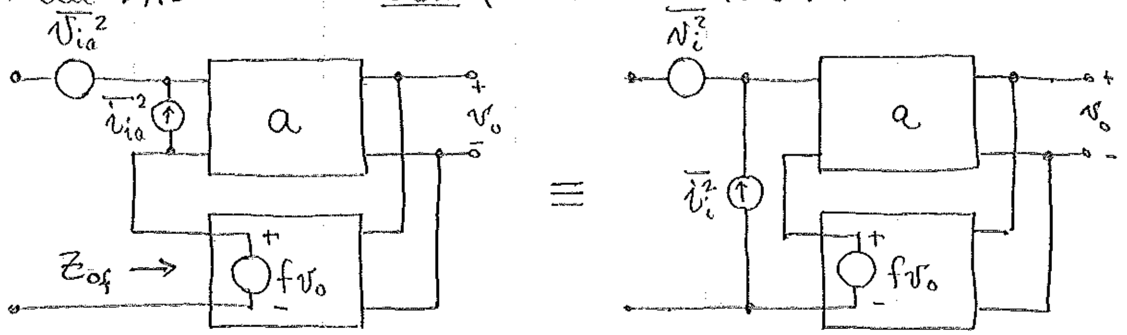
Effect of Feedback on Noise

Consider a series-shunt feedback amplifier and its equivalent circuit. Assume an ideal feedback network.



$\overline{v_{ia}^2}$, $\overline{i_{ia}^2}$ } EIG in basic amplifier

$\overline{v_i^2}$, $\overline{i_i^2}$ } EIG in overall circuit

- To find $\overline{v_i^2}$, short-circuit each input and the output terminals. But considering that for the feedback network $Z_o = 0$

$$\overline{v_i^2} = \overline{v_{ia}^2}$$

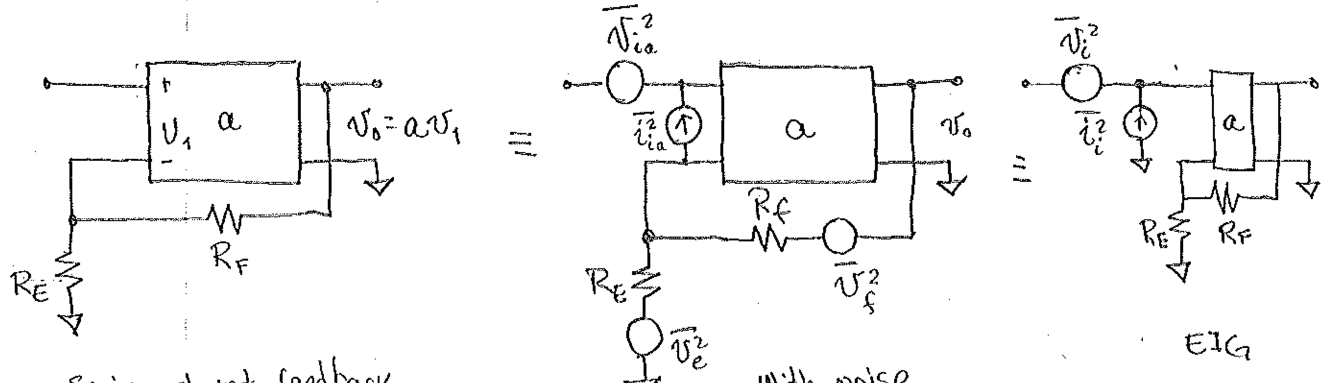
- To find $\overline{i_i^2}$, open-circuit each input and output. Note that

$$\overline{i_i^2} = \overline{i_{ia}^2}$$

This implies that in the case of IDEAL FEEDBACK the input noise generators can be moved unchanged outside the feedback loop and the feedback loop has NO EFFECT on the circuit noise performance.

On the output, feedback reduces the circuit gain, therefore reducing noise in the same proportion as the signal. This leaves the signal-to-noise ratio unchanged.

- Practical Considerations: Consider a resistive divider feedback loop.



Series shunt feedback — With noise sources — EIG

Computing $\overline{v_i^2}$ (short-circuit inputs and equate)

CKT W/N.S.
$$v_o = v_{ia}\frac{R_f}{R_f+R_e} + i_{ia}\frac{R_F R_E}{R_F+R_E} + \frac{R_F}{R_F+R_E}v_e + \frac{R_E}{R_F+R_E}v_f$$

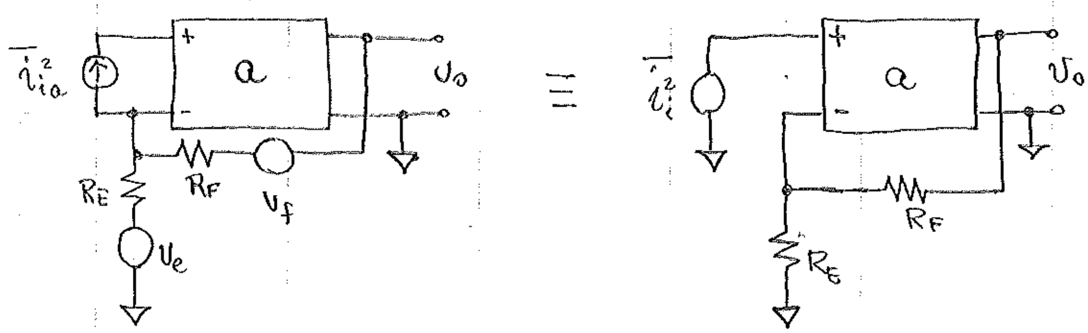
(Resolve the circuit)

