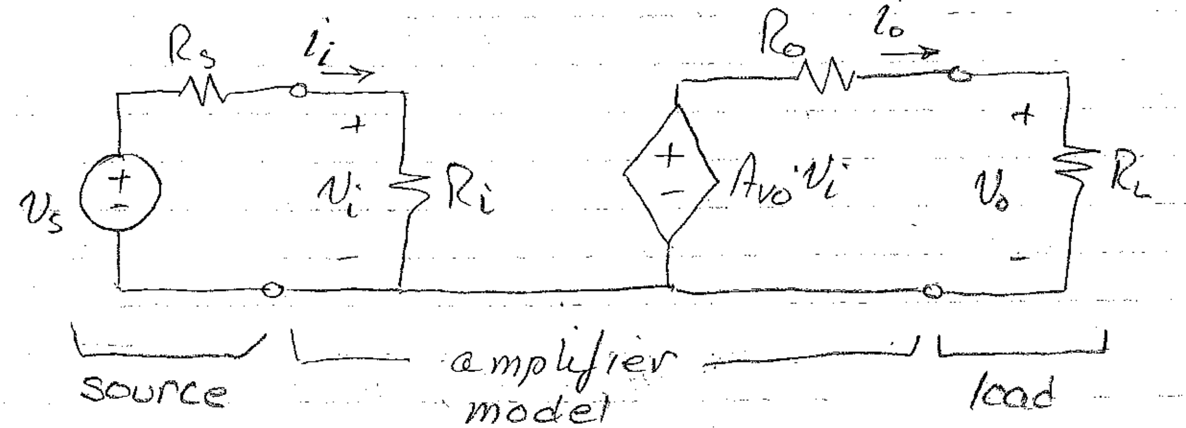
AMPLIFIER CIRCUIT MODELS

VOLTAGE AMPLIFIER

We can construct a circuit model for a voltage amplifier as follows. We have attached a Thevenin equivalent to represent the signal source (a transducer) as well as a resistance to represent a load.



The source is v_s but the voltage input to the amplifier is v_i:

$$v_i = v_s \frac{R_i}{R_i + R_s}$$

So we can define two voltage gains. To be clear, we'll give them different names:

$$A_{vs} \equiv \frac{v_o}{v_s} \qquad A_{vi} \equiv \frac{v_o}{v_i}$$

ANALYSIS:

$$v_o = A_{vo} \cdot v_i \frac{R_L}{R_L + R_o}$$

$$\therefore \quad A_{vi} \triangleq \frac{v_o}{v_i} = A_{vo} \frac{R_L}{R_L + R_o}$$

Also,

$$A_{vs} \triangleq \frac{v_o}{v_s} = A_{vo} \frac{R_L}{R_L + R_o} \frac{R_i}{R_i + R_s}$$

Now if $R_L = \infty$, i.e. the output is open-circuit, the gain $A_{vi} = A_{vo}$. So we call A_{vo} the OPEN-CIRCUIT VOLTAGE GAIN.

Looking at A_{vs}, we see that if we have

$$R_i \gg R_s \quad \text{and} \quad R_o \ll R_L \implies A_{vs} \simeq A_{vo}$$

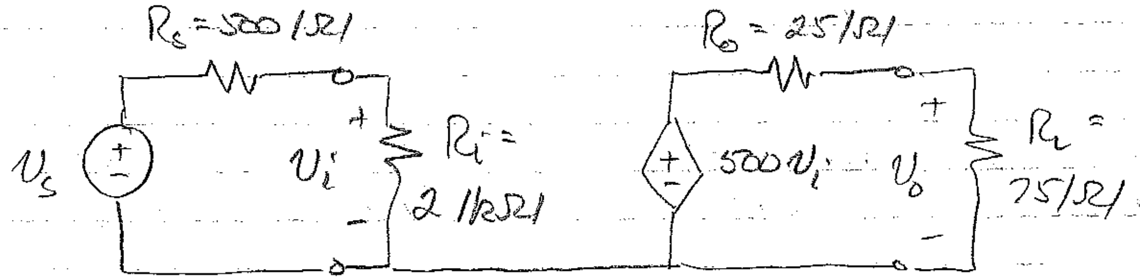
If these conditions on R_i and R_o hold, then the amplifier is close to an "ideal" amplifier in the sense that

$$v_i \simeq v_s \qquad v_o \simeq A_{vo} v_i,$$

that is, there is no loss of signal across R_s or R_o.

