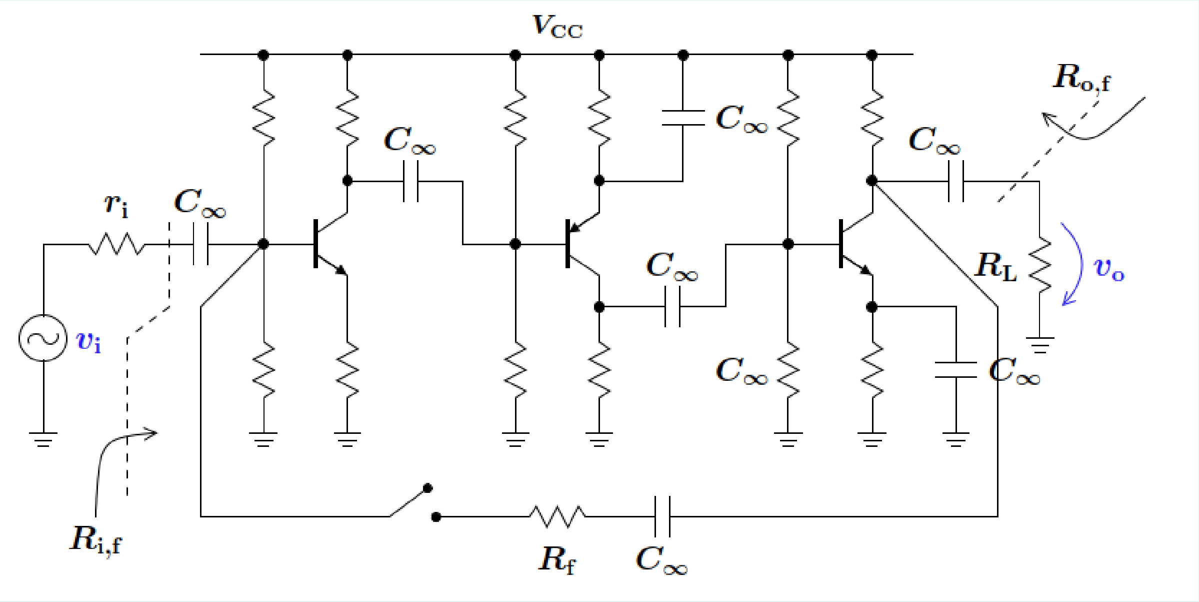
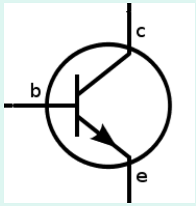
ELEC 301 - Real opamps

