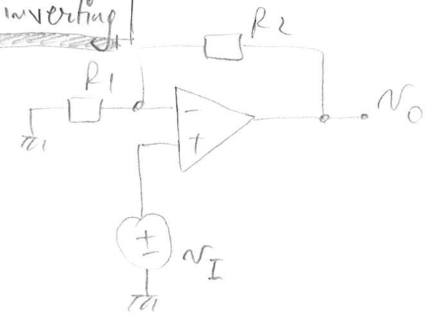
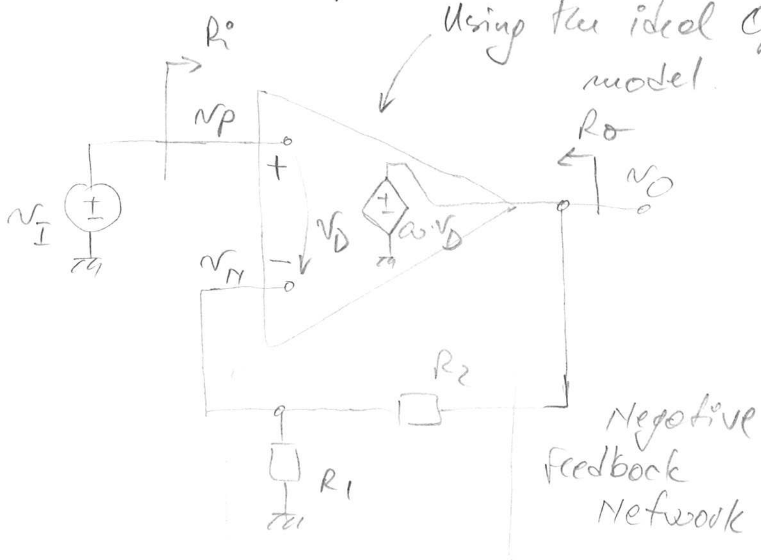
1.3. Basic Op Amp Configurations (summary of last time)

Noninverting



Using the ideal Op Amp model



$$A = \frac{v_O}{v_I} = \underbrace{\left(1+\frac{R_2}{R_1}\right)}_{\triangleq A_{ideal}} \left(\frac{1}{\underbrace{1+\left(1+\frac{R_2}{R_1}\right)\cdot\frac{1}{a}}} \right)$$

closed loop gain.

$$\left(1+\frac{R_2}{R_1}\right) \triangleq \frac{1}{\beta}$$

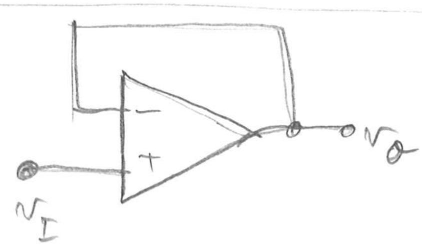
$$A = \frac{v_O}{v_I} = \left(1+\frac{R_2}{R_1}\right)\cdot\frac{1}{1+\frac{1}{a\beta}} = \boxed{A_{ideal}\cdot\frac{1}{1+\frac{1}{a\beta}} = A}$$

$$\boxed{A_{ideal} = \lim_{a\to\infty} A = 1+\frac{R_2}{R_1}}$$

$$\boxed{\begin{array}{l} R_i \cong \infty \\ R_o \cong 0 \end{array}}$$

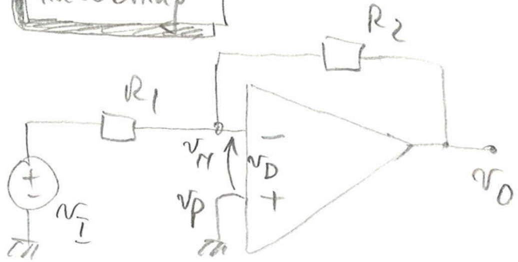
Voltage Follower

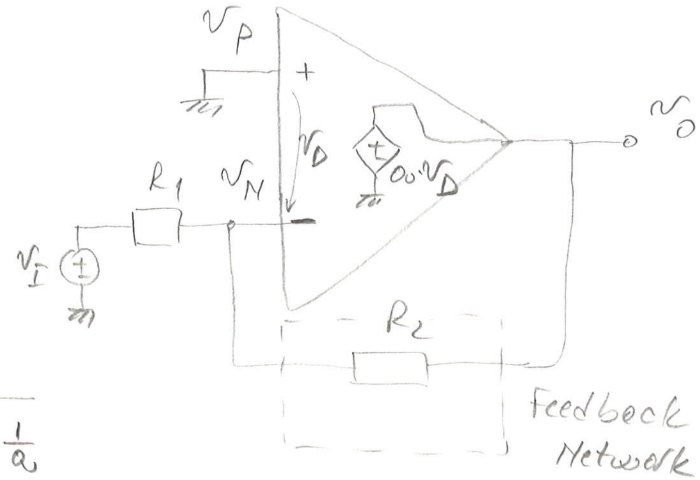
$R_1 \to \infty$
$R_2 \to 0$



It's a resistance transformer. $A = 1$

Inverting





$$A = \frac{v_O}{v_I} = \underbrace{\left(-\frac{R_2}{R_1}\right)} \cdot \frac{1}{1 + \left(1 + \frac{R_2}{R_1}\right) \cdot \frac{1}{a}}$$

