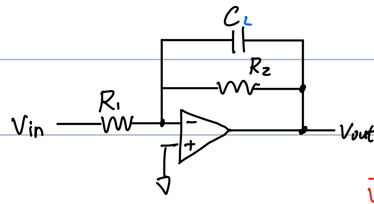
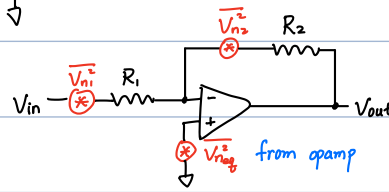
Analysis P/M ! +/− feedback !

Design DOF $\overset{typ.}{>>}$ # constraints



E. $\frac{V_o}{V_i} = -\frac{R_2}{R_1}\frac{1}{1+sC_LR_2}$

$f_{LP} = \frac{1}{2\pi R_2 C_L}$ R need ↓



Noise (*) R generate thermal noise $\overline{V_n^2} = 4kTR\Delta f$ → bw

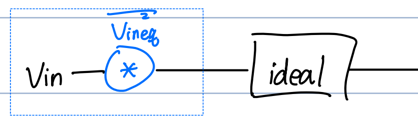
Q: thermal → $\overline{V_{neq}^2} \sim \Delta f$ + ~~flicker $\sim \frac{1}{f}$~~

$\overline{V_{out}^2} = \overline{V_{n1}^2}\left(\frac{R_2}{R_1}\right)^2 + \overline{V_{n2}^2} + \overline{V_{neq}^2}\left(1+\frac{R_2}{R_1}\right)^2$

$\overline{V_{out}^2} = 4kT\Delta f(R_1G^2+R_2) + \overline{V_{neq}^2}(1+G)^2$

Vin ↓

$\overline{V_{ineq}^2} = \frac{\overline{V_{out}^2}}{G^2} \doteq 4kTR_1\Delta f\left(1+\frac{1}{G}\right) + \overline{V_{neq}^2}\left(1+\frac{1}{G}\right)^2$



∴ need $V_{in} > \overline{V_{ineq}^2}$; R↓, Δf↓

Δf↓ → want perfectly enclose signal when filtering → C_2↑

∴ Z↓ (R and C), C↑ → $\overline{V_{out}^2}$↓ → power↑

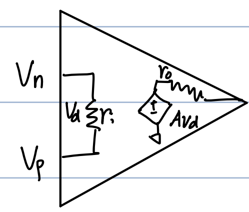
if need $G\overset{\times 2}{\uparrow}$, $R_2\overset{\times 2}{\uparrow}$, $C\overset{\times 1/2}{\downarrow}$, $\overline{V_{out}^2}\overset{\times 2^2}{\uparrow}$, $SNR = \frac{(GV_{in})^2}{\overline{V_{out}^2}}$ = same (if $G>>1$)

single-ended vs. differential ($v_d(t) = V_1(t) - V_2(t)$)

Opamp ⊂ amplifier

volt $A_v \doteq A_{oc}\left(\frac{R_i}{R_i+R_s}\right)\left(\frac{R_L}{R_L+R_o}\right)$

Assume unilateral : $i \cancel{\rightleftarrows} 0$; but actually bilateral → 2-port model

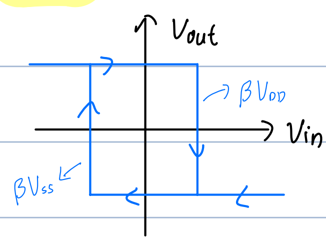


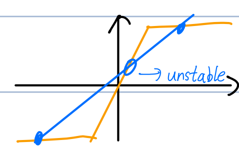
ni find intersection of load line (V_{out} vs $V_p - V_N$)

positive feedback → Schmitt trigger

$V_p - V_N = \frac{R_1}{R_2+R_1}V_{out} - V_{in}$

$\equiv +\beta V_{out} - V_{in}$

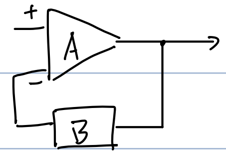




when $V_{in} > 0$, but $V_+ > V_{in} > 0$

need $V_{in} > V_+ = \beta V_{DD}$ to switch

Feedback



$G = \frac{V_o}{V_i} = \frac{A}{1+A\beta}$

$= \frac{1}{\beta}\frac{T}{1+T}$ → error factor $T \equiv A\beta$ (loop gain)

