EECS 16A Dis 10B Notes

Tuesday, November 2, 2021 5:29 PM

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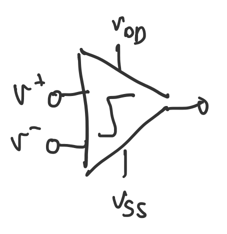
1. Testing for Negative Feedback

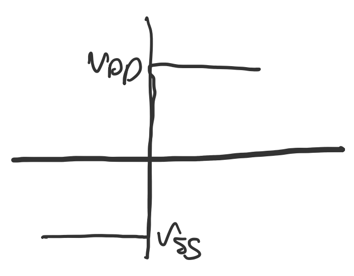
While it is tempting to say "if the feedback voltage is connected to the negative op-amp terminal, then we have negative feedback," this is not always true. Here is a two-step procedure for determining if a circuit is in negative feedback:

- (1) **Step 1: Zero out all independent sources**, replacing voltage sources with wires and current sources with opens as we did in superposition. You do not need to zero out the voltage sources that serve as the power supplies to the op-amp, since they are not treated as signals and almost considered part of the op-amp. *(turn off input ind. sources)*
- (2) **Step 2: Wiggle the output and check the loop**. The goal is to see how the feedback loop responds to a change. Assume that the output increases slightly. Check the direction of change of the feedback signal and the error signal from the circuit. Any change in the error signal will cause a new change in the output. This change is the feedback loop's response to the initial change. *(kink output and see how it changes w/ "next timestep")*
  - If the error signal decreases, then the output must also decrease. This is the *opposite direction* we initially assumed, i.e. the loop is trying to correct for the change. So the circuit is in negative feedback.
  - If the error signal instead increased, then the output would also increase. This is the *same direction* we initially assume, i.e. the initial increase lead to further increase. We call this positive feedback.

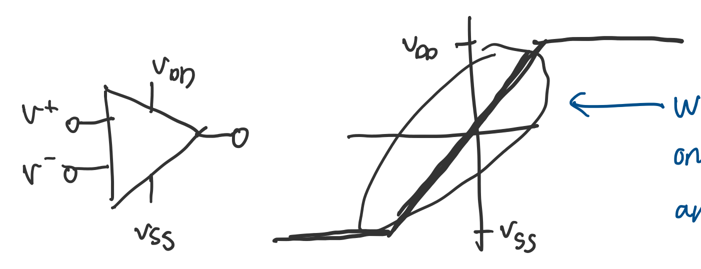
Comparator:



$V_{out} = \begin{cases} V_{DD} & V_+ > V_- \\ V_{SS} & V_+ < V_- \end{cases}$

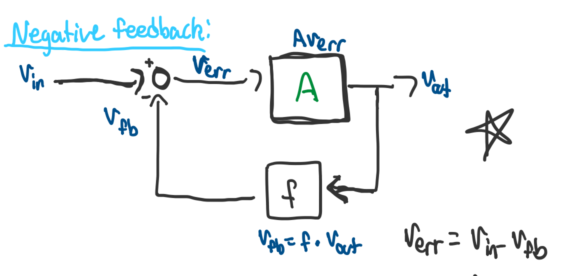


Op-amp:



← We will be focusing on the linear region when analyzing op amps

Negative feedback:



$V_{err} = V_{in} - V_{fb}$

$V_{out} = A \cdot V_{err}$

$V_{fb} = f \cdot V_{out}$

$V_{err} = V_{in} - V_{out}$

$V_{out} = A \cdot V_{err}$

$= A(V_{in} - V_{fb})$

$= A(V_{in} - f \cdot V_{out})$

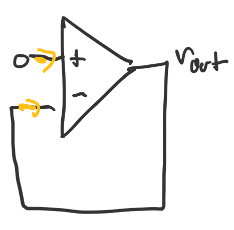
$V_{out} + A \cdot f V_{out} = A V_{in}$

