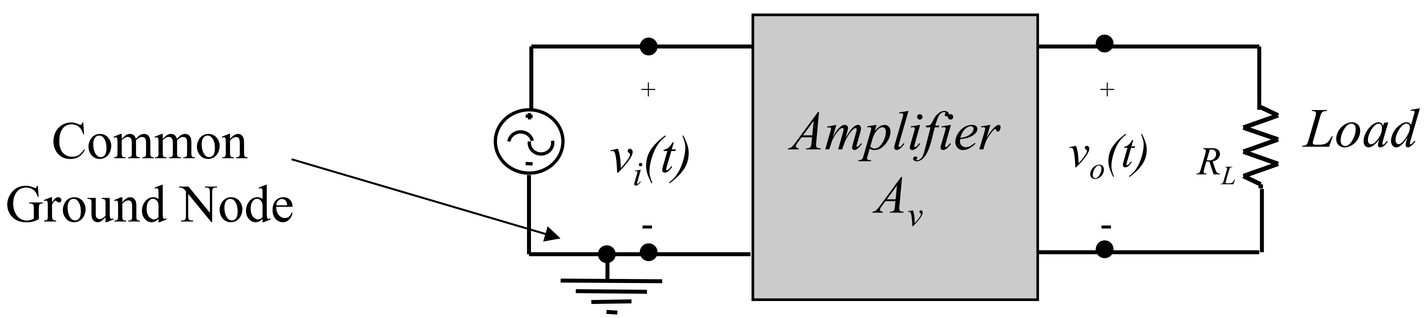
BME 301

10 - Amplifiers and Feedback

Basic Amplifier Types

- An amplifier produces an output signal with the same wave shape as the input signal but usually with a larger amplitude.

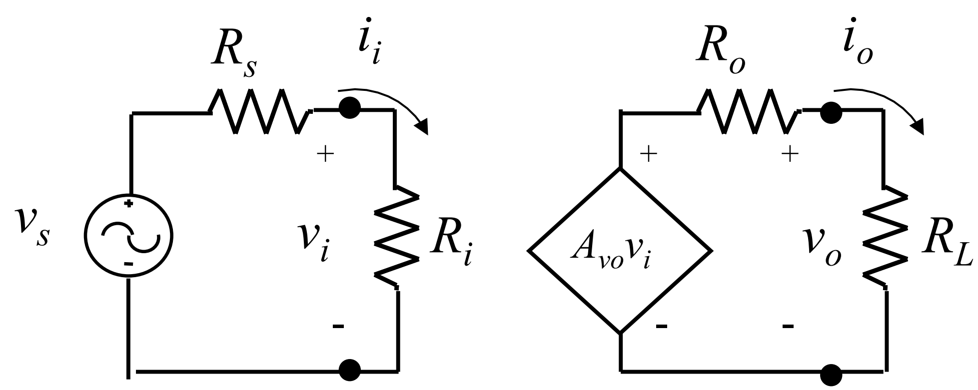
$$v_o(t)=A_v\, v_i(t)$$



- A_v is called the voltage gain and if <0 then the amplifier is inverting; otherwise non-inverting.

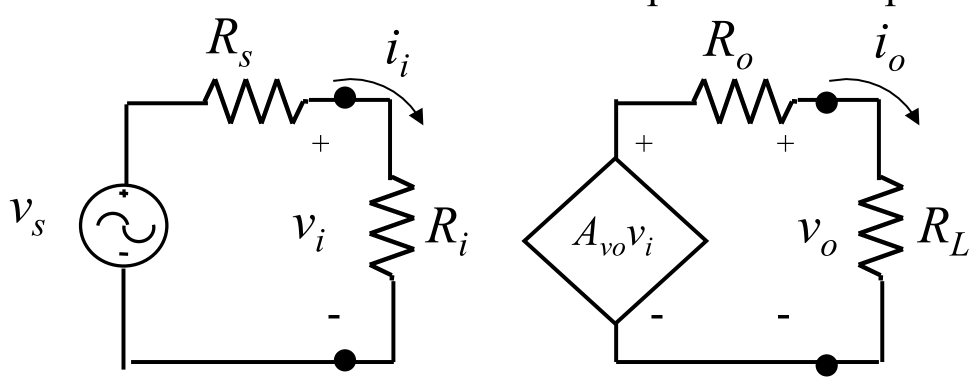
Voltage-Amplifier Model

- Circuit Parameters:
  - Starting from the left
    - v_s is the source input voltage and represents a microphone of an audio amplifier or the action potential of a muscle.
    - R_S is the resistance of the source voltage device
    - v_i is the voltage to the input of the amplifier
    - i_i is the current flowing in the input of the amplifier
    - $R_i = v_i / i_i$ is the resistance at the input to the amplifier



