Amplification

Electronique des Systèmes d'Acquisition
ELEC 101

Site web: http://perso.telecom-paristech.fr/jabbour/enseignement/elec101/

Plan

Amplifier

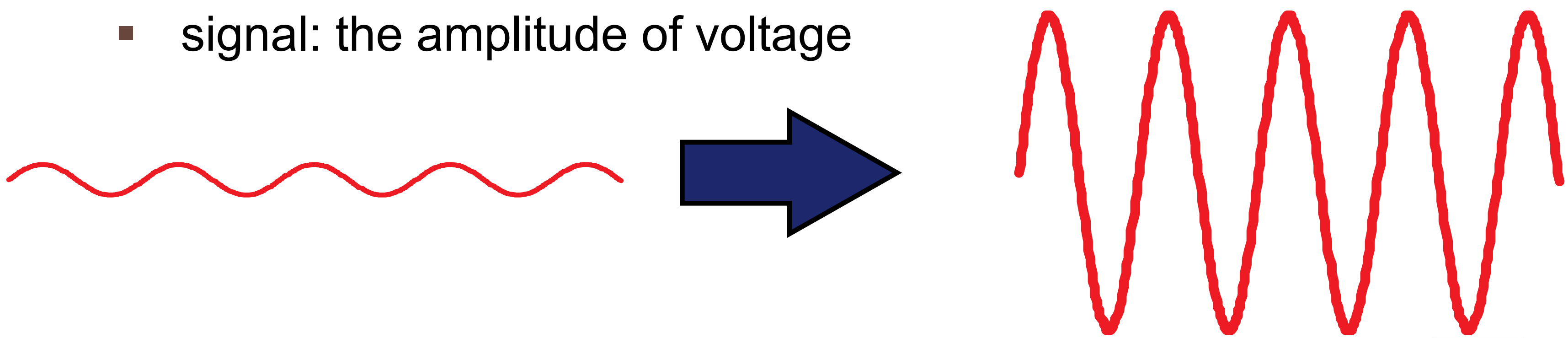
- Large signal and small signal
- Performance indices
- Exercises