$\approx \frac{1}{\beta}$ if $T \gg 1$

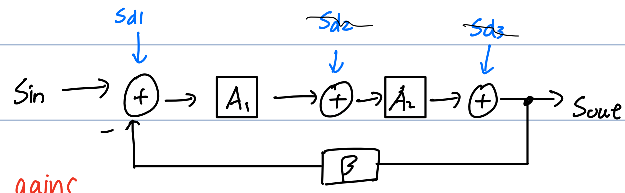
gain → control

(R easier to control than opamp A)

Desensitivity $\frac{\Delta G}{G} = \cancel{\frac{1}{1+T}\frac{\Delta A}{A}}$ but $\approx \frac{\Delta \beta}{\beta}$

E. $S_{out} = \frac{A}{1+\beta A}\left(S_{in} + S_{d1} + \cancel{\frac{S_{d2}}{A_1}} + \cancel{\frac{S_{d3}}{A_1A_2}}\right)$

↳ better bw   ↳ attenuated by preceding gains



Analysis 1. find if feedback

a. find feedback type (V/I?)

b. +/− feedback?

c. find fwd path & back network

d. find the right two-port eq. for the network

type:

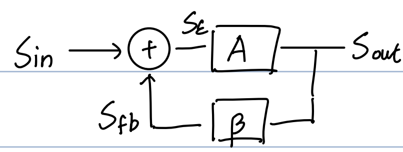
i/o	v	i
	(aka II)	
v	series-shunt	sr-sr
i	sh-sh	sh-sr

E.ni $S_{in} = V_{in}$ → series measure

$S_{out} = V_{out}$ → shunt measure

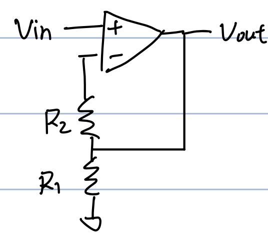
$S_{fb} = V_- = \underbrace{\frac{R_1}{R_1+R_2}}_{\beta} V_{out}$

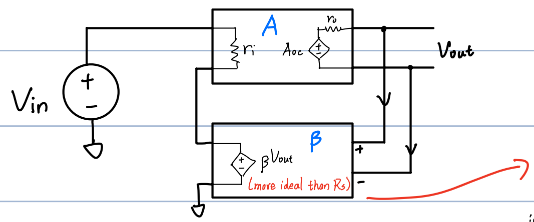
$S_\varepsilon = S_{in} - S_{fb} = V_+ - V_-$



$\frac{S_{out}}{S_{in}} = \frac{A}{1+\beta A}$

$\frac{S_\varepsilon}{S_{in}} = \frac{1}{1+\beta A}$

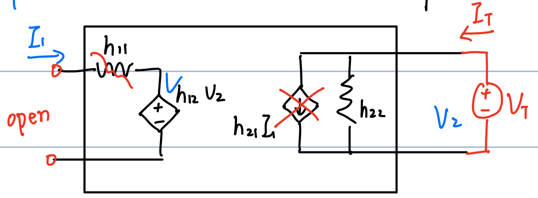


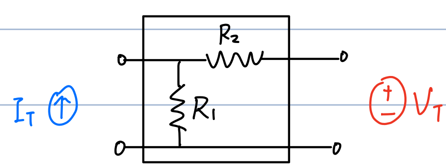


Need Th eq. circuit w/ a VCVS

indep. VC → CS in ; dep. VS → VS out

Two-port   Test w/ other indep. src.