L20 - Oct 27

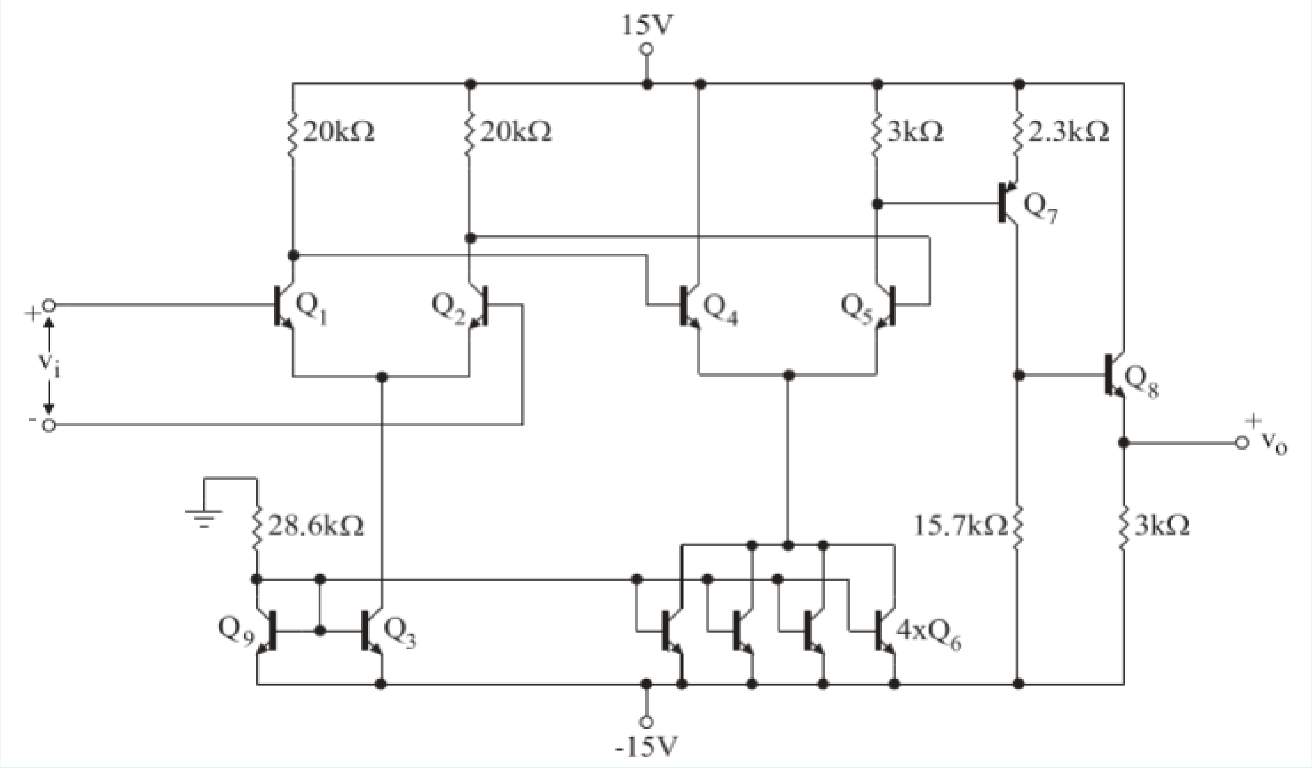
Instructor: Edmond Cretu

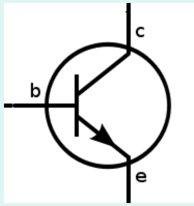




Last time

- Frequency behavior of differential amplifier stage
- Example - analysis of a simple BJT operational amplifier





L20 Q01 opamp

- Why did we use a common-collector configuration for the output stage?

A. Because it has a current amplification

B. Because it has a voltage amplification

C. Because it gives the lowest output resistance

D. Because it gives the highest output resistance

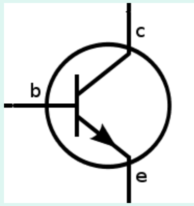
Opamp non-idealities

- A real opamp circuit - measures of imperfections (deviations from the ideal opamp model)
- **Slew-rate** = maximum rate of change of the output waveform
  $SR=(dv_O/dt)_{max}$
- Exm: unity-gain buffer configuration, harmonic input voltage => max input signal slope when sin(ωt)=0

$$\max\left(\frac{dv_i}{dt}\right)\Bigg|_{v_i=V_i\sin\omega t}=\omega V_i\le SR$$

The maximum input frequency that will generate distortions in the output signal:

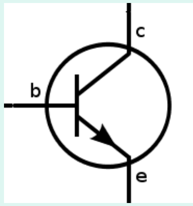
$$\omega_{Max}=\frac{SR}{V_i}$$



Full-power bandwidth

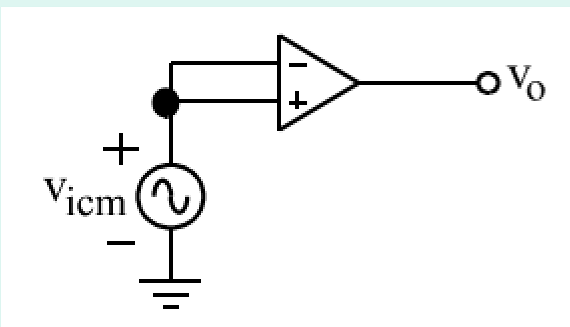
- **Full-power bandwidth** = the bandwidth at which the amplifier can deliver maximum power to the load without distortions, for a given maximum output voltage