Bottom line: We want a voltage amplifier to have a high input impedance and a low output impedance. We will define these impedances more carefully later.

EXAMPLE



GIVEN: $v_s = 20\sqrt{2}\cos(\omega t + \varphi)\ [mV]$

FIND: $A_{vs},\ A_{vi},\ A_i,\ A_p$

ANALYSIS:

$$v_o = 500\,v_i \cdot \frac{R_L}{R_L + R_o} = 375\,v_i$$

$$v_i = v_s \cdot \frac{R_i}{R_i + R_s} = 0.8\,v_s$$

so

$$A_{vs} = \frac{v_o}{v_s} = 500\,\frac{R_L}{R_L+R_o}\cdot\frac{R_i}{R_i+R_s} = 300\ [V/V]$$

$$A_{vi} = \frac{v_o}{v_i} = 500\,\frac{R_L}{R_L+R_o} = 375\ [V/V]$$

$$A_i = \frac{v_o/R_L}{v_i/R_i} = A_{vi}\cdot\frac{R_i}{R_L} = 10^4\ [A/A]$$

$$A_p = A_{vi}\,A_i = 3.75\times10^6\ [W/W]$$

dB?

$$A_{vs} = 300\ [V/V] = 49.5\ [dB]$$
$$A_{vi} = 375\ [V/V] = 51.5\ [dB]$$
$$A_i = 10^4\ [A/A] = 80.0\ [dB]$$
$$A_p = 375\times10^6\ [W/W] = 65.7\ [dB]$$

CASCADED AMPLIFIERS

SEDRA Ex 1.3

We can show that for two cascaded amplifiers, with gains A_{V1} and A_{V2},

$$A_V = A_{V1} \cdot A_{V2}$$

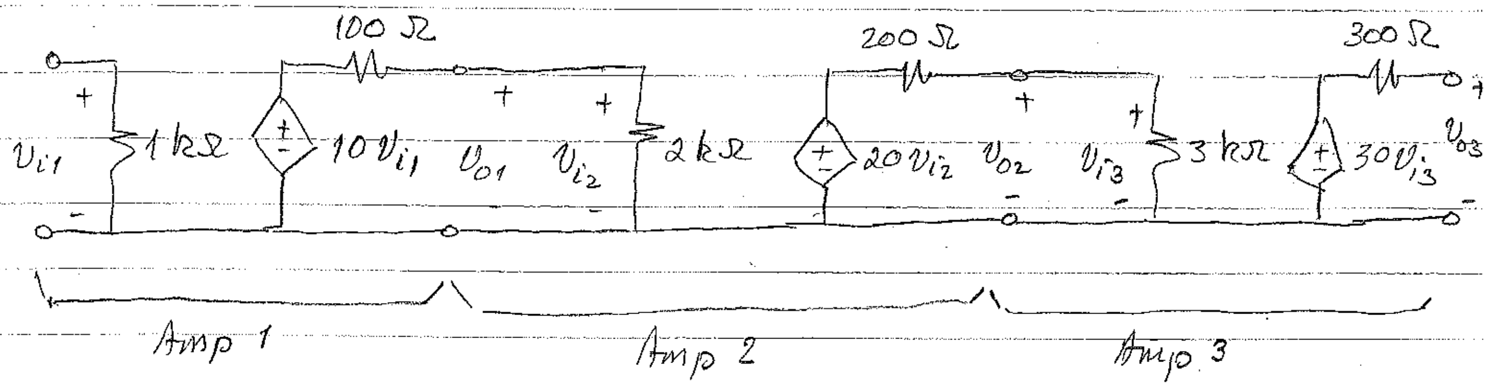
so the voltage gains multiply.

This example is from Hambley, 2nd ed.

