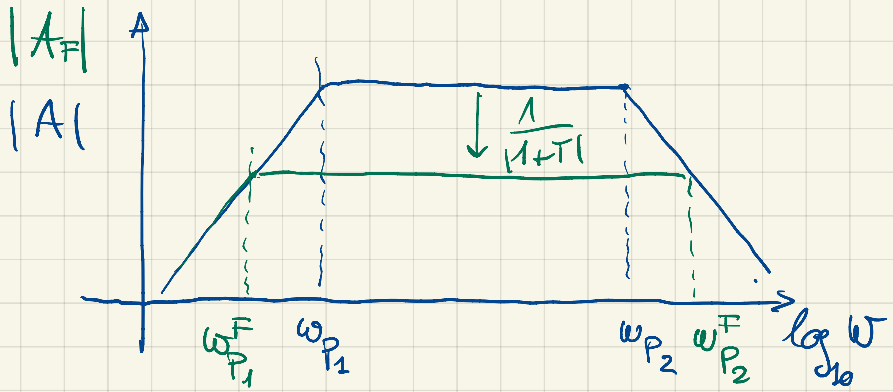
$$A = \frac{A_{MB}}{1+\frac{s}{\omega_p}} \longrightarrow A_F = \frac{\frac{A_{MB}}{1+s/\omega_p}}{1+\frac{\beta A_{MB}}{1+s/\omega_p}}$$

WE CAN RE-ARRANGE $A_F$

$$A_F = \frac{A_{MB}}{1+\beta A_{MB} + s/\omega_p} = \underbrace{\frac{A_{MB}}{1+\beta A_{MB}}}_{A_{FMB}} \cdot \frac{1}{1+\frac{s}{\omega_p(1+\beta A_{MB})}}$$

IF FEEDBACK IS NEGATIVE, THE MID-BAND GAIN DROPS BY A FACTOR $1+T_{MB}$, BUT THE POLE MOVES FURTHER TO THE RIGHT BY THE SAME FACTOR

EXERCISE: VERIFY THE SAME HAPPENS TO A LOW FREQUENCY POLE

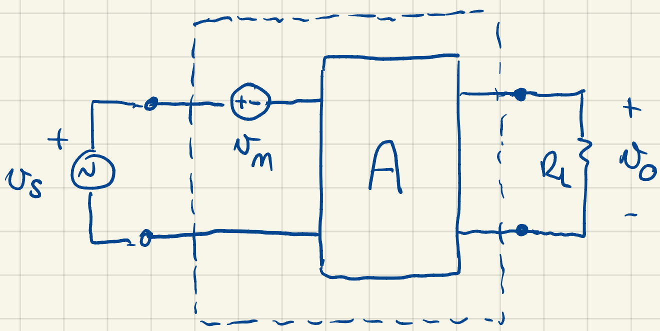



$$\omega^F_{P_2} = \omega_{P_2} |1+T|$$

$$\omega^F_{P_1} = \frac{\omega_{P_1}}{|1+T|}$$

THE FEEDBACK AMPLIFIER BANDWIDTH IS WIDENED WITH RESPECT TO THE ORIGINAL ONE!

## 4. NOISE ATTENUATION

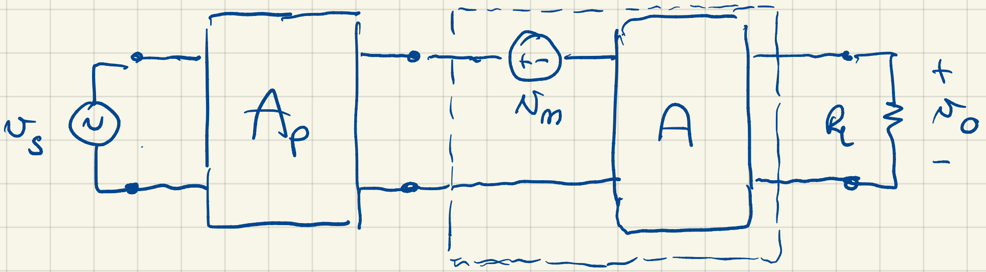



$$v_o = A v_s \pm A v_n$$

$$SNR_o = \frac{A v_s}{A v_n} = \frac{v_s}{v_n} = SNR_i$$

A "NOISY" AMPLIFIER IS REPRESENTED BY AN IDEAL ONE AND A SERIES NOISE VOLTAGE SOURCE.