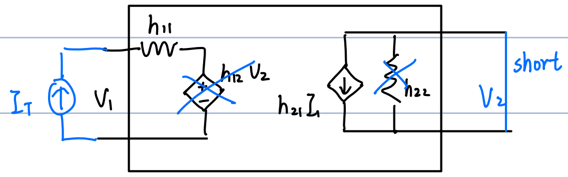


$$\begin{cases} V_1 \equiv h_{11} I_1 + h_{12} V_2 \\ I_2 \equiv h_{21} I_1 + h_{22} V_2 = \frac{V_{out}}{R_1+R_2} \end{cases}$$

$R_T = \frac{V_T}{R_T} = h_{22} = R_1 + R_2 = h_{22}$

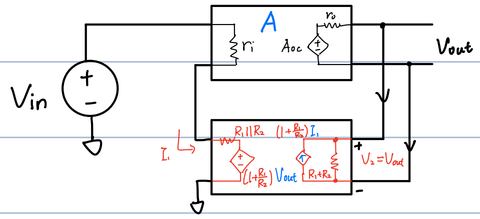
$V_1 = V_T \frac{R_1}{R_1+R_2} = h_{12} V_T$

$h_{12} = \frac{R_1}{R_1+R_2}$

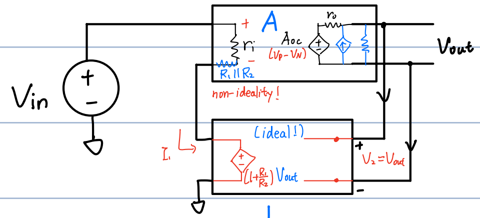


$V_1 = I_{test}\, h_{11} = I_{test}\,(R_1 \| R_2) \rightarrow h_{11} = \frac{R_1 R_2}{R_1+R_2}$

$I_2 = h_{21}\, I_T = -\frac{R_1}{R_1+R_2} I_T \rightarrow h_{21} = -\frac{R_1}{R_1+R_2}$



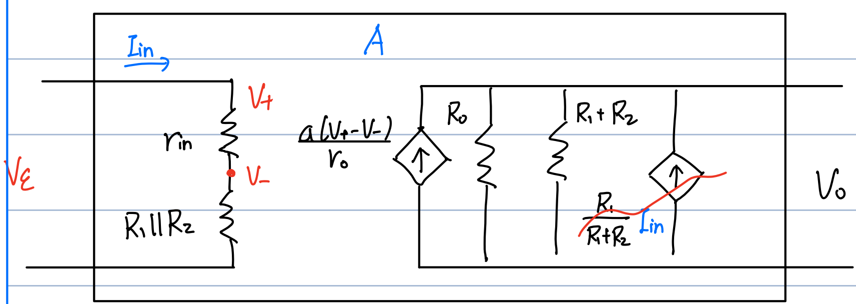
V_{fb} is only output!



if $r_i >> (R_1 \| R_2)$, input loaded

The $(1+\frac{R_1}{R_2})I_1$ suggest feedforward

↳ just β now



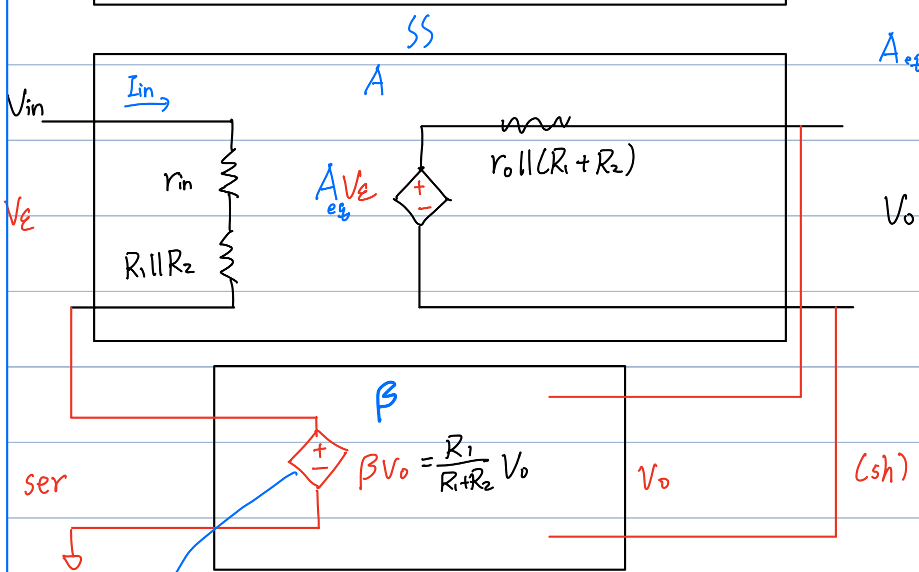
$I_{in} = \frac{V_\varepsilon}{r_{in}+R_1\|R_2}$ $\quad V_P - V_N = \frac{r_{in}}{r_{in}+R_1\|R_2} V_\varepsilon$

