# Current and Voltage Amplifiers

**Q:** *I'll admit to being **dog-gone** confused.*

*You say that **every** amplifier can be described **equally** well in terms of **either** its open-circuit voltage gain $A_{vo}$, **or** its short-circuit current gain $A_{is}$.*

*Yet, amps I have seen are denoted **specifically** as either a dad-gum **current** amplifier or a gul-darn **voltage** amplifier.*

***Are** voltage and current amplifiers **separate** devices, and if so, **what** are the differences between them?*

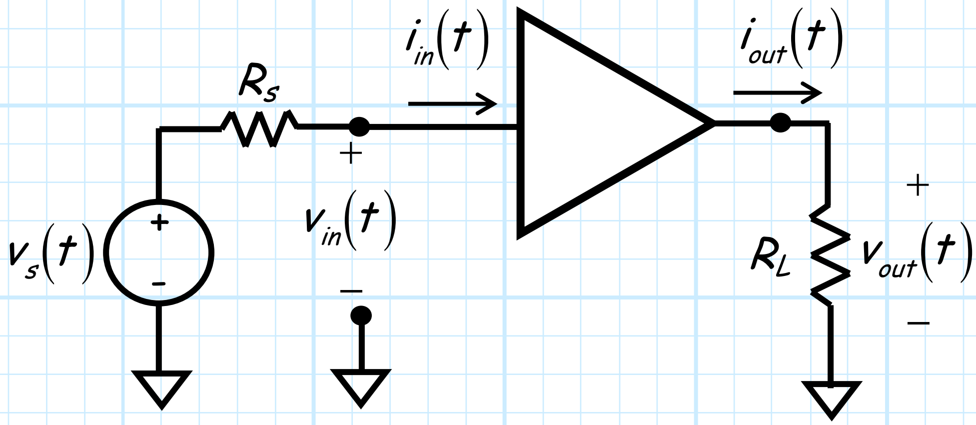
**A:** **Any** amplifier can be used as **either** a current amp **or** as a voltage amp.

However, we will find that an amp that works well as **one** does not generally work well as the **other**! Hence, we can in general **classify** amps as either voltage amps or current amps.

# Define a gain

To see the difference we first need to provide some **definitions**.

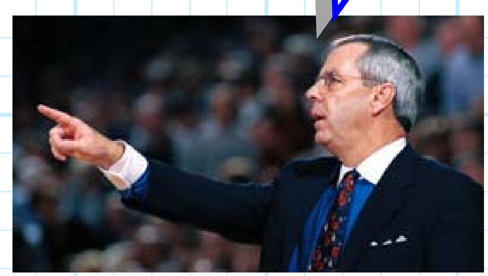
First, consider the following circuit:




**Q:** *Isn't that just $A_{vo}$ ??*

We **define** a voltage gain $A_v$ as:

$$A_v \doteq \frac{v_{out}(t)}{v_s(t)}$$



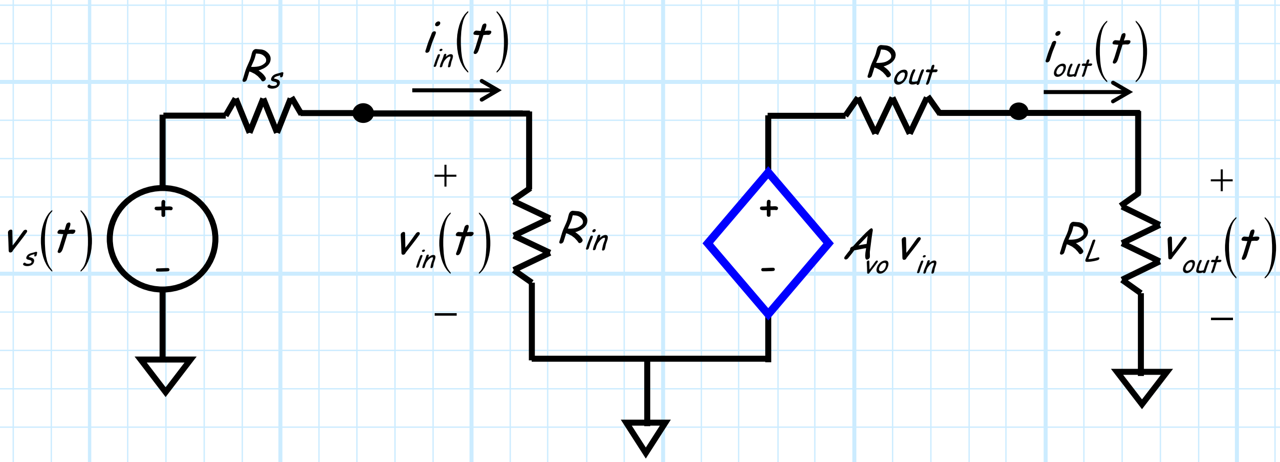
**A:** NO! Notice that the output of the amplifier is **not open circuited**.

# This is what the model is for

Likewise, the **source** voltage $v_s$ is **not** generally equal to the **input** voltage $v_{in}$.