INTRODUCING A PRE-AMPLIFIER (HIGH GAIN, VERY LOW NOISE)

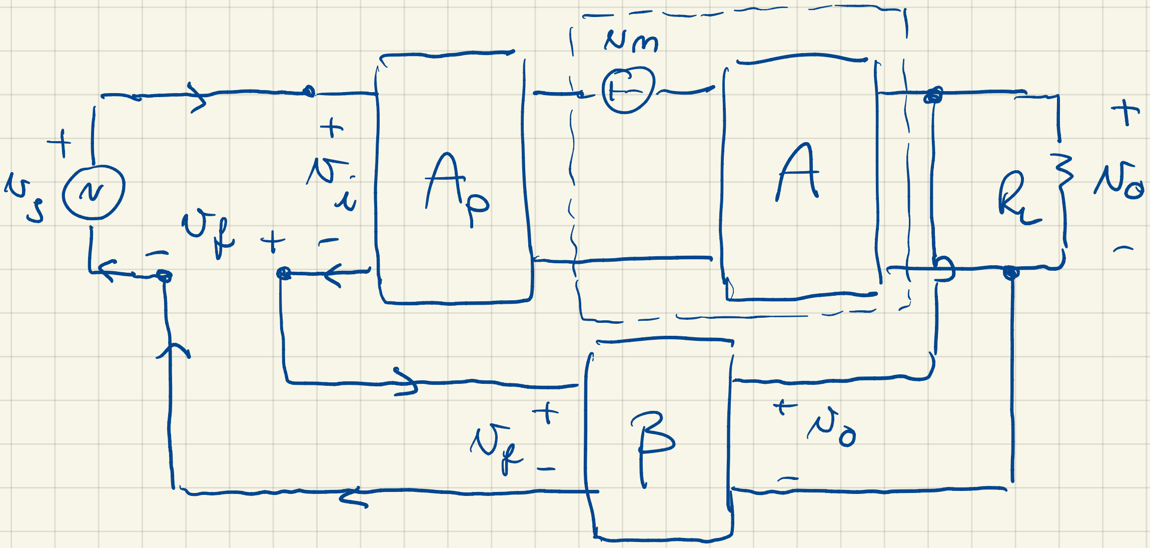



NOW WE FIND $v_o = A_p A v_s + v_m \cdot A$ AND THEREFORE

$$SNR_o = A_p \cdot SNR_i$$

WE HAVE IMPROVED $SNR_o$ BY A FACTOR $A_p$

WE CAN USE FEEDBACK TO KEEP THE SIGNAL GAIN TO A TARGET LEVEL, WHILE BOOSTING THE $SNR_o$




$$v_o = v_s \cdot \frac{A_p A}{1 + \beta A_p A} + v_m \cdot \frac{A}{1 + \beta A_p A}$$

$SNR_o = A_p \, SNR_i$ WE ARE STILL BOOSTING THE SNR!