... Making $R = R_F \| R_E$ and adding the thermal contributions

$$\overline{v_i^2} = \overline{v_{ia}^2} + \overline{i_{ia}^2}R^2 + 4KTR$$

- $4KTR$ — Thermal noise of $R_E \| R_F$
- $\overline{i_{ia}^2}R^2$ — Usually negligible
- $\overline{v_{ia}^2}$ — Amplifier noise

Computing $\overline{i_i^2}$ (Open ckt inputs and equate)



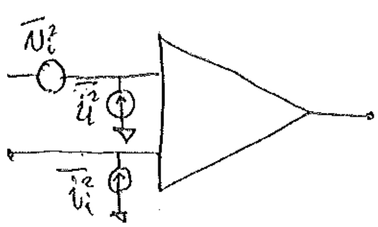
$$i_{ia} = i_i$$

v_e and v_f are not amplified in this case and the contribution of the current source is the same in both cases.

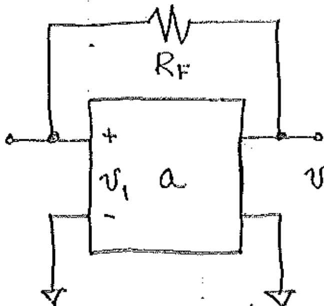
Thus, the input noise current is unaffected by the presence of feedback.

- Also applies for any series feedback at input.
  $R_F \to \infty \Rightarrow R \Rightarrow R_E$

OpAmps are considered 3-port devices and use a different circuit.

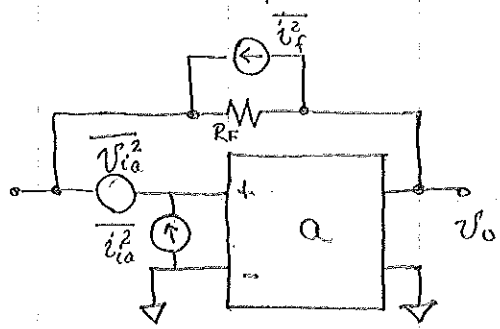


As a second practical case, consider a shunt-shunt feedback

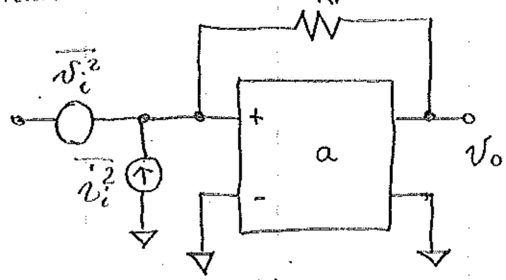


Basic circuit

$\equiv$



Circuit with noise sources



Circuit wit EIG

Finding i_i: Open-ckt input and solve for v_o & equate

$$v_{o1} = i_{ia} R_F \qquad v_{o2} = v_{ia} \qquad v_{o3} = i_f R_F \qquad \text{In ckt 3: } v_o = i_i R_F$$

Thus $\quad i_i R_F = i_{ia} R_F + v_{ia} + i_F R_F \quad \therefore \quad i_i = i_{ia} + \dfrac{v_{ia}}{R_F} + i_F$

Assuming independence:

$$\overline{i_i^2} = \overline{i_{ia}^2} + \frac{\overline{v_{ia}^2}}{R_F^2} + 4KT\frac{1}{R_F}$$

- $\overline{i_{ia}^2}$ ← Amplifier current noise
- $\overline{v_{ia}^2}/R_F^2$ ← Attenuated amplifier noise (negligible)
- $4KT\frac{1}{R_F}$ ← Thermal noise in R_F

Finding v_i: Short-ckt input and solve for v_o & equate:

Note that all current sources are shorted and $\overline{v_i^2} = \overline{v_{ia}^2}$

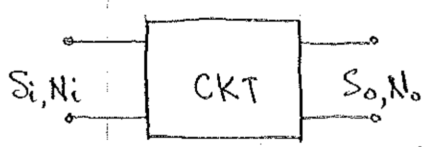
- In this case, the feedback has no effect on the voltage input noise.
- This second case readily applies to op-amps, because connecting one input to GND makes op-amp a two-port device
- When analyzing a BJT, these results justify ignoring C_μ ⇒ Behaves as shunt feedback and has no thermal noise component. The second term would become $\overline{v_{ia}^2}/|Z_F|^2$ with Z_F the impedance of C_μ, very large at practical frequencies, justifying the term as negligible

<u>Noise Figure</u>: Specifies noise performance in ckt. or device.

- Usage limited to circuits with resistive source impedance

Noise figure: $F = \frac{\text{input SNR}}{\text{output SNR}}$ in dB $(10 \log_{10})$

- F measures the SNR degradation caused by the circuit



If for example $SNR_i = 50dB$ and $F = 5dB$ then $SNR_o = 45dB$

Assume S & N represent the signal & noise power in a ckt.

$$F = \frac{S_i}{N_i} \cdot \frac{N_o}{S_o} \quad **$$

Assuming an ideal noiseless amplifier, all noise will come from the source resistance @ input. If the amplifier has gain G

$$S_o = G S_i \quad \text{and} \quad N_o = G N_i \Rightarrow F = 1 = 0dB$$

However, decomposing F as in **, $F = \frac{N_o}{G N_i}$ resulting

$$F = \frac{\text{Total output noise}}{\text{Output noise due to source resistance}}$$

F is specified for a small bandwidth around some $f \gg \Delta f$: Spot noise figure

<u>Noise Temperature</u>: (T_n)

The temperature at which the source resistance R_s must be held such that the noise output in the circuit due to R_s equals the noise output due to the complete circuit.

- Useful for noise measures in very-low-noise amplifiers where $F \cong 1$