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

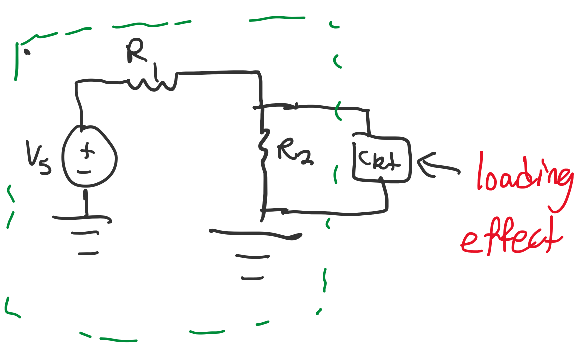
As $A \to \infty$, $\left(\frac{A}{1+Af}\right)$

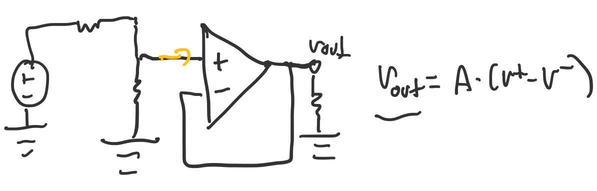
$\frac{1}{\frac{1}{A} + f} \xrightarrow{A \to \infty} \frac{1}{f}$ $V_{out} = \frac{1}{f} \cdot V_{in}$

$V_{out} = V_{in}$



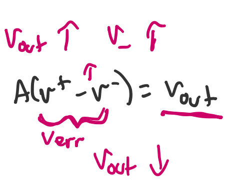
1. $I^+ = I^- = 0$
2. $V^+ = V^-$ (neg feedback)





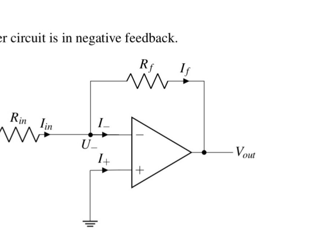
$V_{out} = A \cdot (V^+ - V^-)$

(a) Show that the voltage buffer circuit is in negative feedback. Note that here v_{in} is acting as a voltage source.



$V_{out} = V_{in}$

1. Zero out independent sources



Negative feedback!

$V_{out} \uparrow$: $V_{err} \downarrow$ $V_{out} \downarrow$

$V_{out} \downarrow$: $V_{err} \uparrow$ $V_{out} \uparrow$

$V_{err} = V^+ - V^-$

Positive feedback!

$V_{out} \uparrow$: $V_{err} \uparrow$ $V_{out} \uparrow$

$V_{out} \downarrow$: $V_{err} \downarrow$ $V_{out} \downarrow$

Negative feedback has opposite signs for V_{out}

Positive feedback has same signs for V_{out}

$V_{out} \uparrow$ $V_- \uparrow$

$A(V^+ - V^-) = V_{out}$ (V_{err}) $V_{out} \downarrow$

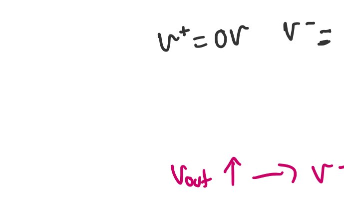
$V_{out} = V_{in}$

$V^+ = V^-$

$V_{out} = A(V^+ - V^-) \uparrow$

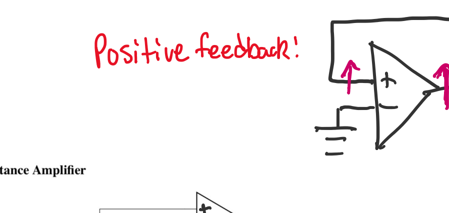
$V_{out} \uparrow$

(b) Show that the inverting amplifier circuit is in negative feedback.



