Exercise 05: Feedback Analysis and simulation

<Advanced Analogue Building Blocks>

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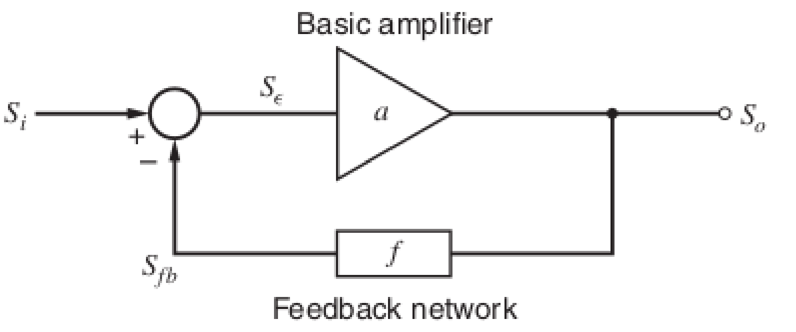
Contents

- A short review of feedback loop-gain
- Return ratio analysis for feedback loop
- Exercise:
  - Analysis of a capacitive-feedback amplifier
  - “stb” simulation in virtuoso

Overview of feedback

- Basic diagram of negative feedback
  - Loop-gain (***T***), closed-loop gain (***A***), …
  - Stability: phase margin, gain margin,...



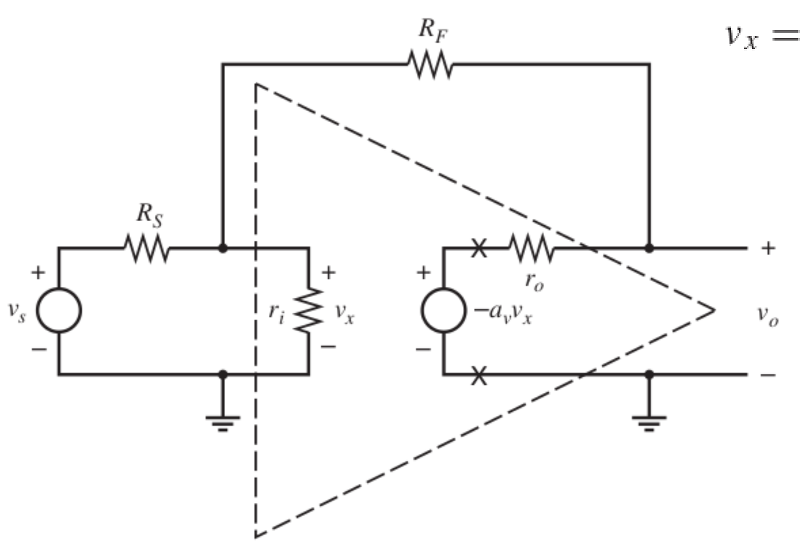
$$\frac{S_o}{S_i} = A = \frac{a}{1+af} \qquad T = af$$

- it's not straight-forward to get the feedback diagram
  - Load effect from the feedback loop
  - Forward feedback by the feedback loop, …
- How to analysis a feedback loop?
  - Two-port network analysis
  - **Return ratio** methods
- Simulation: "**stb**" in Spectre

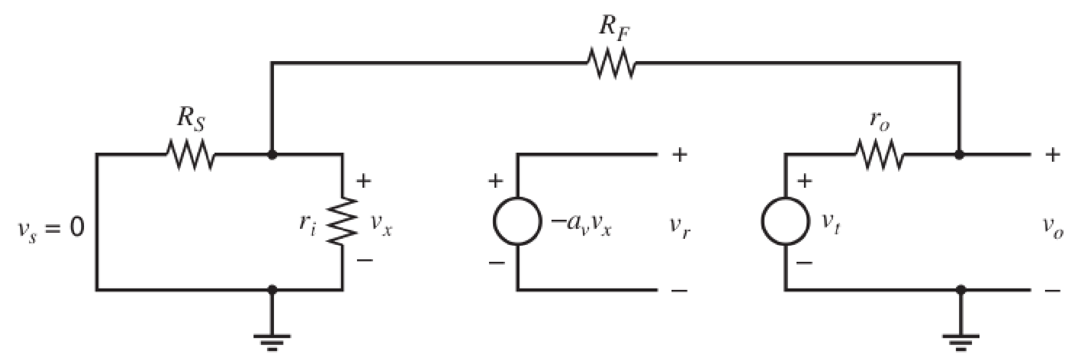
Return ratio

- Procedure for analysis **loop-gain** using return-ratio method
  - Set all independent sources to zero
  - Disconnect the dependent source from the rest of the circuit, which introduces a break in the feedback loop
  - On the side of the break that is not connected to the dependent source, connect an independent test source ***S***S_t of the same sign and type as the dependent source
  - Find the return signal S_r generated by the dependent source.