GIVEN: Amplifier 1: $A_{vo1} = 10$ $R_{i1} = 1\,k\Omega$ $R_{o1} = 100\,\Omega$
Amplifier 2: $A_{vo2} = 20$ $R_{i2} = 2\,k\Omega$ $R_{o2} = 200\,\Omega$
Amplifier 3: $A_{vo3} = 30$ $R_{i3} = 3\,k\Omega$ $R_{o3} = 300\,\Omega$

FIND: Parameters of "simplified" model, if amps are cascaded in the order 1, 2, 3.

SOLUTION: The best approach here is to draw the cascaded amplifiers and see what's going on.



ANALYSIS:

$$v_{o1} = v_{i2} = 10\, v_{i1} \cdot \frac{2000}{2100}$$

$$v_{o2} = v_{i3} = 20\, v_{i2} \cdot \frac{3000}{3200}$$

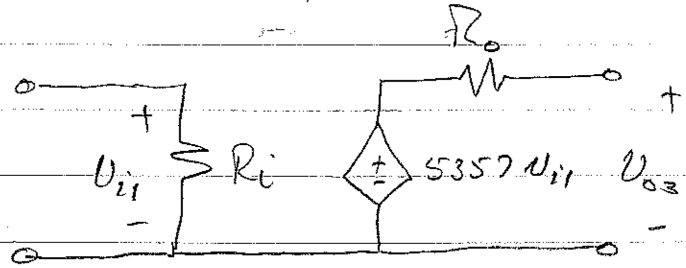
$$v_{o3} = 30\, v_{i3}$$

But then $v_{o3} = 30 \cdot 20 \cdot 10\, v_{i1} \cdot \frac{3000}{3200} \cdot \frac{2000}{2100}$

or...

$$\frac{v_{o3}}{v_{i1}} = 5357.$$

So the overall effect is



What about R_i, R_o?

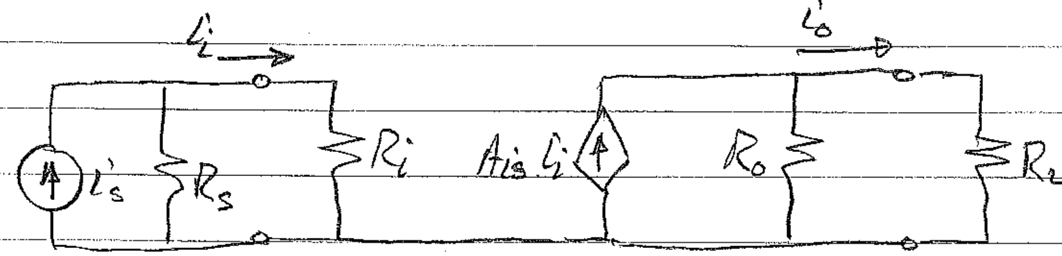
We will learn to calculate input/output impedance rigorously, but for now it should be clear that

$$R_i = 1\,k\Omega$$

$$R_o = 300\,\Omega$$

Analysis of Current Amplifier Model

Let's assume a current source as input:



Then:

$$i_i = i_s \cdot \frac{R_s}{R_s + R_i}$$

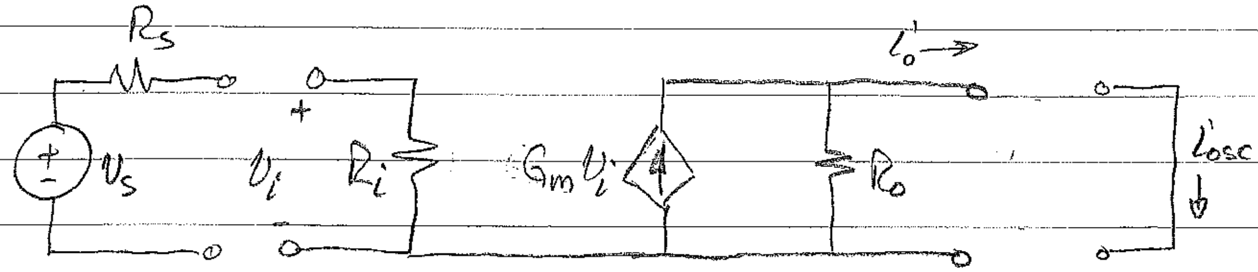
$$i_o = A_{is}\, i_i \cdot \frac{R_o}{R_o + R_L}$$

$$\Rightarrow \quad i_o / i_s = A_{is} \left(\frac{R_o}{R_o + R_L} \right) \left(\frac{R_s}{R_s + R_i} \right)$$

Re-write as $\quad i_o / i_s = A_{is} \cdot \dfrac{1}{1 + R_L/R_o} \cdot \dfrac{1}{1 + R_i/R_s}$

So i_o approaches $A_{is}\, i_s$ if $R_o >> R_L$, and $R_i << R_s$. These conditions for "ideality" are opposite those for the voltage amplifier.