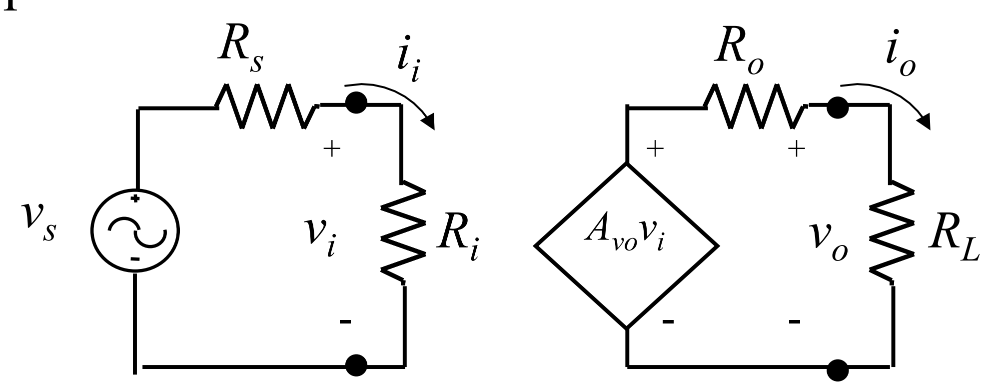
Voltage-Amplifier Model

- Circuit Parameters:
  - Moving to the right side of the model
    - We see on the right part of the model a new icon called dependent voltage source.
      - It's voltage which depends on a voltage at left side of the model, the input voltage at the amplifier
      - In particular, it's the voltage across the input resistor R_i.
      - And the gain of the amplifier when nothing is connected to it's output
    - Open Circuit Voltage Gain A_{vo}
    - R_o is the resistance at output of the amplifier
    - V_o is the voltage at the output of the ampilier
    - i_0 is the current flowing in the output of the amplifier
    - $R_L = v_o / i_o$ represents the device connect to the output of the amplifier.



Voltage-Amplifier Model

- Performance parameters:
  - Voltage Gain $A_v = v_o / v_i$ from the input of the amplifier to the output of the circuit
  - Voltage Gain $A_{vs} = v_o / v_s$ from the source of the amplifier model to the output of the circuit
  - Current Gain $A_i = i_o / i_i$
  - Power Gain $G = P_o / P_i$ from the input of the amplifier to the output of the circuit
  - Power Gain $G_S = P_o / P_s$ from the source of the amplifier model to the output of the circuit