$$T=-\frac{S_r}{S_t}$$



$$v_x = \frac{R_S||r_i}{R_S||r_i + R_F + r_o} v_t \qquad v_r = -a_v v_x \qquad \mathscr{R} = -\frac{v_r}{v_t} = \frac{R_S||r_i}{R_S||r_i + R_F + r_o} a_v$$



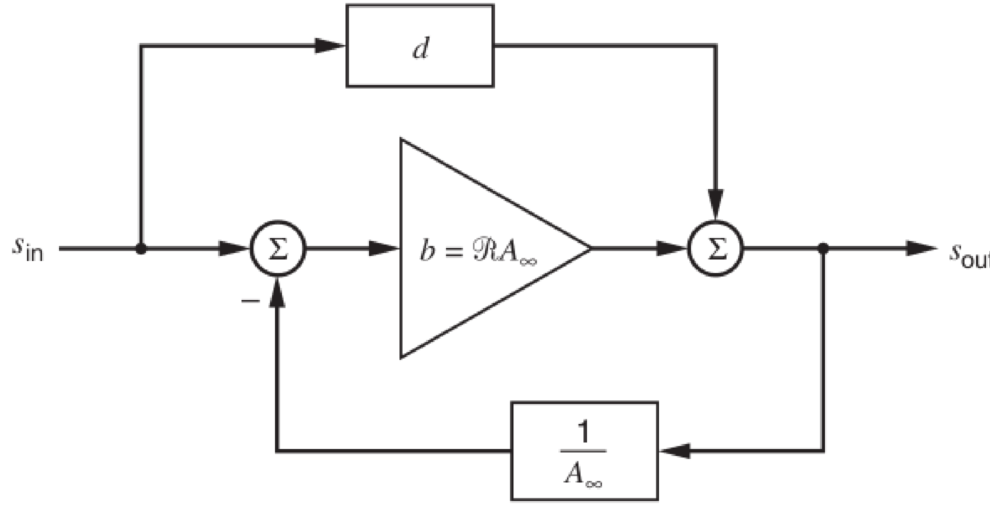
[P. R. Gray, Analysis and design of analog integrated circuits, 5th edition]

Return ratio

- Analysis of **closed-loop gain** using return ratio method

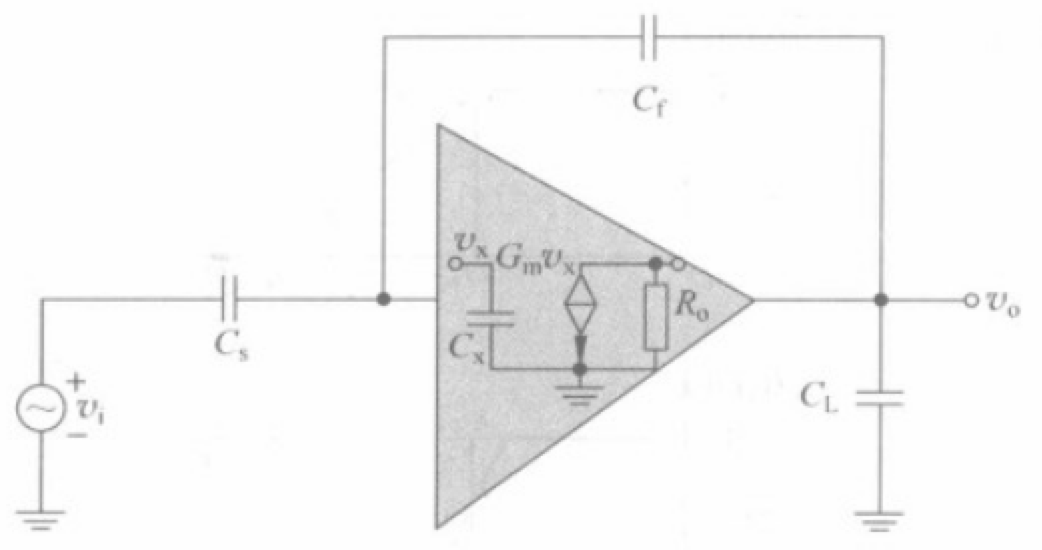
$$A(s) = A_\infty \frac{T(s)}{1+T(s)} + \frac{d(s)}{1+T(s)}$$