$A_{eq} = \frac{V_o}{V_\varepsilon} = \frac{1}{V_\varepsilon}\left(\frac{a(V_P-V_N)}{r_o} + \cancel{\frac{R_1}{R_1+R_2} I_{in}}\right)(R_o \| (R_1+R_2))$

$= \left[\frac{a\, r_{in}/r_o}{r_{in}+R_1\|R_2} + \cancel{\frac{R_1}{R_1+R_2} \cdot \frac{1}{r_{in}+R_1\|R_2}}\right](r_o \| (R_1+R_2))$

since $a\frac{r_{in}}{r_o}$ large!

$A_{eq} \approx a$ if $r_{in} \rightarrow \infty$, $r_o \rightarrow 0$.



$V_o = A_{eq} V_\varepsilon$, hiding $(V_P - V_N)$

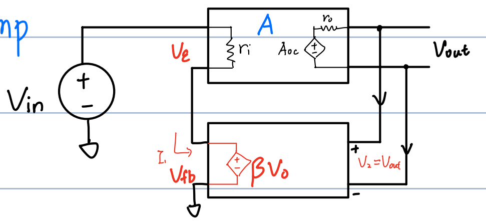
$\beta = \frac{V_{fb}}{V_o} = \frac{R_1}{R_1+R_2}$

Open loop gain $= \frac{V_o}{V_{in}}\Big|_{V_{fb}=0} = A_{eq} \approx a \frac{r_{in}}{r_{in}+(R_1\|R_2)} \frac{R_1+R_2}{r_o+R_1+R_2}$

Loop gain $= A_{eq}\,\beta$

Closed loop gain $= \frac{V_o}{V_{in}} = \frac{A_{eq}}{1+A_{eq}\beta} \rightarrow \frac{1}{\beta}$

Imp



$G = \frac{V_{out}}{V_{in}}$: closed loop gain

assume small g_{12} (unilateral)

shunt (v out measure)

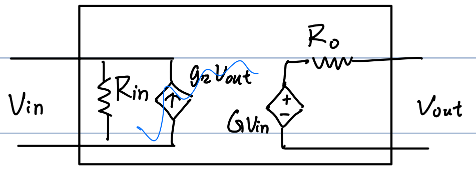
1. V_T (open out) $\quad V_\varepsilon = \frac{V_o}{A_{oc}} = \frac{V_T}{1+\beta A_{oc}}$

$$i_T = \frac{1}{r_{in}} \frac{V_T}{1+\beta A_{oc}} \rightarrow R_{in} = r_{in}(1+\beta A_{oc}) \rightarrow \text{feedback strengthens } R_{in} \quad :)$$

2. V_T (gnd in) $\quad V_\varepsilon = -\beta V_T$

$$i_T = \frac{V_T - A_{oc} V_\varepsilon}{r_o} \quad :)$$

$$= \frac{V_T}{r_o}(1+\beta A_{oc}) \quad \rightarrow R_{out} = \frac{r_{out}}{1+\beta A_{oc}}$$