$$\omega_m V_{\max} = SR \Rightarrow f_m = \frac{SR}{2\pi V_{\max}}$$



Common-mode rejection ratio

- Only a CM voltage is applied as input - ideally the output $v_o = 0$
- In a real opamp there are both gains for the DM and the CM input voltage (cause: asymmetries in the input stage)



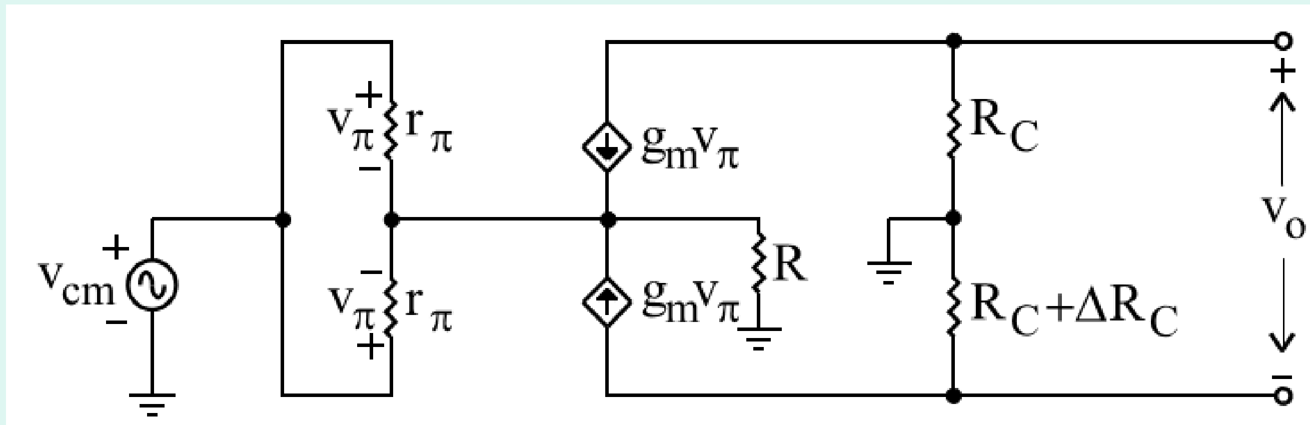
$$\begin{cases} v_+ = v_{icm} + \dfrac{v_{id}}{2} \\ v_- = v_{icm} - \dfrac{v_{id}}{2} \end{cases} \rightarrow \begin{cases} v_{icm} = \dfrac{v_+ + v_-}{2} \\ v_{id} = v_+ - v_- \end{cases} \rightarrow v_o = A_d v_{id} + A_{cm} v_{icm}$$

Common-mode rejection ratio (CMRR):

$$CMRR \overset{def}{=} \frac{|A_d|}{|A_{cm}|} \Leftrightarrow CMRR_{dB} = 20\log\frac{|A_d|}{|A_{cm}|}$$

CM excitation of the differential stage

- Small signal model, R_C asymmetry, equivalent transistors, finite output resistance R of the current source
- Evaluate the CM gain:



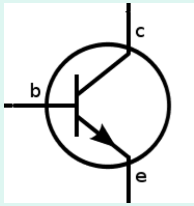
$$v_o = -g_m v_\pi \left[R_C - \left(R_C + \Delta R_C \right) \right]$$

$$v_\pi = \frac{\frac{r_\pi}{2} v_{cm}}{\frac{r_\pi}{2} + R\left(\beta+1\right)}$$

$$v_o = g_m v_{cm} \frac{\Delta R_C}{1 + 2 g_\pi R\left(\beta+1\right)} = v_{cm} \frac{\Delta R_C}{\frac{1}{g_m} + 2R \frac{\beta+1}{r_\pi} \frac{r_\pi}{\beta}}$$

$$v_o \approx \alpha \frac{\Delta R_C}{2R} v_{cm} \Rightarrow A_{cm} \approx \frac{\Delta R_C}{2R}$$

$$CMMR = \frac{|A_d|}{|A_{cm}|} = \frac{g_m R_C}{\frac{\Delta R_C}{2R}} = g_m 2R \frac{R_C}{\Delta R_C}$$