- Very tedious to get this formula
  - A_{oo}: ideal closed-loop gain (idea amplifier, or set the coefficient of a dependent source to be infinity, and calculate the V_o/V_i)
  - d(s): gain of direct feed-through (set the coefficient of a dependent source to be zero, and calculate the V_o/V_i)



Exercise: analysis

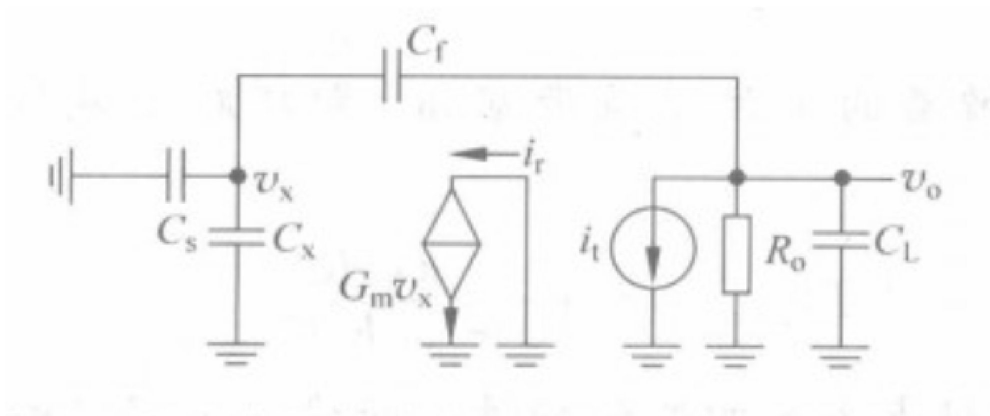
- Capacitive-feedback amplifier with OTA used
  - Loop-gain
  - Closed-loop gain



Exercise: analysis loop-gain

- Derive Loop-gain expression ***T(s)***
- Draw the bode-plot, calculate the bandwidth, unity gain-bandwidth
- Estimate the phase margin

Exercise: analysis loop-gain



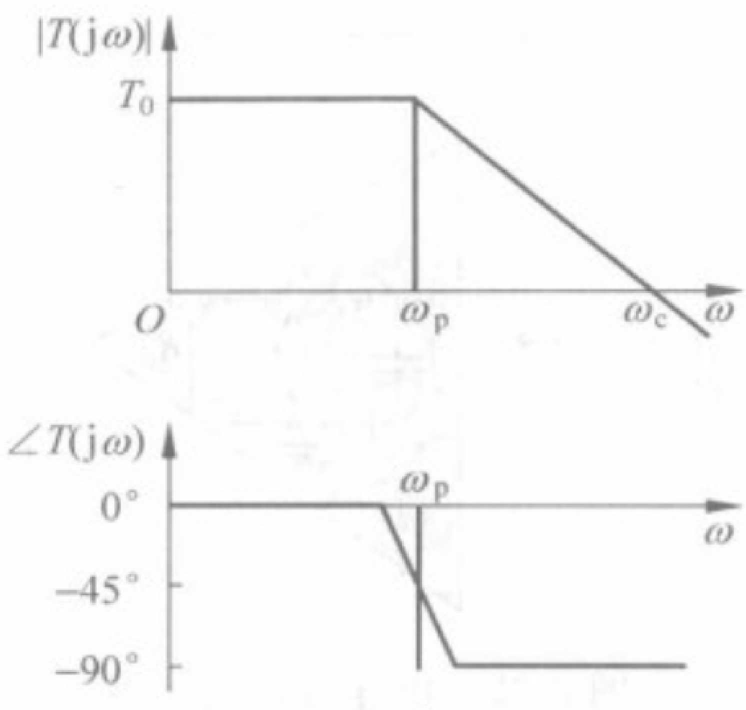
$$v_x = \frac{C_f}{C_f + C_s + C_x} v_o = \beta v_o$$

$$\beta = \frac{C_f}{C_f + C_s + C_x}$$ Feedback ratio

$$v_o = -i_t \left(R_o \| \frac{1}{sC_{L,tot}}\right)$$

Effective loading $$C_{L,tot} = C_L + (1-\beta) C_f$$ Loading effect of feedback loop