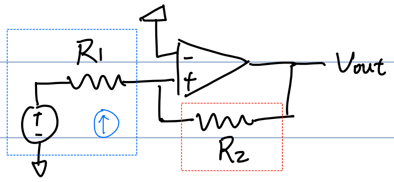


For any feed back network w/ $A\,(+r_i, r_o)$ and β

$$G = \frac{A_{oc}}{1+\beta A_{oc}}$$

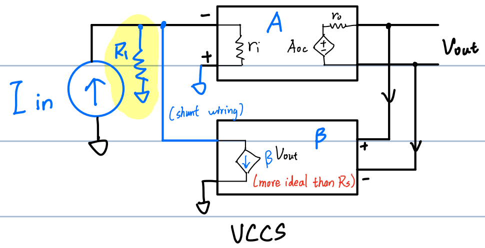
$$\left.\begin{aligned} R_{in} &= R_{in}(1+\beta A_{oc}) \\ R_{out} &= R_{out}(1+\beta A_{oc})^{-1} \end{aligned}\right\} \text{for ser-sh}$$

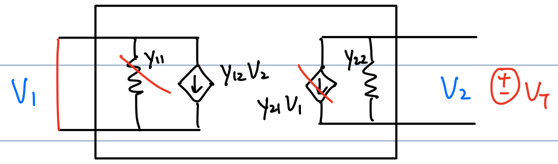
Sh-sh



$S_{out} = V_{out}$ (shunt)