Operational amplifier

- Performance indices
- Feedback
- Exercises

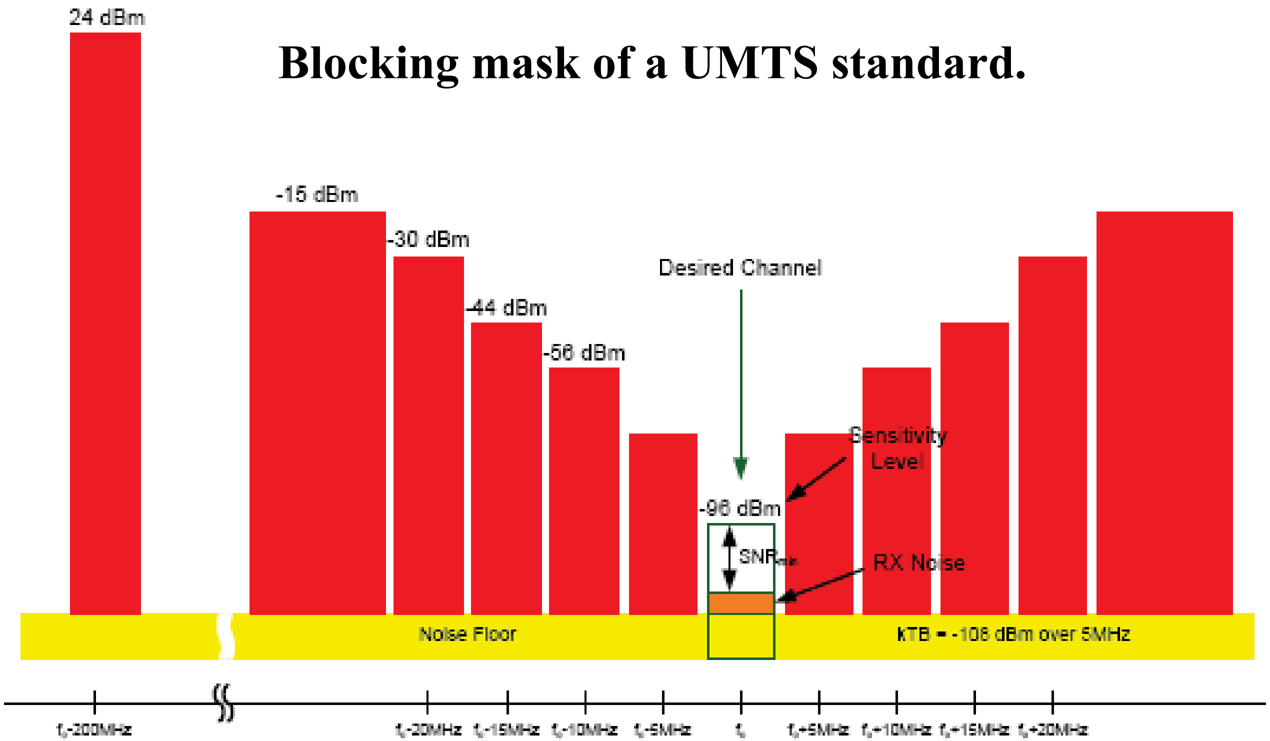
Information, Signal, Amplification

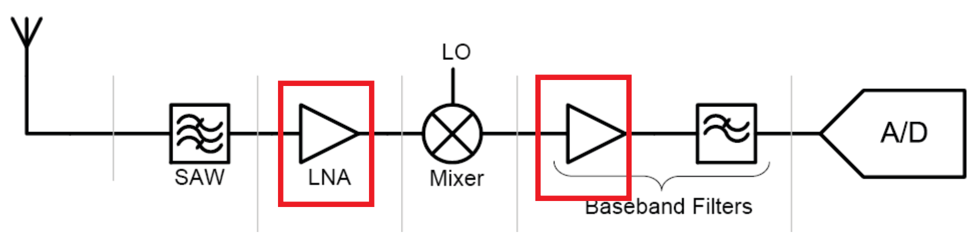
- **Information is carried by the variation of electrical signal**
- **Signal : current, voltage, charge quantity, electrical magnetical fields.**
- **Variable carrier of information : amplitude, frequency, or phase**
- **Objectives of the amplification function**
  - **Linear** amplification (without deformation)
  - Of a variable signal (speech, sound, image, radio, video)
  - signal: the amplitude of voltage



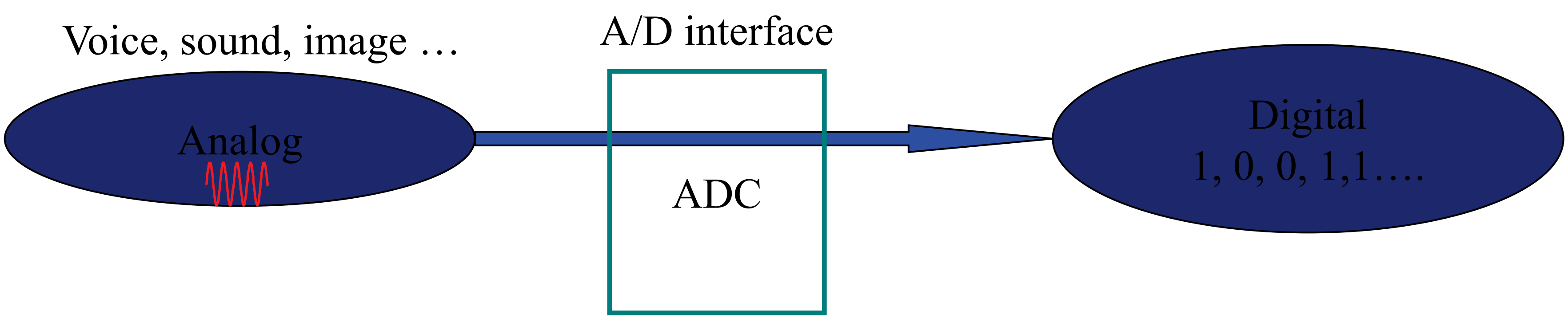
Amplification in digital world

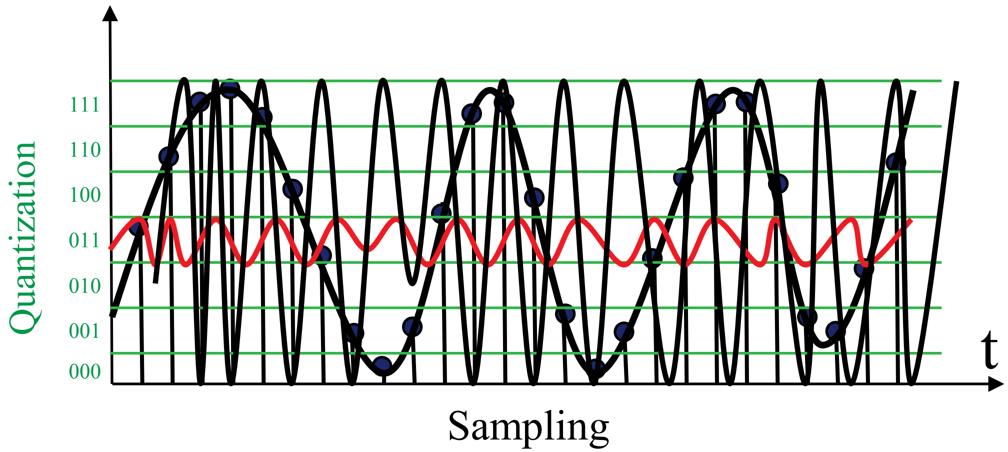
Blocking mask of a UMTS standard.