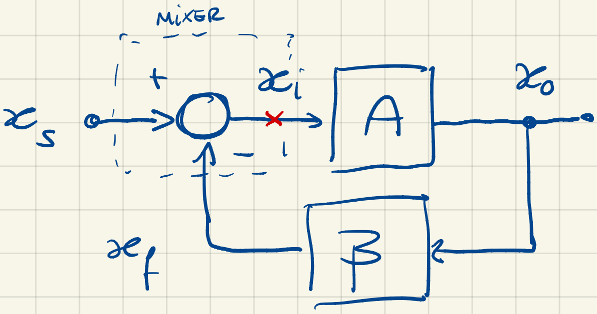
BUT NOW IF $\beta \cdot A_p A \gg 1$

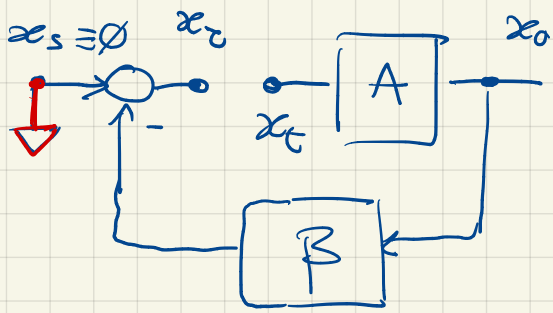
$$A_F = \frac{v_o}{v_s} = \frac{A_p A}{1 + \beta A_p A} \cong \frac{1}{\beta}$$ FREELY ADJUSTABLE!

# ◊ ANALYSIS OF FEEDBACK AMPLIFIERS

WE NEED METHODS TO DERIVE $T$ FROM THE AMPLIFIER CIRCUIT

## #1. DIRECT CIRCUIT INSPECTION




$$x_r = -x_t A\beta = -x_t \cdot T \iff T = -\left.\frac{x_r}{x_t}\right|_{v_s \equiv 0}$$

THIS PROCEDURE HAS AT LEAST TWO ISSUES

1. CUTTING THE LOOP WE CHANGE THE LOADING EFFECTS $\Rightarrow$ $T$ WILL CHANGE.

   ↳ WE NEED SPECIFIC PROCEDURES TO PREVENT THE LOADING EFFECTS FROM CHANGING SIGNIFICANTLY

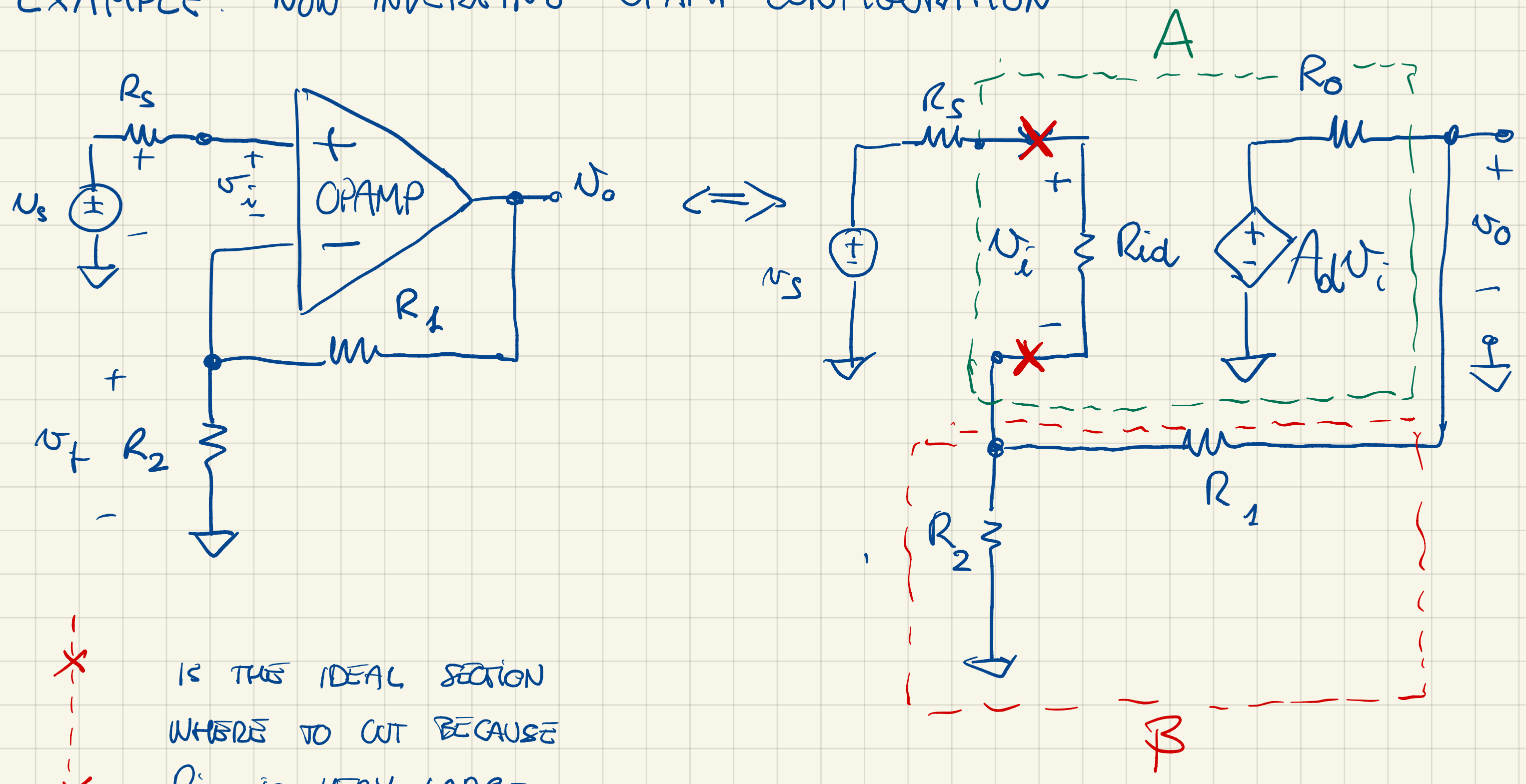
2. THE AMOUNT OF PERTURBATION OF $T$ DEPENDS ON THE CUT LOCATION!