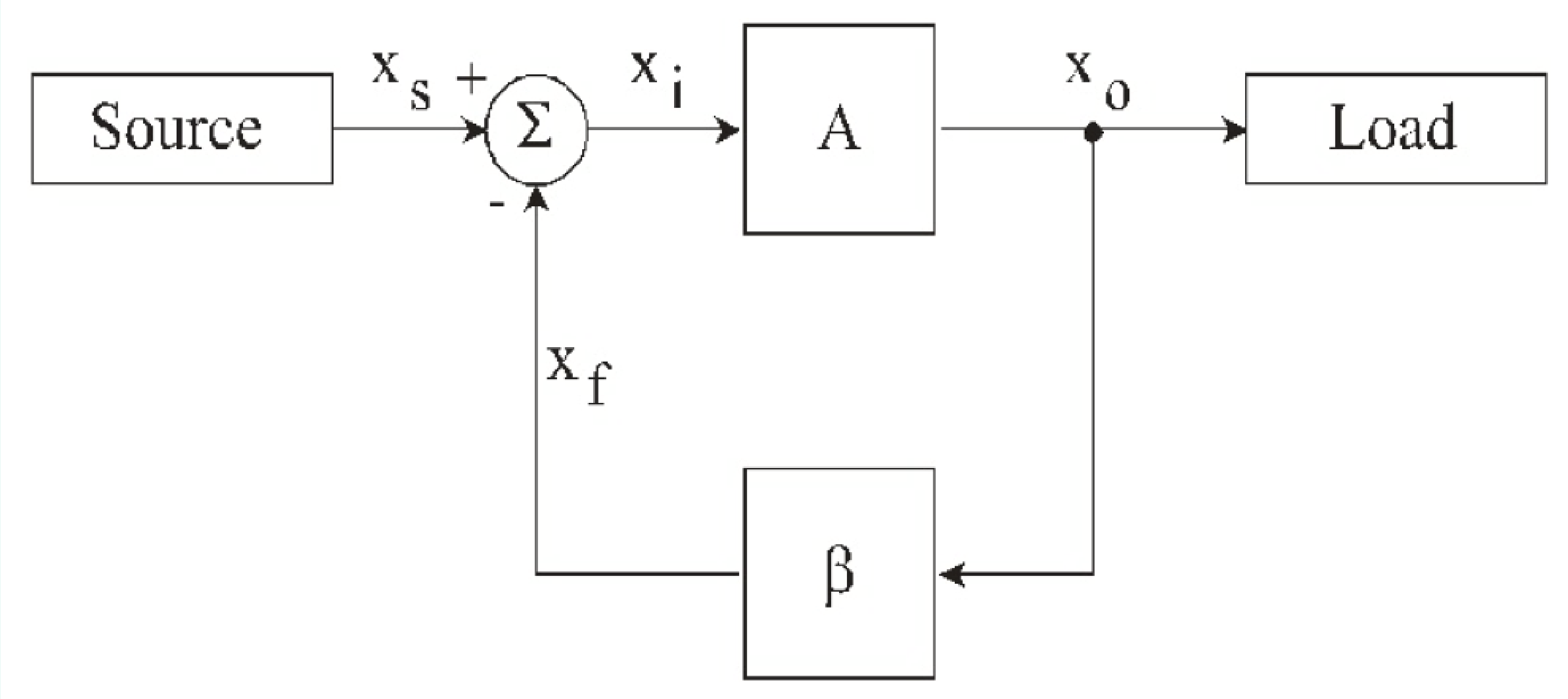


Introduction to feedback networks

- Feedback uses:
  - de-sensitize gain
  - reduced distortion
  - extend bandwidth
  - control input and output impedances
  - increase signal-to-noise ratio
  - (positive feedback) - active oscillators