$$i_r = -i_t \left(R_o \| \frac{1}{sC_{L,tot}}\right) G_m \beta$$

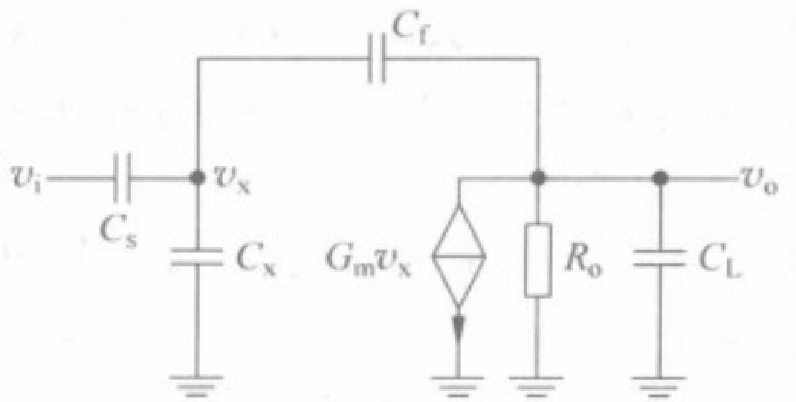


$$T(s) = -\frac{i_r}{i_t} = \frac{\beta G_m R_o}{1 + sR_o C_{L,tot}}$$

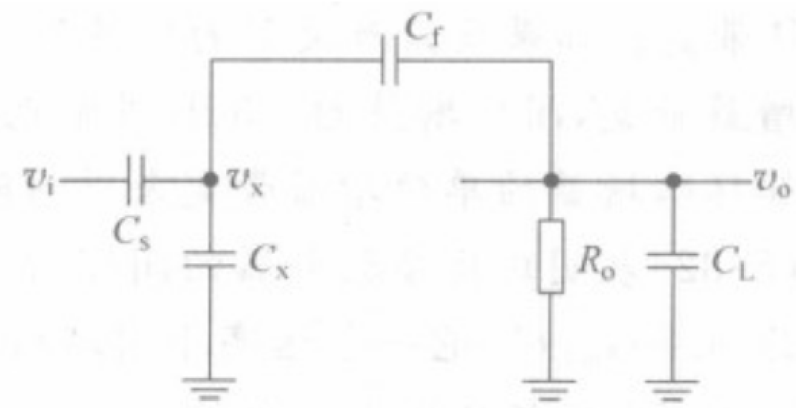
$$T_0 = \beta G_m R_o,\ \omega_p = \frac{1}{R_o C_{L,tot}},\ \omega_c = T_0 \omega_p,\ PM \approx 90$$

Exercise: analysis closed-loop gain

- Calculate the full expression of ***d(s)*** and A_{oo}
- Simplify ***d(s)*** at frequency much higher than bandwidth of ***T(s)***
- Simplify ***d(s)*** at low frequency and calculate the static gain-error



Small signal circuit



Small signal circuit for calculating *d(s)*

1. In the small signal circuit, set G_m to be infinity to calculate the A_{oo}

$$A_\infty = -\frac{C_s}{C_f}$$

2. In the small signal circuit, set G_m to be 0 to calculate the d*(s)*

$$d = \frac{\left(R_o \parallel \frac{1}{sC_L} + \frac{1}{sC_f}\right) \parallel \frac{1}{sC_x}}{\left(R_o \parallel \frac{1}{sC_L} + \frac{1}{sC_f}\right) \parallel \frac{1}{sC_x} + \frac{1}{sC_s}} \frac{R_o \parallel \frac{1}{sC_L}}{R_o \parallel \frac{1}{sC_L} + \frac{1}{sC_f}}$$

High frequency:

$$d \approx \frac{C_s C_f}{C_f C_L + (C_x + C_s)(C_f + C_L)}$$

$$A(s) = -\frac{C_s}{C_f} \frac{1 - \frac{sC_f}{G_m}}{1 + \frac{sC_{L,tot}}{\beta G_m}}$$

Zero in right half plan?

-3dB bandwidth?

low frequency:

$$d \approx 0 \qquad A_0 = -\frac{C_s}{C_f} \frac{T_0}{1 + T_0}$$

Static gain error:

$$\varepsilon = \frac{A_\infty - A_0}{A_\infty} = \frac{1}{1 + T_0} \approx \frac{1}{T_0}$$

Exercise: simulation

- The **STB** analysis linearizes the circuit about the DC operating poing and computes the loop-gain, gain and phase margins (if the sweep variable is frequency), for a feedback loop and a gain device.
- Refer to the Spectre Simulation Reference for details
- In “Ex05/OTA_LoopGain”, using the stored states, do simulation. Try to understand the simulation result

Try to understand the results if the simulation go beyond your expectation…
I am just too lazy to verify it when I prepare the exercise. Haha~