$$\lim_{a \to \infty} A = A_{ideal} = -\frac{R_2}{R_1} \qquad \text{Phase } \phi(\omega) = -\pi = -180^\circ$$

In the limit, because $v_D = \frac{v_O}{a} \to 0$, v_N would follow v_P due to the Op Amp action via the negative feedback. Hence v_N appears to be a $\boxed{\text{virtual ground}}$.

This is true only because of the negative feedback.

So, we can approximate $\boxed{\begin{array}{c} R_i \cong R_1 \\ R_o \cong 0 \end{array}}$

(1.4) Ideal Op Amp Circuit Analysis

When Op Amp is operated with negative feedback:

$$v_D = \frac{v_O}{a} \xrightarrow[a \to \infty]{} 0 \implies \lim_{a \to \infty} v_N = v_P \quad : \text{"}v_N \text{ approaches } v_P\text{"}$$

Concept: - This property is called $\boxed{\text{input voltage constraint}}$. It makes the input terminals appear as if they were shorted together!

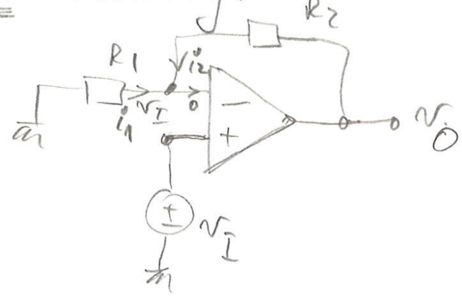
Concept: - Because $r_d \to \infty$ and no current is drawn, currents are zero and this property is called $\boxed{\text{input current constraint}}$. Inputs appear to be an open circuit!

$\implies$ designation of $\boxed{\text{virtual short}}$ concept!

$\boxed{\text{important}}$: when operated with $\boxed{\text{negative feedback}}$, the OpAmp will provide the necessary current so that to drive v_D to 0. In other words to make v_N approach v_P but without drawing any current at the OpAmp inputs!

The virtual short concept is used to quickly analyze circuits.

Example: noninverting:



$v_N = v_I$ due to virtual short

$i_1 = -i_2$

$$\left.\begin{array}{l} i_1 = -\dfrac{v_I}{R_1}, \quad i_2 = \dfrac{v_O - v_I}{R_2} \end{array}\right\} \Rightarrow$$

$$\Rightarrow \frac{v_I}{R_1} = \frac{v_O - v_I}{R_2} \Leftrightarrow v_I (R_2 + R_1) = R_1 v_O \Rightarrow$$

$$\Rightarrow \boxed{\frac{v_O}{v_I} = 1 + \frac{R_2}{R_1} = A_{ideal}}$$

⚠ $\boxed{\text{Important}}$: Virtual-short-concept valid only for negative feedback, when v_N is tracking v_P!!!

Using the virtual short concept, one can easily analyze:

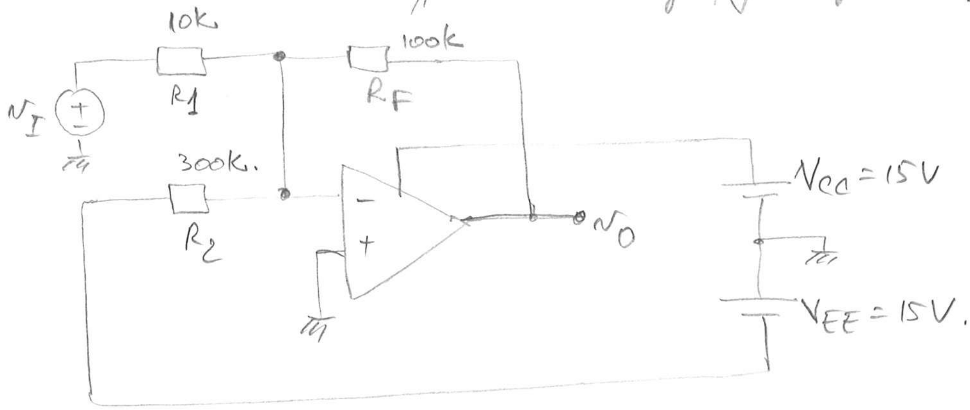
- summing amplifier
- difference amplifier
- Differentiator
- integrator.