   ↳ WE NEED GUIDELINES TO CHOOSE THE LOCATION OF THE CUT SO THAT PERTURBATION IS MINIMIZED.

3. THIS APPROACH DOES NOT PROVIDE ENOUGH INSIGHT TO ALLOW DESIGNING THE AMPLIFIER. FOR EXAMPLE, NO INFORMATION IS AVAILABLE ON $R_{in}$, $R_{out}$ ....

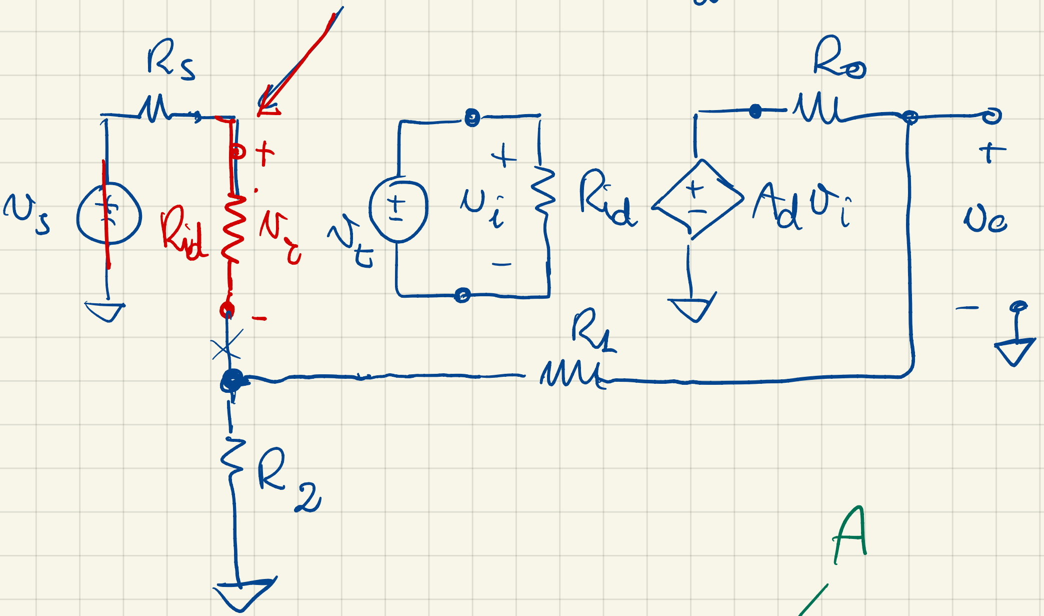
CONCLUSION: THIS APPROACH ONLY WORKS WELL IN SOME PARTICULAR CASES.