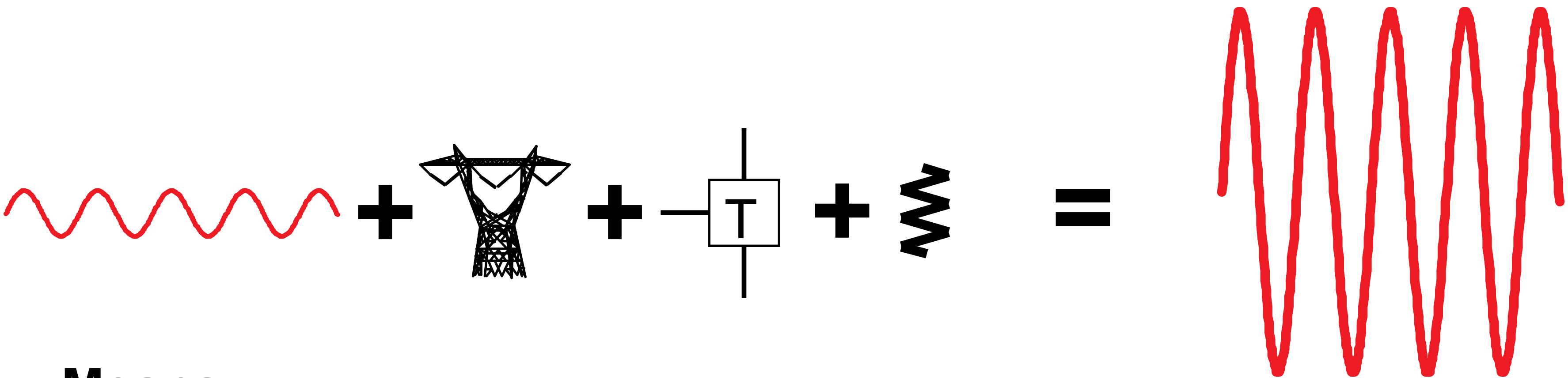


Amplification in digital world





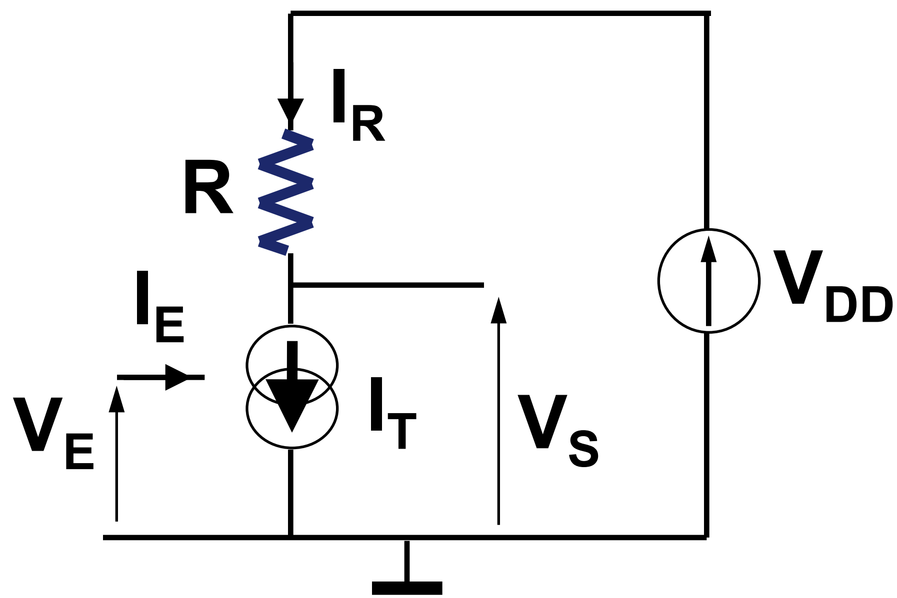
Amplification



Means

- Energy resource (dc voltage)
- Modulator of current driven by voltage (transistor)
- Current/voltage converter (load resistance)