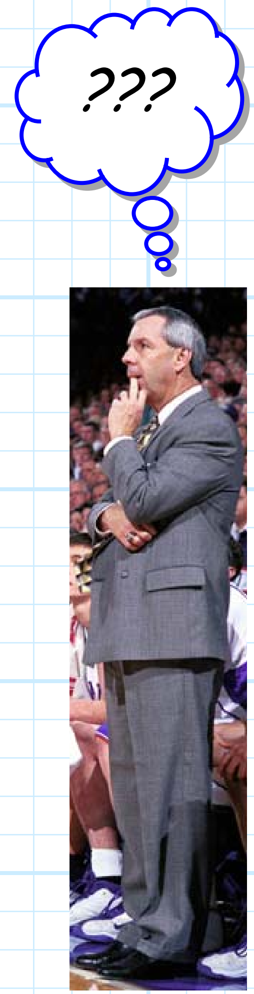
We must use a **circuit model** to determine voltage gain $A_v$ .

Although we can use **either** model, we will find it easier to analyze the **voltage** gain if we use the model with the dependent **voltage** source:



# The result

Analyzing the **input** section of this circuit, we find:




$$v_{in} = \left( \frac{R_{in}}{R_s + R_{in}} \right) v_s$$

and analyzing the **output**:

$$v_{out} = \left( \frac{R_L}{R_{out} + R_L} \right) A_{vo}\, v_{in}$$

**combining** the two expressions we get:

$$v_{out} = \left( \frac{R_L}{R_{out} + R_L} \right) A_{vo} \left( \frac{R_{in}}{R_s + R_{in}} \right) v_s$$

and therefore the **voltage gain** $A_v$ is:

$$A_v \doteq \frac{v_{out}(t)}{v_s(t)} = \left( \frac{R_L}{R_{out} + R_L} \right) A_{vo} \left( \frac{R_{in}}{R_s + R_{in}} \right)$$

# How to maximize voltage gain

Note in the above expression that the first and third product terms are **limited**:

$$0 \leq \left(\frac{R_L}{R_{out} + R_L}\right) \leq 1 \quad \text{and} \quad 0 \leq \left(\frac{R_{in}}{R_s + R_{in}}\right) \leq 1$$

We find that each of these terms will approach their **maximum** value (i.e., one) when:

$$R_{out} \ll R_L \quad \text{and} \quad R_{in} \gg R_s$$

Thus, if the **input** resistance is very **large** (>>$R_s$) and the **output** resistance is very **small** (<<$R_L$), the voltage gain for this circuit will be **maximized** and have a value approximately **equal** to the **open-circuit voltage gain**!

$$v_o \approx A_{vo}\, v_s \quad \text{iff} \quad R_{out} \ll R_L \;\text{ and }\; R_{in} \gg R_s$$

# A good voltage amplifier

Thus, we can infer **three** characteristics of a good **voltage amplifier**:

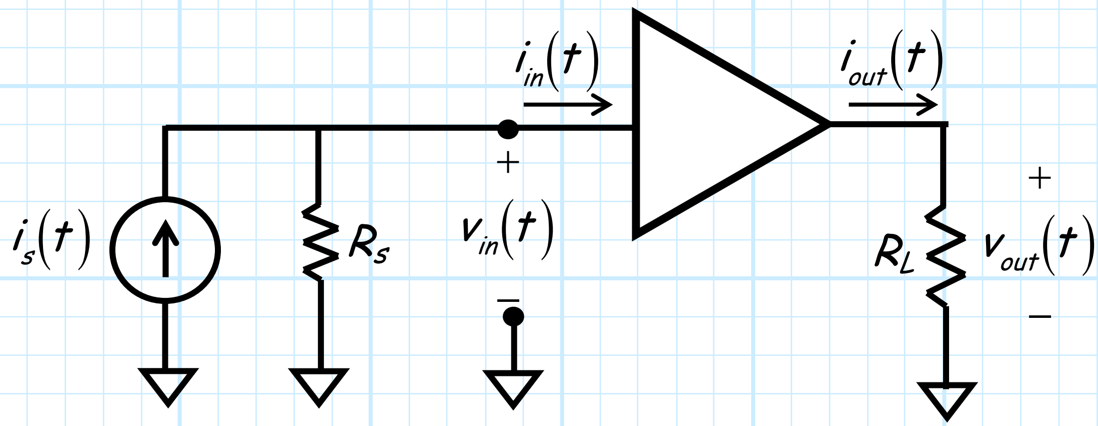
1. Very **large input** resistance ($R_{in} \gg R_s$).