$V_c = V^+ - V^-$

1. Turn off ind. sources



$V^+ = 0V$ $V^- = \left(\frac{R_{in}}{R_f + R_{in}}\right) V_{out} \uparrow$

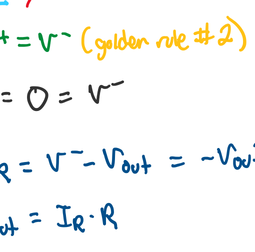
$V_{out} \uparrow \longrightarrow V^- \uparrow \longrightarrow V_{out} \downarrow$

Positive feedback!

$V_{out} \uparrow$ $V^+ \uparrow$

There is no error correction – as V_{out} increases, V^+ increases so V_{out} will keep increasing

2. A Trans-Resistance Amplifier



Calculate v_{out} as a function of I_s and R.

$V_R = I_R R$

$V_R = V^- - V_{out}$

$I_s = I^- + I_R = I_R$ (golden rule #1) ($I^- = 0$)

$V^+ = V^-$ (golden rule #2)

$V^+ = 0 = V^-$

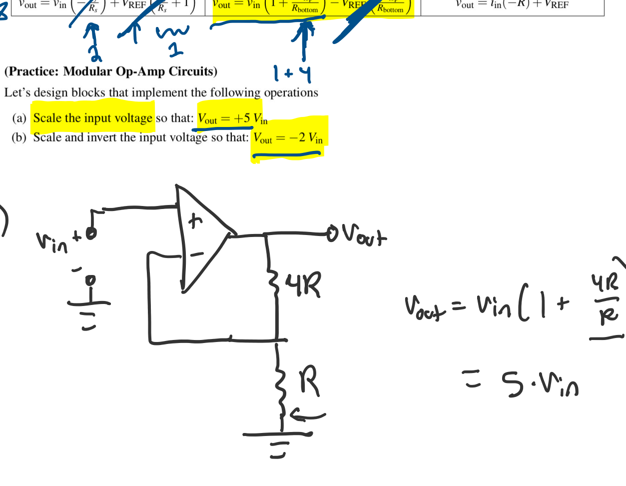
$V_R = V^- - V_{out} = -V_{out}$

$-V_{out} = I_R \cdot R$

$V_{out} = -I_R \cdot R$

$V_{out} = -I_s \cdot R$ current-to-voltage converter

(For Reference: Example Circuits)



$V_{out} = V_{in}$

$V_{out} = 5 \cdot V_{in}$

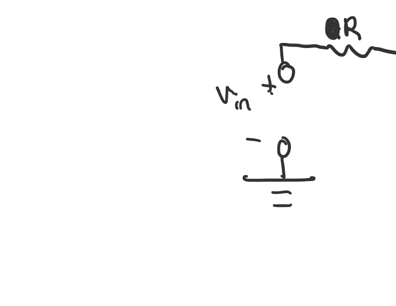
3. (Practice: Modular Op-Amp Circuits)

Let's design blocks that implement the following operations

(a) Scale the input voltage so that: $V_{out} = +5\,V_{in}$

(b) Scale and invert the input voltage so that: $V_{out} = -2\,V_{in}$

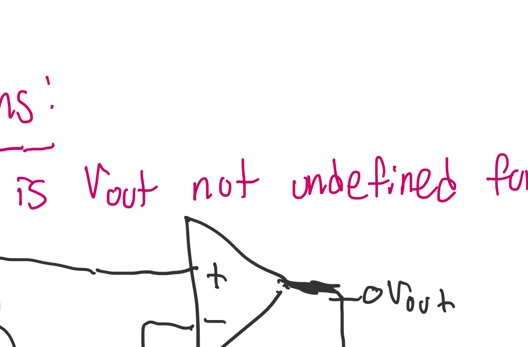
a)