EXAMPLE: NON INVERTING OPAMP CONFIGURATION




IS THE IDEAL SECTION WHERE TO CUT BECAUSE $R_{id}$ IS VERY LARGE

THIS "COPY" OF $R_{id}$ IS KEEPING THE LOADING EFFECT UNCHANGED




$$T = -\frac{x_r}{x_t} = -\frac{v_r}{v_t} = +\frac{1}{\cancel{v_t}} \cdot \overset{A}{A_d \cancel{v_t}} \cdot \overbrace{\frac{R_2 /\!/ (R_{id}+R_s)}{R_o + R_1 + R_2 /\!/ (R_{id}+R_s)} \cdot \frac{R_{id}}{R_s + R_{id}}}^{\beta}$$

$$T = A_d \cdot \underbrace{\frac{R_{id}}{R_s + R_{id}}}_{\simeq 1} \cdot \frac{R_2 /\!/ (R_{id}+R_s)}{R_o + R_1 + R_2 /\!/ (R_{id}+R_s)}$$

SUPPOSING THAT $A_d \cdot \beta \gg 1 \implies A_f = \frac{A_d}{1+T} \simeq \frac{1}{\beta}$

NORMALLY $R_s \ll R_{id}$ AND $R_o \ll R_1, R_2$ AND THEREFORE

$$A_F \cong \underbrace{\left(1 + \frac{R_S}{R_{id}}\right)}_{\substack{\cong \\ 1 \quad R_S \ll R_{id}}} \cdot \left(1 + \frac{R_o + R_1}{R_2 /\!/ (R_{id} + R_S)}\right) \cong 1 + \frac{R_1}{R_2} \qquad \blacksquare$$

$$R_2 /\!/ R_{id} \cong R_2$$

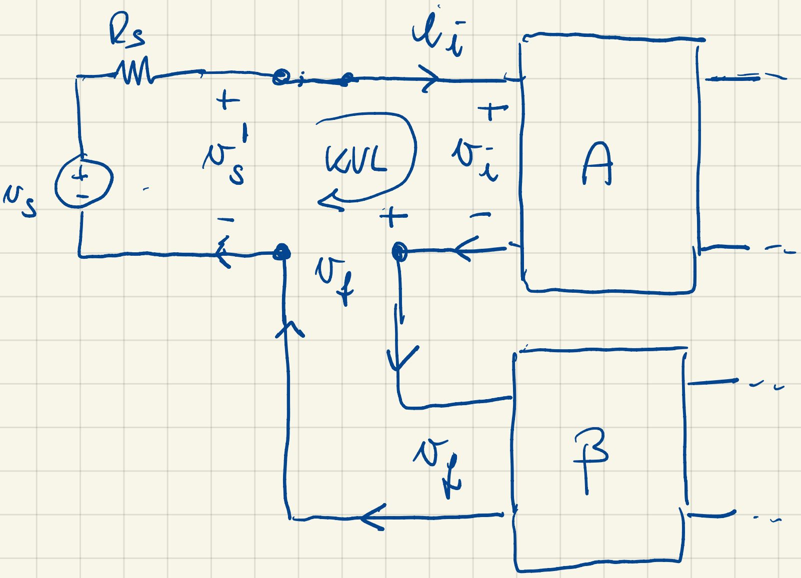
$$R_o + R_1 \cong R_1$$

## #2 GENERALIZED FEEDBACK THEORY FOR ELECTRONIC AMPLIFIERS

OUR APPROACH IN THIS COURSE

THE TOPOLOGY OF THE AMPLIFIER (VOLTAGE, CURRENT, TRANS-RESISTANCE, TRANS-CONDUCTANCE) IS EXACTLY IDENTIFIED BY THE TYPE OF MIXING AND SENSING.