Information flow perspective

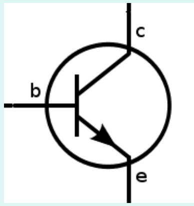
- The signal x_s can be a voltage or a current
- Generic signal flowchart



$$\left.\begin{aligned} x_o &= Ax_i \\ x_f &= \beta x_o \\ x_i &= x_s - x_f \end{aligned}\right\} \Rightarrow A_f = \frac{x_o}{x_s} = \frac{Ax_i}{x_i + x_f} = \frac{A}{1 + A\beta}$$

$A\beta =$ "the loop gain"

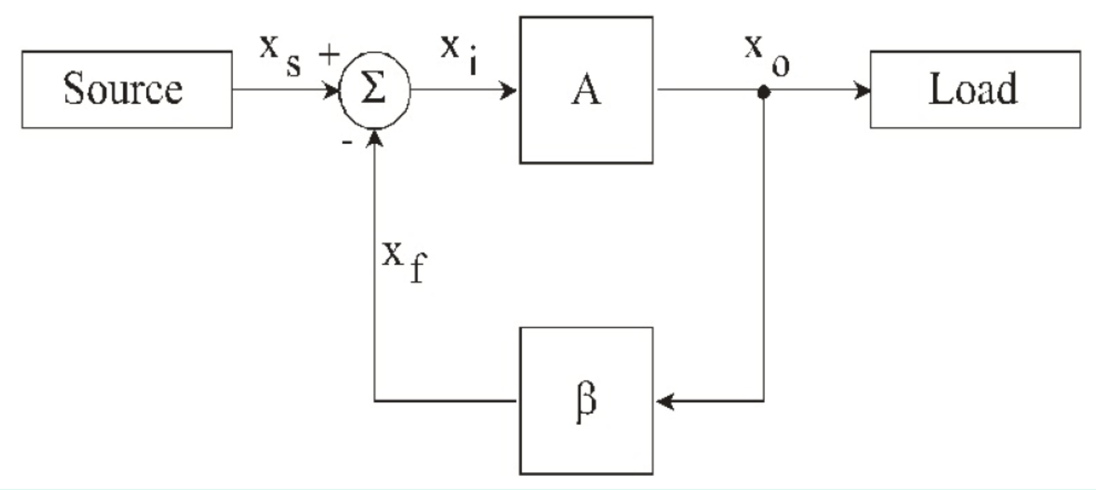
$1 + A\beta =$ "the amount of feedback"



Information flow - negative feedback amplifiers

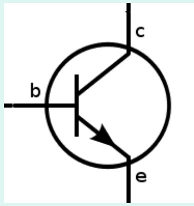
- Usually the loop gain is very large due to A: Aβ>>1=> the gain is the feedback amplifier is entirely determined by the feedback network

$$A_f = \frac{A}{1+A\beta} = \frac{1}{\beta + \frac{1}{A}} = \frac{1}{\beta}\frac{1}{1+\frac{1}{A\beta}} \underset{A\beta\gg1}{\approx} \frac{1}{\beta}\left(1-\frac{1}{A\beta}\right) \approx \frac{1}{\beta}$$



$$x_i = \frac{x_o}{A} = \frac{x_s}{1+A\beta} = \frac{x_s}{A\beta}\frac{1}{1+\frac{1}{A\beta}} \underset{A\beta\gg1}{\approx} 0$$

$$x_f = \beta x_o \underset{A\beta\gg1}{\approx} \beta\frac{x_s}{\beta} = x_s$$


c
b
e