$V_{out} = V_{in}\left(1 + \frac{4R}{R}\right)$

$= 5 \cdot V_{in}$

b) $V_{out} = -2V_{in}$



$V_{out} = V_{in}\left(\frac{-R_f}{R_s}\right)$

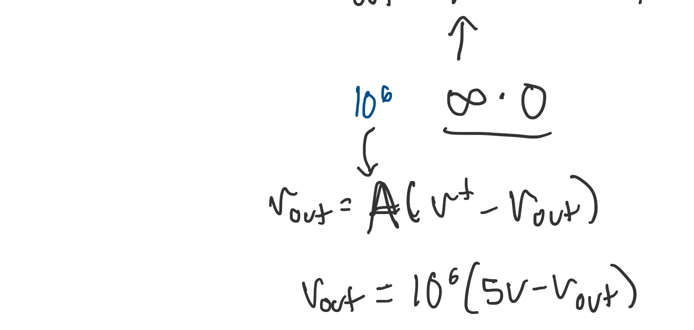
$= V_{in}\left(-\frac{2R}{R}\right)$

$= -2V_{in}$

Questions:

1. Why is V_{out} not undefined for op amps?

Ex.



In real life, op amps have large gain but not infinite

$V^+ = V^-$

$V_{out} = A(V^+ - V^-)$

10^6 $\infty \cdot 0$

$V_{out} = A(V^+ - V_{out})$

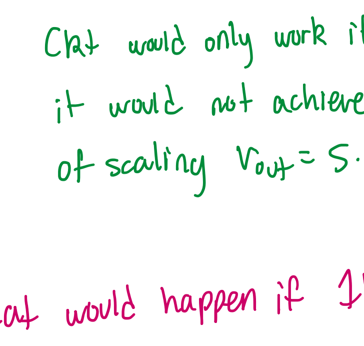
$V_{out} = 10^6(5V - V_{out})$

$V_{out} \approx 4.998 \sim 5V$

$V^+ \simeq V^-$

2. For 3a, why can't we use inverting amplifier w/ $R_f = R_s = 0$?

Inverting amplifier w/ $R_f = R_s = 0$

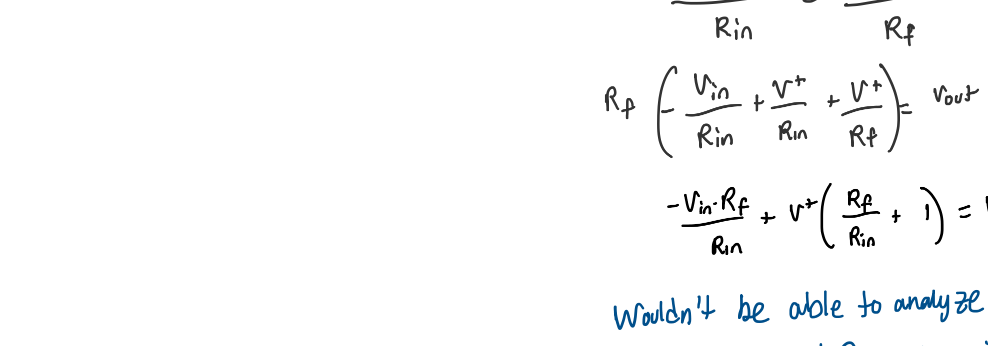


$V^+ = V^-$

Ckt would only work if $V_{in} = V_{REF}$, but it would not achieve the desired functionality of scaling $V_{out} = 5 \cdot V_{in}$

3. What would happen if 1b was in positive feedback?

(b) Show that the inverting amplifier circuit is in negative feedback.



$V^- = 0$

$\frac{V_{in} - V^+}{R_{in}} = \frac{V^+ - V_{out}}{R_f}$

$R_f\left(-\frac{V_{in}}{R_{in}} + \frac{V^+}{R_{in}} + \frac{V^+}{R_f}\right) = V_{out}$

$\frac{-V_{in} \cdot R_f}{R_{in}} + V^+\left(\frac{R_f}{R_{in}} + 1\right) = V_{out}$

Wouldn't be able to analyze ckt further. As $V_{out} \uparrow$, $V^+ \uparrow$ so there is not much point to further checking what V_{out} would be