Amplifier : basic circuit



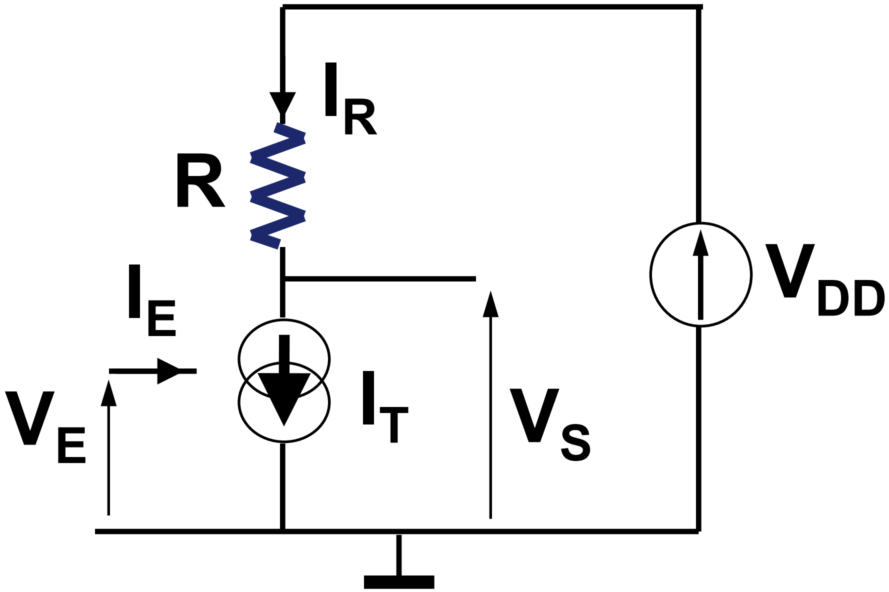
- Energy resource : VDD $\rightarrow$ I_R , I_T
- Modulator of current : $I_T = f(V_E)$
- Current/voltage converter : $V_S = g(I_T)$

- Gain
- Linearity
- Bandwidth

Basic amplifier

- **Ideal**
  - $I_T = g_m \cdot V_E$
  - $V_S = V_{DD} - R \cdot I_R$
  - $V_S = V_{DD} - R \cdot g_m \cdot V_E$

Gain=$\partial Vs / \partial Ve$= - R· g_m

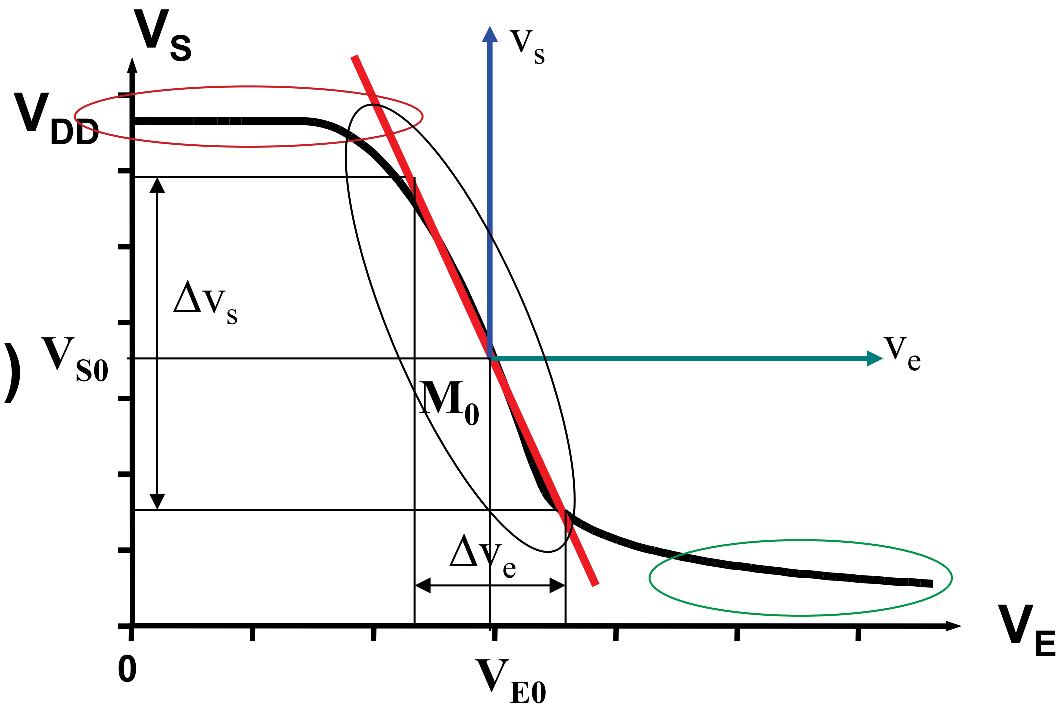


- **Reality**
  - $I_T = f(V_E)$: Non linear function
  - i.e. : $I_T = K \cdot (V_E - V_T)^2$

