IN}} = R_{IN} = R_2 + R_1(1 + KZ)$

For R_{out}:





$R_{out} = \frac{V_T}{i_T}$

$i_2 = K i_3\left(\frac{R_1}{R_1 + R_2}\right)$

KCL @ C: $i_T = i_3 + Z i_2$

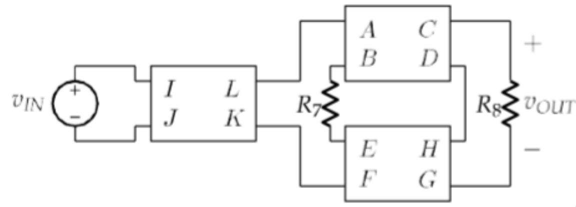
$i_T = \frac{V_T}{R_3} + Z\left[K i_3\left(\frac{R_1}{R_1 + R_2}\right)\right]$

$i_T = \frac{V_T}{R_3}\left[2K\left(\frac{R_1}{R_1 + R_2}\right)\right]$

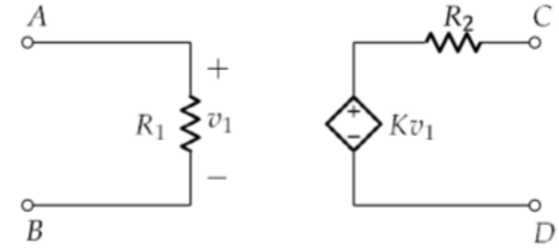
$\frac{V_T}{i_T} = \frac{R_3}{2K\left(\frac{R_1}{R_1 + R_2}\right)}$

$\frac{V_T}{i_T} = R_{out} = \frac{R_3(R_1 + R_2)}{R_1 + R_2 + R_1 Z K}$

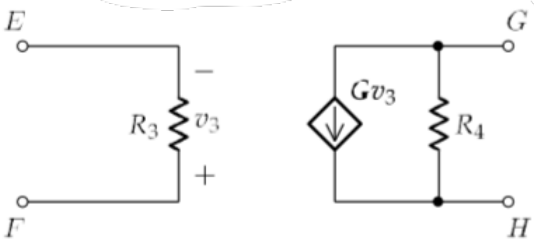
A8. For the cascaded amplifier circuit in (c), find voltage gain, v_O/v_{IN}, and the input and output resistances using the circuits in (d)-(f).



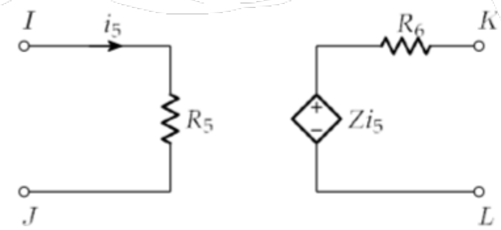
(c)



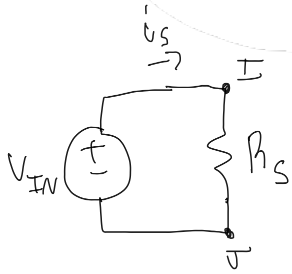
(d)

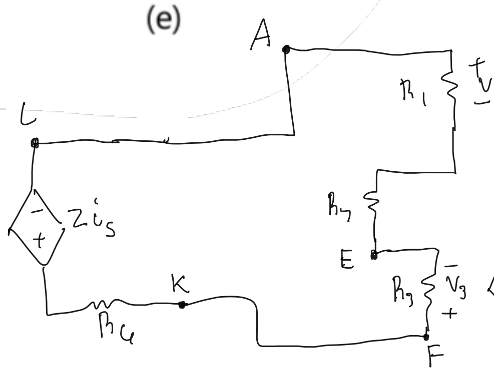


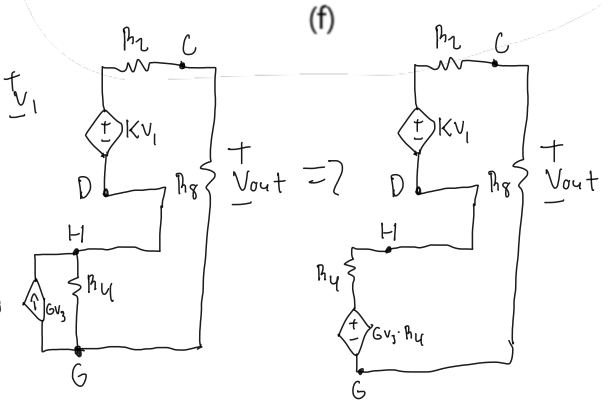
(e)



(f)







$V_{IN} = i_s R_s$

$i_s = \frac{V_{IN}}{R_s}$

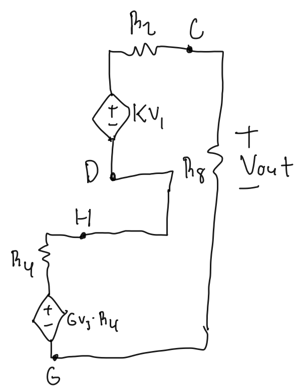
Volt divide: $V_1 = -Z i_s \left(\frac{R_1}{R_1+R_3+R_6+R_7}\right)$

$V_1 = -Z\, V_{IN} \left(\frac{R_1}{R_s(R_1+R_3+R_6+R_7)}\right)$

$V_3 = Z\, V_{IN} \left(\frac{R_3}{R_s(R_1+R_3+R_6+R_7)}\right)$

$R_{in} = \frac{V_{IN}}{i_{IN}} = \frac{V_{IN}}{i_s}$

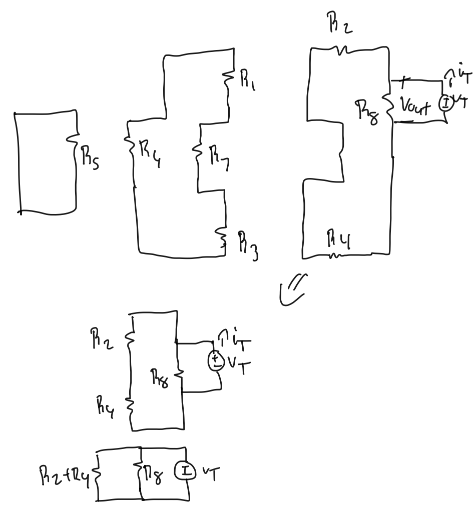
$\therefore R_{in} = R_s$



For R_{out}:

$V_{IN}=0 \therefore Z i_s = 0,\ V_1 = 0,\ V_3 = 0$

$KV_1 = 0 \quad GV_3 = 0$



$V_{out} = (GV_3 R_4 + KV_1)\left(\frac{R_8}{R_4+R_2+R_8}\right)$

$V_{out} = \left(GR_4\left(Z V_{IN}\left(\frac{R_3}{R_s(R_1+R_3+R_6+R_7)}\right)\right) + K\left(-Z\, V_{IN}\left(\frac{R_1}{R_s(R_1+R_3+R_6+R_7)}\right)\right)\right)\left(\frac{R_8}{R_4+R_2+R_8}\right)$

$\frac{V_{out}}{V_{IN}} = Z\left(\frac{GR_4R_3 - KR_1}{R_s(R_1+R_3+R_6+R_7)}\right)\left(\frac{R_8}{R_4+R_2+R_8}\right)$

$\therefore R_{out} = (R_2+R_4)\,||\,R_8$