} : signal processing applications

because they are all negative feedback OpAmp configurations.

- Negative-resistance converter : impedance transformation.

Example : The use of summing amplifier to offset and amplify input v_I.



$\boxed{\text{Offsetting}}$ amplifier

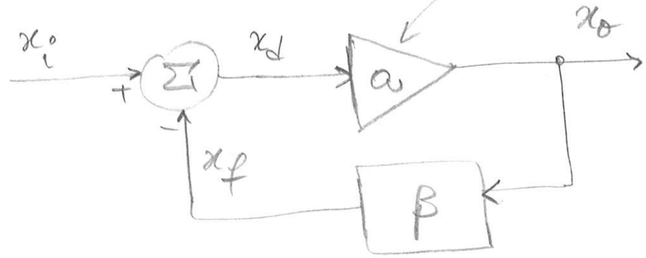
$$v_O = -\left(\frac{R_F}{R_1}\right) v_I - \frac{R_F}{R_2}\cdot(-V_{EE})$$

$$= -\frac{100k}{10k} v_I - \frac{100k}{300k}(-15V) = \boxed{-10\cdot v_I + 5V = v_O}$$

1.5. Negative feedback

- Basic structure of a negative-feedback circuit.

≜ error amplifier.



$a \triangleq$ open loop gain
$\beta \triangleq$ feedback factor.

$$\left.\begin{aligned} x_o &= a\cdot x_d = a(x_i - x_f) \\ x_f &= \beta x_o \end{aligned}\right\} \Rightarrow x_o = a x_i - a\cdot\beta x_o$$

$$\Rightarrow x_o(1+a\beta) = a x_i$$

$$\Rightarrow \boxed{\frac{x_o}{x_i} = \frac{a}{1+a\beta}} = A \triangleq \text{Closed Loop Gain}$$

$$\boxed{A = \frac{a}{1+a\beta}} = \frac{1}{\beta}\cdot\frac{a\cdot\beta}{1+a\beta} = \frac{1}{\beta}\cdot\frac{T}{1+T}$$

$\boxed{T = a\beta}$ $\triangleq$ loop gain.

Letting $T \to \infty$ leads to the ideal situation:

$$\lim_{T\to\infty} A = \boxed{A_{ideal} = \frac{1}{\beta}.}$$

A becomes independent of a.

Hence:

$$\boxed{A = A_{ideal}\cdot\frac{T}{1+T} = A_{ideal}\cdot\frac{1}{1+\frac{1}{T}}}$$

Definition: Error function $\triangleq \dfrac{1}{1+\frac{1}{T}} = 1 - \dfrac{1}{1+T} = 1 - \varepsilon$

$\varepsilon = \dfrac{1}{1+T}$ $\triangleq$ fractional deviation.

$$\Rightarrow \boxed{A = A_{ideal}\cdot(1-\varepsilon)}$$

$T \nearrow \Rightarrow \varepsilon \searrow$ and error function $\to 1$ while $A \to A_{ideal}$.

Definition: Gain error (%) $= 100\cdot\dfrac{A - A_{ideal}}{A_{ideal}} \cong -\dfrac{100}{T}$

- Effect of negative feedback on signals x_d, x_f:

$$\begin{cases} x_d = \dfrac{x_o}{a} = \dfrac{A\cdot x_i}{a} = \dfrac{\cancel{a}}{1+a\beta}\cdot\dfrac{1}{\cancel{a}}x_i = \dfrac{1}{1+T}\cdot x_i \\[2ex] x_f = \beta x_o = \beta A x_i = \dfrac{\beta a}{1+a\beta}x_i = \dfrac{T}{1+T}x_i = \dfrac{1}{1+\frac{1}{T}}\cdot x_i \end{cases}$$

$$\Rightarrow \boxed{\lim_{T\to\infty} x_d = 0} \qquad \boxed{\lim_{T\to\infty} x_f = x_i}$$

Negative feedback makes gain in closed loop $A = \frac{a}{1+a\beta}$ be $1+T$ times smaller.

Benefits of negative feedback:

a) - Gain desensitivity

$$\frac{dA}{A} = \frac{1}{1+T}\,\frac{da}{a}.$$

The effect of a given percentage change in a upon A is reduced $(1+T)$ times!

$(1+T) \triangleq$ desensitivity factor.

b) - Nonlinear Distortion reduction. (Linearization)

The transfer curve $v_O(v_I)$ is linearized.

Applying negative feedback around an OpAmp - which may have a nonlinear transfer curve - but with a large a (which will make T large) - makes A stay linear even though a is not. $\triangleq$ linearizing effect.

c) Some noise (depending where it emerges) is attenuated.

d) Input / Output resistances.