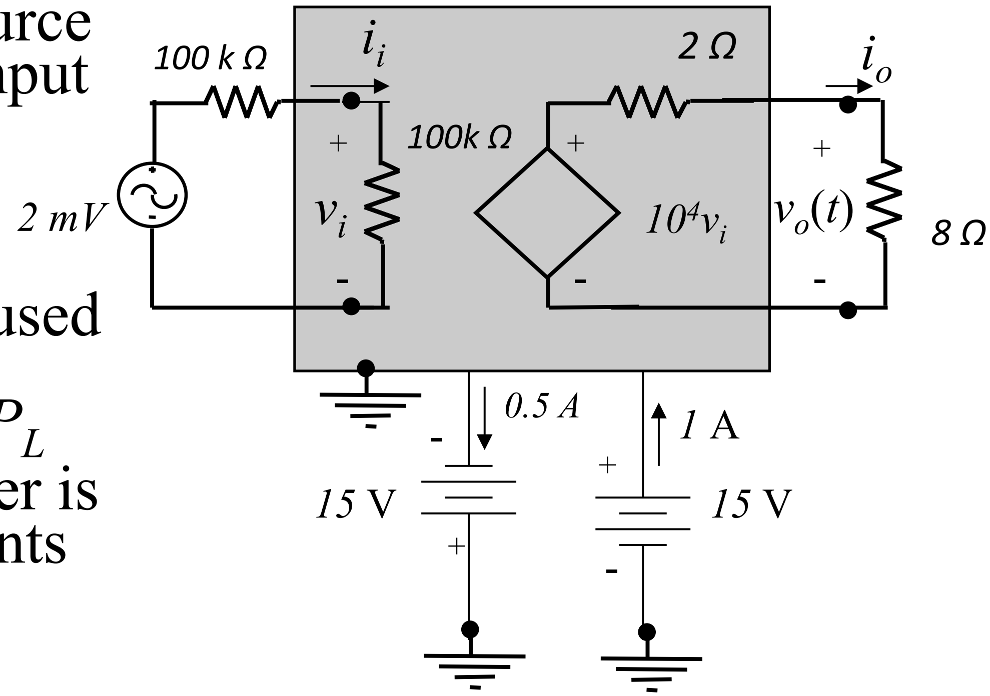
Power Supply Efficiency

- In addition to the DC power, there is power from the source which is delivered to the input of the amplifier, P_i.
- Therefore, the total input power is $P_{DC} + P_i$
- A portion of this power is used to provide the gain and is delivered the output load, P_L
- The remainder of this power is dissipated by the components of the amplifier, P_d

$$P_{DC} + P_i = P_d + P_L$$

- The amount of from the DC source delivered to the load is called the power efficiency, η

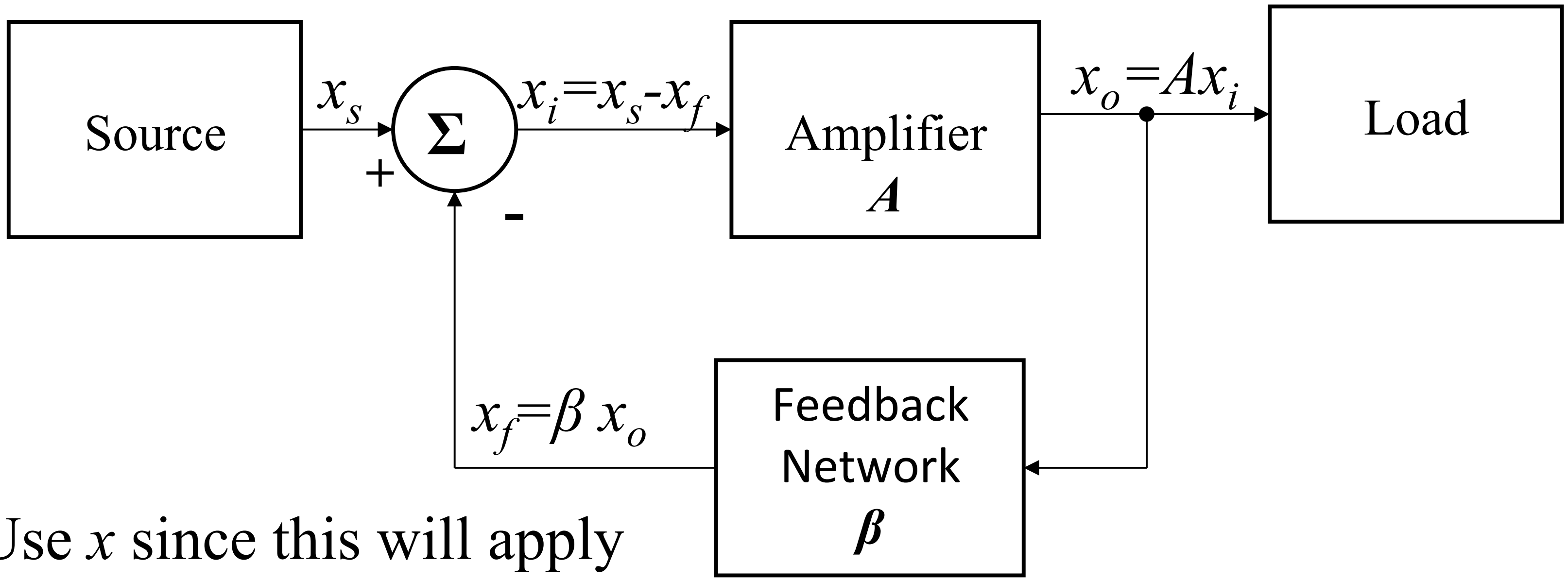
$$\eta = P_L / P_{DC}$$



Feedback

- Types of Feedback
  - Positive: aids the input signal
  - Negative: reduces the input signal
- Positive Feedback Benefits
  - Oscillators
- Negative Feedback Benefits
  - Stabilization of Gain
  - Reduction of Nonlinear Distortion
  - Reduction of noise
  - Control of input and output impedances
  - Extension of Bandwidth
- Design of feedback amplifier to avoid unwanted oscillations