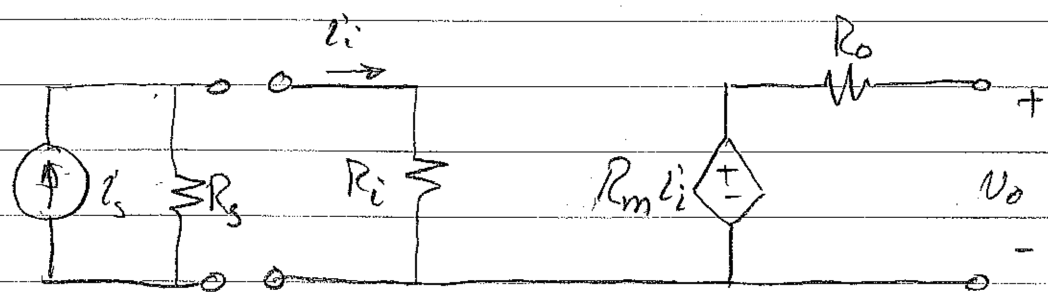
TRANSCONDUCTANCE AMPLIFIER is modeled using a voltage controlled current source:



Here, $i_{osc} = G_m v_i$, hence we have

$$G_m = \frac{i_{osc}}{v_i} \quad \text{UNITS: S (Siemens)}$$

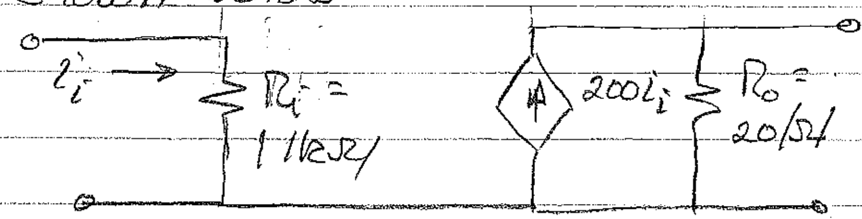
TRANSRESISTANCE AMPLIFIER is modeled using a current-controlled voltage source:



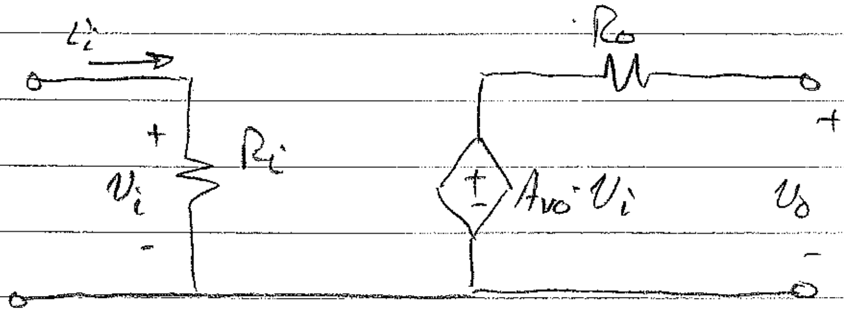
$$v_{oc} = R_m i_i \Rightarrow R_m = \frac{v_{oc}}{i_i}$$

UNITS: Ω (Ohms)

EXAMPLE: Find the parameters of a voltage amplifier that has the same i_{osc} as the current amplifier shown below



Let's first draw what we are looking for:



$$i_{osc} = 200\, i_i = 200\, v_i / R_i$$

But we also have $i_{osc} = \dfrac{A_{vo} \cdot v_i}{R_o}$

So $\dfrac{A_{vo} v_i}{R_o} = 200 \dfrac{v_i}{R_i} \Rightarrow A_{vo} = 200 \dfrac{R_o}{R_i} = 4$