$S_{in} = I_{in}$ (shunt addition of V_{in} and V_{fb}) } sh-sh

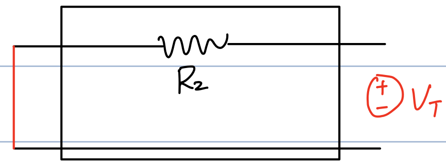


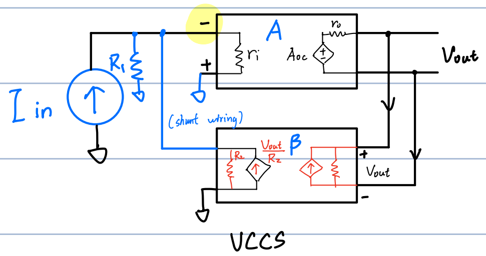


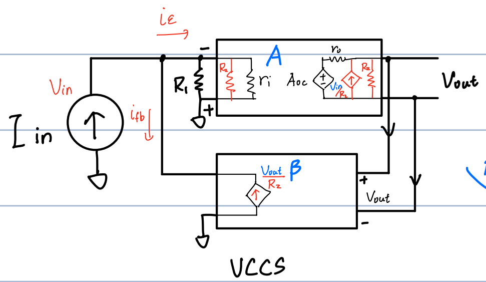
symmetry →

$$y_{12} \overset{\cdots}{=} -\frac{1}{R_2} = y_{21}$$

$$y_{22} = R_2 = y_{11}$$

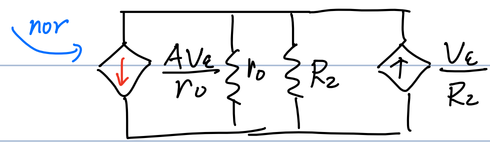






$V_\varepsilon = (R_1 \| R_2 \| R_{in})\, i_\varepsilon$

nor

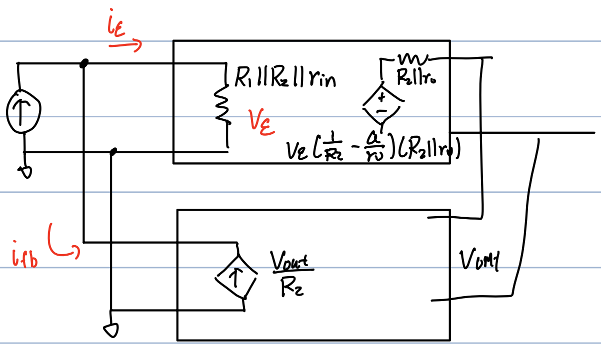


→ $R_{eq} = r_o \| R_2$

Th { $I_{eq} = V_\varepsilon\left(\frac{1}{R_2} - \frac{a}{r_o}\right)$

$V_o = V_\varepsilon\left(\frac{1}{R_2} - \frac{a}{r_o}\right)(r_o \| R_2)$

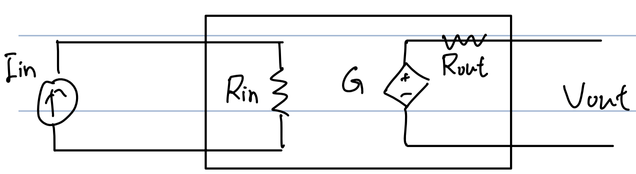
$V_{in} = -V_\varepsilon$



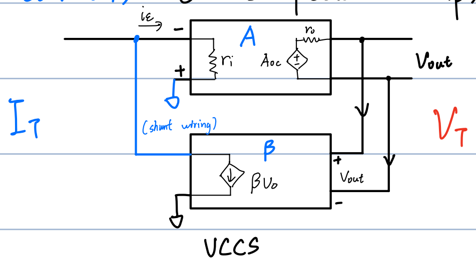
$$A_{eq} = \left(\frac{1}{R_2} - \frac{a}{r_o}\right)(R_2 \| r_o)\,(R_1 \| R_2 \| R_{in})$$

$$\beta = \frac{1}{R_2}$$

$$G = \frac{A_{eq}}{1+\beta A_{eq}}$$



$i \to v$ (sh-sh) (transimpedance amp)



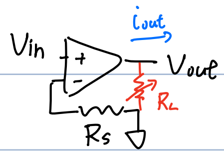
$$R_{in} \doteq \frac{r_{in}}{1+\beta A_{oc}}$$

$$R_{out} \doteq \frac{r_{out}}{1+\beta A_{oc}}$$

Summary 1. identify I/O $\to$ ser/sh

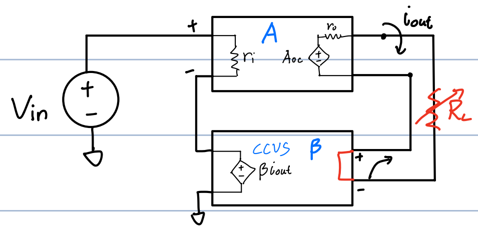
2. draw ideal feedback config.

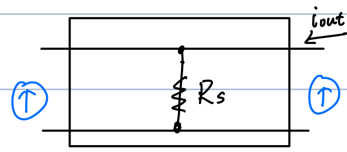
E3. VCCS



ser- ser

assume $V_P = V_N$ ∴ $i_{out} = \frac{V_{in}}{R_s}$ indep. of load R_L (can be E. a diode)





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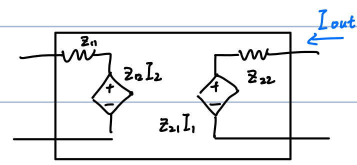
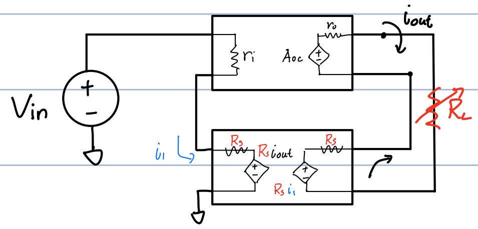
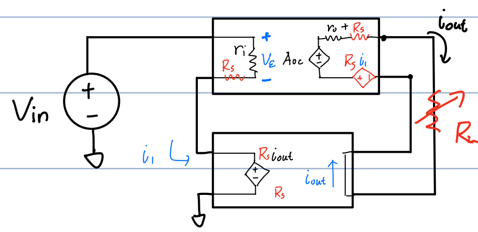


Apply symmetrical I_T $\xrightarrow{\cdots}$ $z_{22} = R_s = z_{11}$

$z_{12} = R_s = z_{21}$





$$i_1 = \frac{V_P - V_N}{r_{in}}$$