### # SERIES MIXING

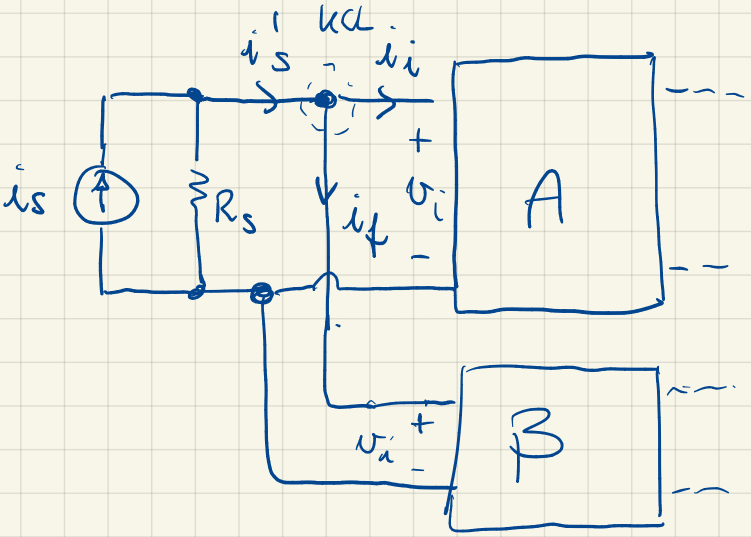



$$v_i = v_s' - v_f$$

IN SERIES MIXING WE HAVE A SINGLE LOOP AT THE INPUT WHERE THE SOURCE VOLTAGE, THE FEEDBACK VOLTAGE AND THE INPUT VOLTAGE ARE RELATED TO ONE ANOTHER BY KVL

EFFECT: $R_{in}^F \gg R_{in}$

### # SHUNT MIXING



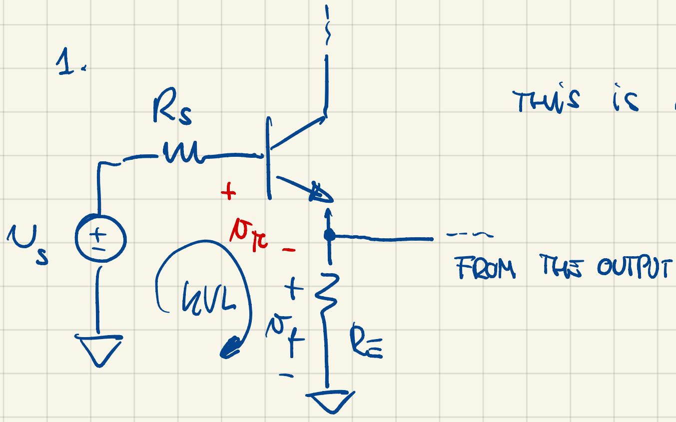

$$i_i = i_s' - i_f$$

A SINGLE NODE AT THE INPUT WHERE THE SOURCE CURRENT, THE FEEDBACK CURRENT AND THE INPUT CURRENT ARE RELATED TO ONE ANOTHER BY KCL

EFFECT: $R_{in}^F \ll R_{in}$

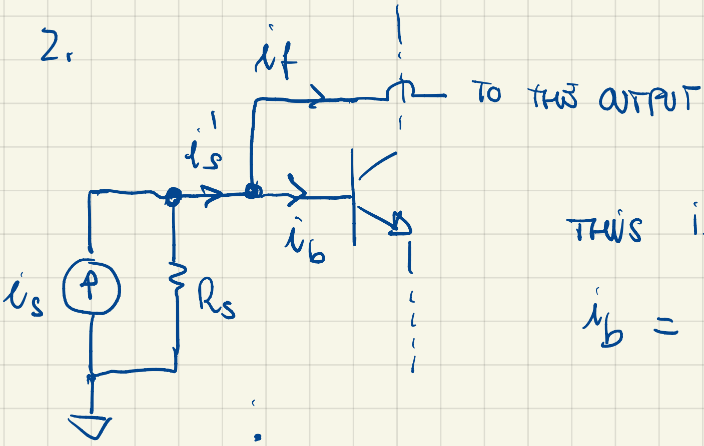
EXAMPLES

1.