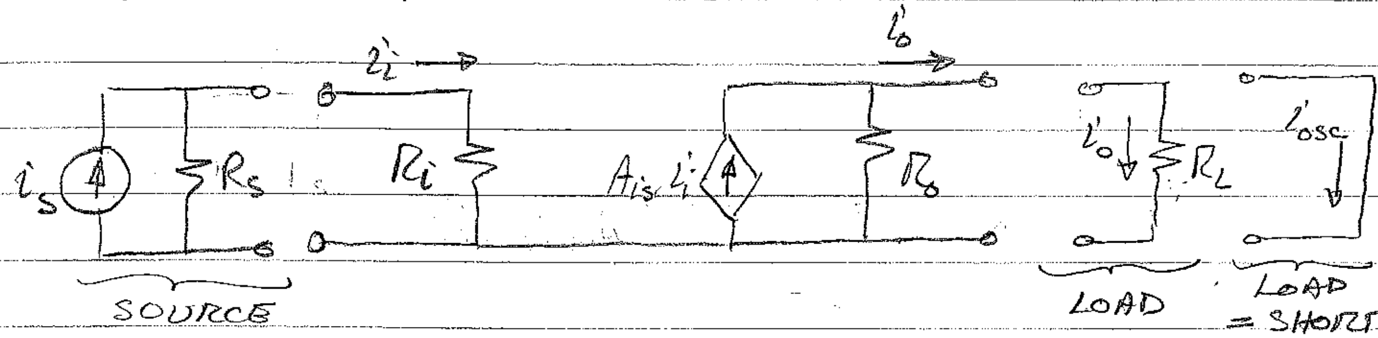
Also, R_i and R_o stay the same so...

$$A_{vo} = 4 \quad R_i = 1000\,\Omega, \; R_o = 20\,\Omega$$

OTHER AMPLIFIER TYPES

We can model the amplification process in several different ways.

CURRENT AMPLIFIER



For the current amplifier we use a current-controlled current source:

- controlling current ≡ input current i_i
- gain is specified by short-circuit output current A_{is}

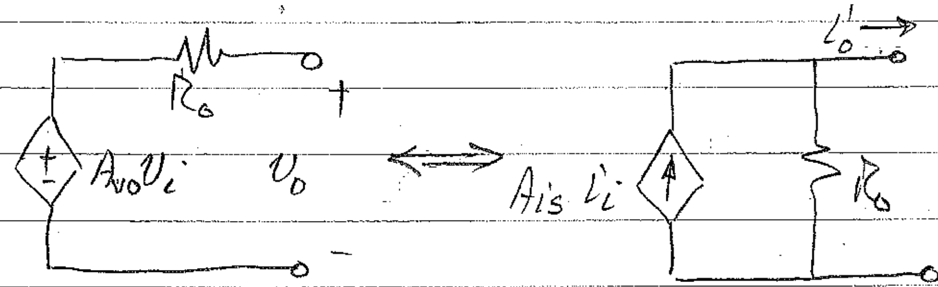
So if the output → short, $i_o = i_{osc}$ and $A_i = A_{is}$.

Thus, $A_{is} \equiv \dfrac{i_{osc}}{i_i}$

so A_{is} is the SHORT CIRCUIT CURRENT GAIN

Source Transformation Viewpoint

We can obtain a current amplifier model from a voltage amplifier model (or vice-versa) using source transformation:



So $R_o \longleftrightarrow R_o$

$$\frac{A_{vo}v_i}{R_o} = i_{osc} = A_{is}\, i_i$$

But $i_i = v_i/R_i$, so $\underline{\underline{A_{is} = A_{vo}\frac{R_i}{R_o}}}$

INPUT/OUTPUT RESISTANCE

Definitions:

Input Resistance is the Thevenin equivalent resistance seen at the input terminals of the amp, with a load connected at the output.

Output Resistance is the Thevenin equivalent resistance seen at the output terminals of the amp, with a source connected at the input.

For $\boxed{\text{IDEAL}}$ amplifier models, Table 1.1 gives values of R_i, R_o

Amplifier Type	R_i	R_o	Gain
voltage	∞	0	A_{vo}
current	0	∞	A_{is}
transconductance	∞	∞	G_{m}
transresistance	0	0	R_{m}