Closed-Loop Gain



Use x since this will apply equally to voltages and currents

$x_i = x_s - x_f = x_s - \beta x_o$

$x_o = Ax_i$

$x_o = A(x_s - \beta x_o)$

=>

$$A_f = \frac{x_o}{x_s} = \frac{A}{1 + A\beta}$$

$$Closed-Loop\ Gain = A_f$$

$$Open-Loop\ Gain = A$$

$$Loop\ Gain = A\beta$$

Problems With Positive Feedback

- If $|A\beta| \leq 1$ and $A\beta$ is negative:
  - then $1+A\beta \leq 1$; and A_f (closed-loop gain) > A (open-loop gain)
  - if $A\beta = -1$, then oscillations occur
  - POSITIVE FEEDBACK
- Example:
  - $A = -10$, $\beta = 0.0999$ => $A\beta = -0.999$; $1+A\beta = 0.001$; $A_f = -10^4$
  - Here is a problem using POSITIVE FEEDBACK
    - A: -10 ➔ -9.9 => $A\beta = -0.989$; $1+A\beta = 0.011$; then A_f: -10^4 ➔ -901
    - For a 1% reduction in A there was a 91% reduction of A_f
  - POOR GAIN STABILITY: worse than the original amplifier

Problems (Continued)

- Another Example:
  - As $A\beta$ ➔ -1, A_f ➔ ∞ and this implies for a zero input signal an output signal can be generated and a signal will flow around the loop w/o an input => oscillations. This is ok if an oscillator design is desired.
  - Clearly, a high gain amplifier can be designed with positive feedback; however, care must be taken because any change in the design (temperature shifts increase the power supply voltages) may cause $A\beta$ ➔ -1 and oscillations result

Gain Stabilization Using Negative Feedback

- For Negative Feedback Amplifiers are designed with $A\beta >> 1$ and $A_f \approx 1/\beta$
- This is desirable since the value of β can be designed using solely stable passive components (e.g., resistors and capacitors)
  - This occurs for op amps

Gain Stabilization Using Negative Feedback Continued

- *Example:* $A = 10^4$ and $\beta = 0.01 \Rightarrow A_f = 99$
  - If $A \rightarrow 9000$, then $A_f \rightarrow 98.9$
  - For a 10% reduction in A there was only a 0.1% reduction of A_f
- Therefore, we can design precision amplifiers using Negative Feedback

$$\frac{dA_f}{dA} = \frac{1 + A\beta - A\beta}{(1 + A\beta)^2} = \frac{1}{(1 + A\beta)^2}$$

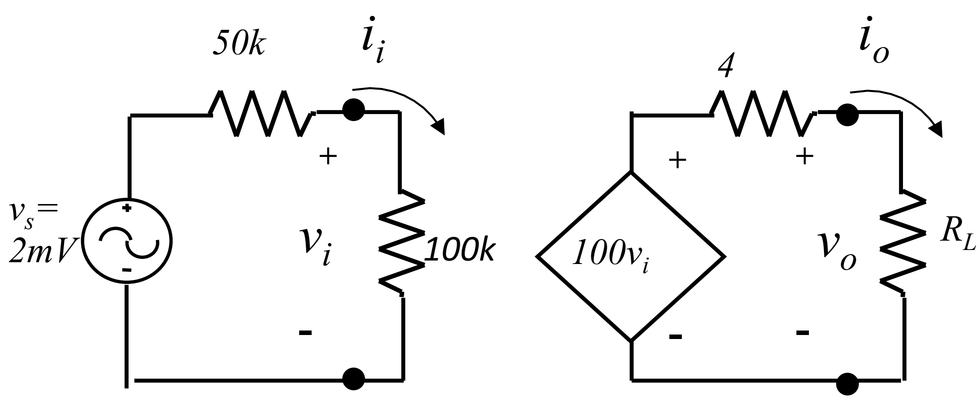
$$dA_f = \frac{dA}{A}\frac{A}{(1 + A\beta)^2} = \frac{dA}{A}\frac{A_f}{1 + A\beta}$$

$$\frac{dA_f}{A_f} = \frac{dA}{A}\frac{1}{1 + A\beta}$$

- This states that for small fractional changes of A_f is the fractional change in A divided by $1+\beta$
- Clearly, if the loop gain $A\beta >> 1$ changes of A_f are less than A

Homework

1. For the following circuit, determine the value of R_L to maximize the power gain for this circuit. Provide a proof. Which value of R_L makes the better design and why?



Homework

2. What are the benefits of negative feedback?
3. What are the problems with positive feedback?
4. HONORS STUDENTS ADD THE FOLLOWING

   Name 3 types of negative feedback applications.