2. Very **small output** resistance ($R_{out} \ll R_L$).

3. Large open-circuit **voltage gain** ($A_{vo} \gg 1$).

# Now for current gain

Now let's consider a **second** circuit:




We define **current gain** $A_i$ as:

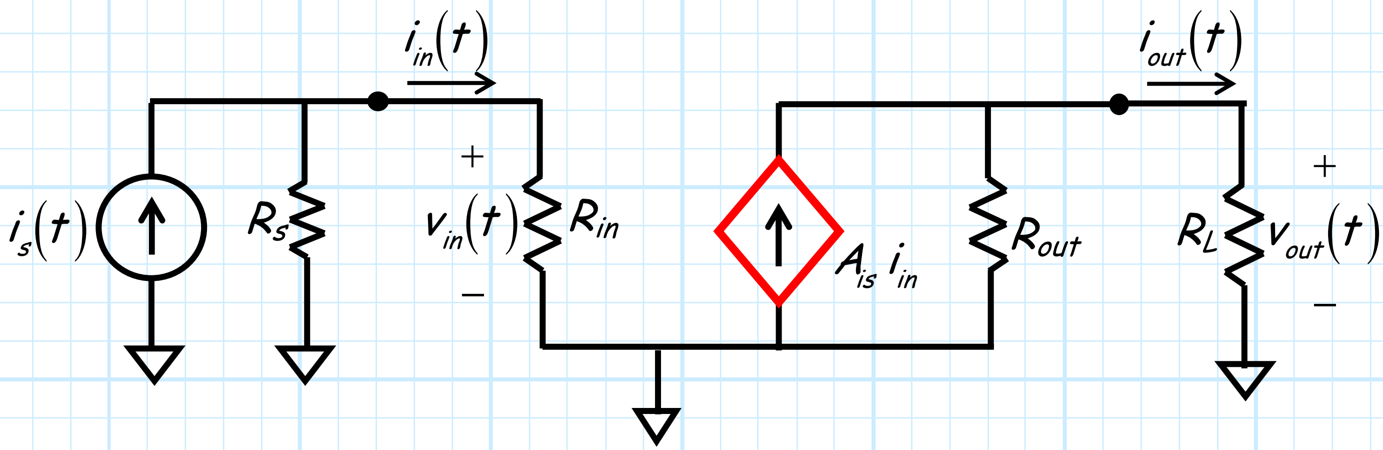
$$A_i \doteq \frac{i_{out}(t)}{i_s(t)}$$

Note that this gain is **not** equal to the **short-circuit** current gain $A_{is}$. This current gain $A_i$ depends on the **source** and **load** resistances, as well as the amplifier parameters.

Therefore, we must use a **circuit model** to determine current gain $A_i$ .

# Use the other model

Although we can use **either** model, we will find it easier to analyze the **current** gain if we use the model with the dependent **current** source:



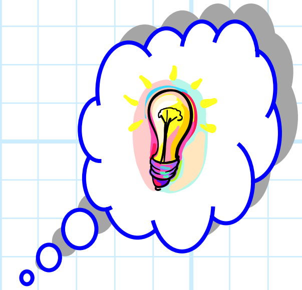

Analyzing the **input** section, we can use **current division** to determine:

$$i_{in} = \left( \frac{R_s}{R_s + R_{in}} \right) i_s$$

We likewise can use current division to analyze the **output** section:

$$i_{out} = \left( \frac{R_{out}}{R_{out} + R_L} \right) A_{is}\, i_{in}$$

# How to maximize current gain



Combining these results, we find that:

$$i_{out} = \left(\frac{R_{out}}{R_{out} + R_L}\right) A_{is} \left(\frac{R_s}{R_s + R_{in}}\right) i_s$$

and therefore the **current gain** $A_i$ is:

$$A_i \doteq \frac{i_o(t)}{i_s(t)} = \left(\frac{R_{out}}{R_{out} + R_L}\right) A_{is} \left(\frac{R_s}{R_s + R_{in}}\right)$$

Note in the above expression that the first and third product terms are **limited**:

$$0 \leq \left(\frac{R_{out}}{R_{out} + R_L}\right) \leq 1 \quad \text{and} \quad 0 \leq \left(\frac{R_s}{R_s + R_{in}}\right) \leq 1$$

We find that each of these terms will approach their **maximum** value (i.e., one) when:

$$R_{out} \gg R_L \quad \text{and} \quad R_{in} \ll R_s$$

# The ideal current amp

Thus, if the **input** resistance is very **small** ($\ll R_s$) and the **output** resistance is very **large** ($\gg R_L$), the voltage gain for this circuit will be maximized and have a value approximately equal to the short-circuit current gain!

$$i_{out} \approx A_{is}\, i_s \quad \text{iff} \quad R_{out} \gg R_L \ \text{ and } \ R_{in} \ll R_s$$

Thus, we can infer **three** characteristics of a good **current amplifier**:

1. Very **small input** resistance ($R_i \ll R_s$).
2. Very **large output** resistance ($R_o \gg R_L$).
3. Large short-circuit **current gain** ($A_{is} \gg 1$).

Note the ideal resistances are **opposite** to those of the ideal **voltage** amplifier!

# You can trust ol' Roy!

*It's actually quite **simple**.*

*An amplifier with **low** input resistance and **high** output resistance will typically provide great **current** gain but lousy **voltage** gain.*

*Conversely, an amplifier with **high** input resistance and **low** output resistance will typically make a great **voltage** amplifier but a dog-gone poor **current** amp.*