THIS IS A CASE OF SERIES MIXING AS $v_\pi \simeq v_S - v_f$

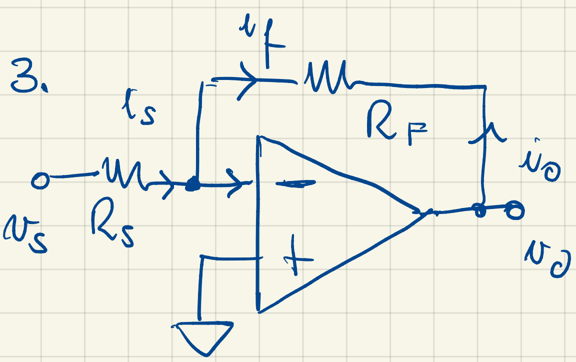
2.




THIS IS A CASE OF SHUNT MIXING AS

$$i_b = i_s' - i_f$$

3.

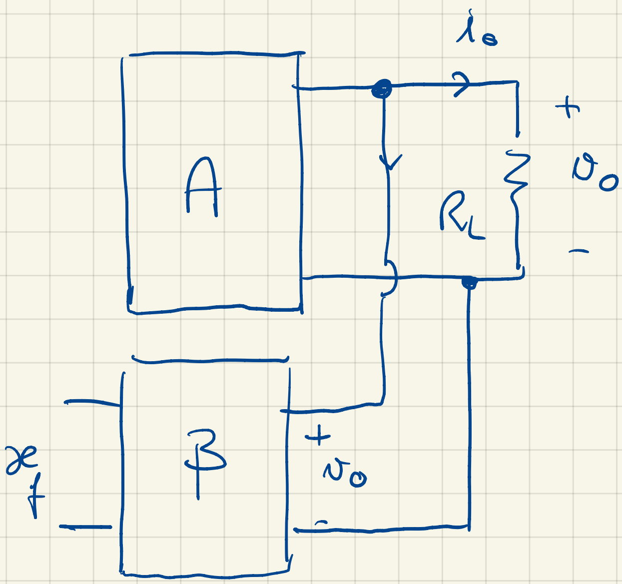



THIS IS ANOTHER CASE OF SHUNT MIXING.

IN THIS CASE $i_f = -i_o = i_s$

SYMMETRICALLY, WE HAVE TWO TYPES OF SENSING, NAMELY

* SHUNT SENSING

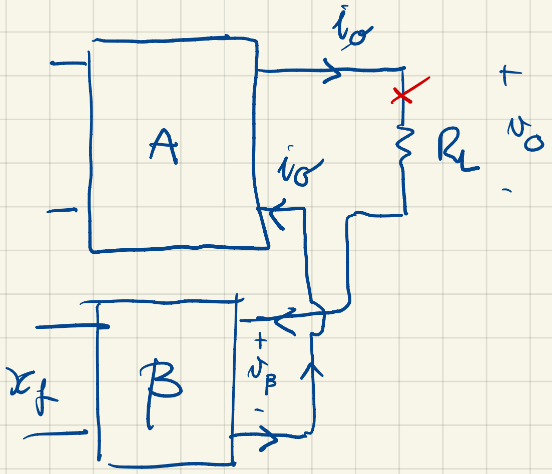



THE B-NETWORK PROBES THE OUTPUT VOLTAGE JUST LIKE A VOLT-METER.

A SIMPLE TEST TO CHECK IF SENSING IS SHUNT TYPE IS TO SHORT $v_o$ : IF NO $x_f$ IS GENERATED, SENSING IS SHUNT.

EFFECT : $R_{out}^F \ll R_{out}$

# SERIES SENSING




IN THIS CASE THE $\beta$-NETWORK SENSES THE LOAD CURRENT $i_o$, LIKE IT WERE AN AMP-METER PLACED IN SERIES WITH THE LOAD

TO VERIFY IF SENSING IS SERIES TYPE, TRY TO CUT THE LOAD CONNECTION. IF $x_f$ IS ZEROED THEN SENSING IS SERIES TYPE.

HERE $R_{out}^{F} >> R_{out}$