- **How to determine performance? -> what kind of analysis?**

Transfer function

- **Transfer function**
  - $\Rightarrow$ Non linear
- **Local linearization**
- $V_S - V_{S0} \approx G \cdot (V_E - V_{E0})$
- $v_s \approx G \cdot v_e$



- **G depend on M_0**
- **M_0 : operation point**

- **To determine operation point M_0**
  - Static analysis

Analysis types

Static analysis

- Parameters of the operation point (M_0)

Large signal analysis

- Transfer function
- Maximal excursions
- Distortion ratio
- Operation point

Small signal analysis « linear analysis »

- Gain, input and output resistances

Harmonic analysis

- Linear analysis + capacitors [$Z(c) = \frac{1}{j\omega C}$]
- Complex gain, bandwidth

Large signal

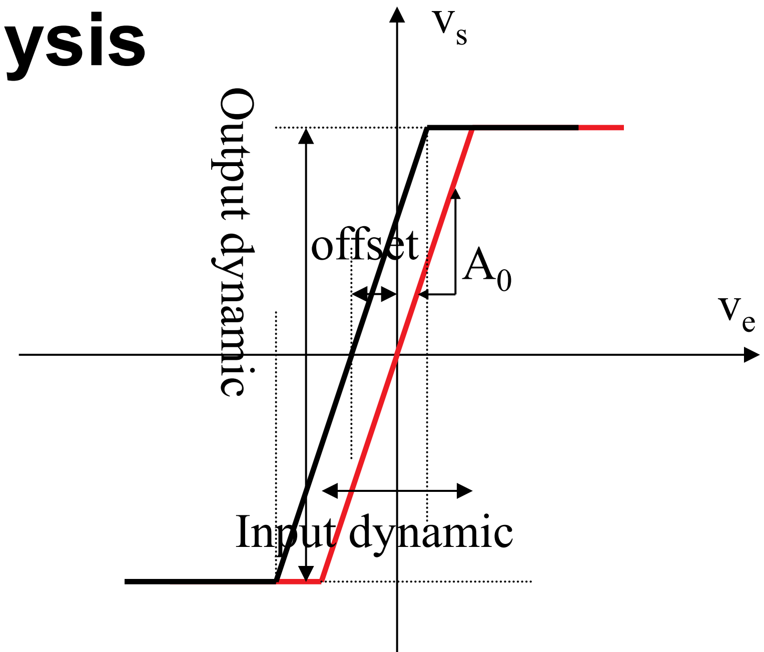
Static and large signal analysis

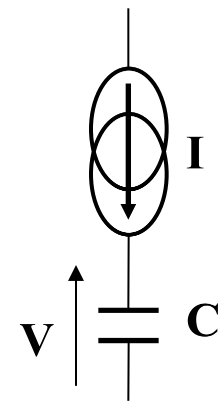
- Transfer function
- Static gain : A_0
- Offset
- Input dynamic
- Output dynamic
- Saturation
- Slew-rate

$Q = V \cdot C$

$I = dQ/dt = C \cdot dV/dt$

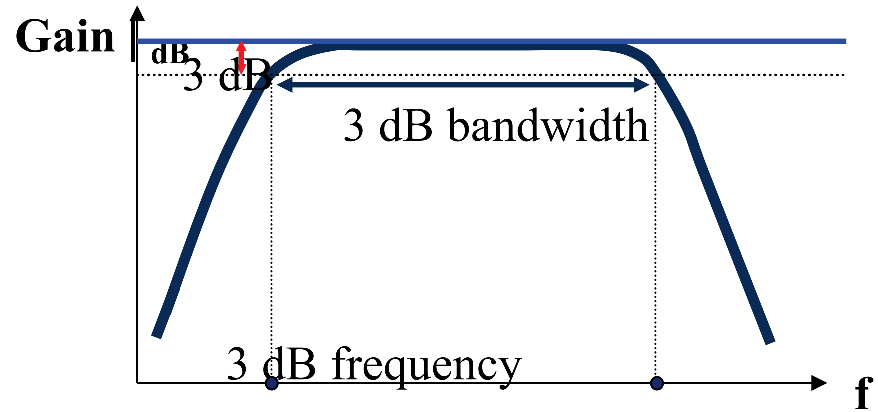
$dV/dt = I/C < I_0/C$

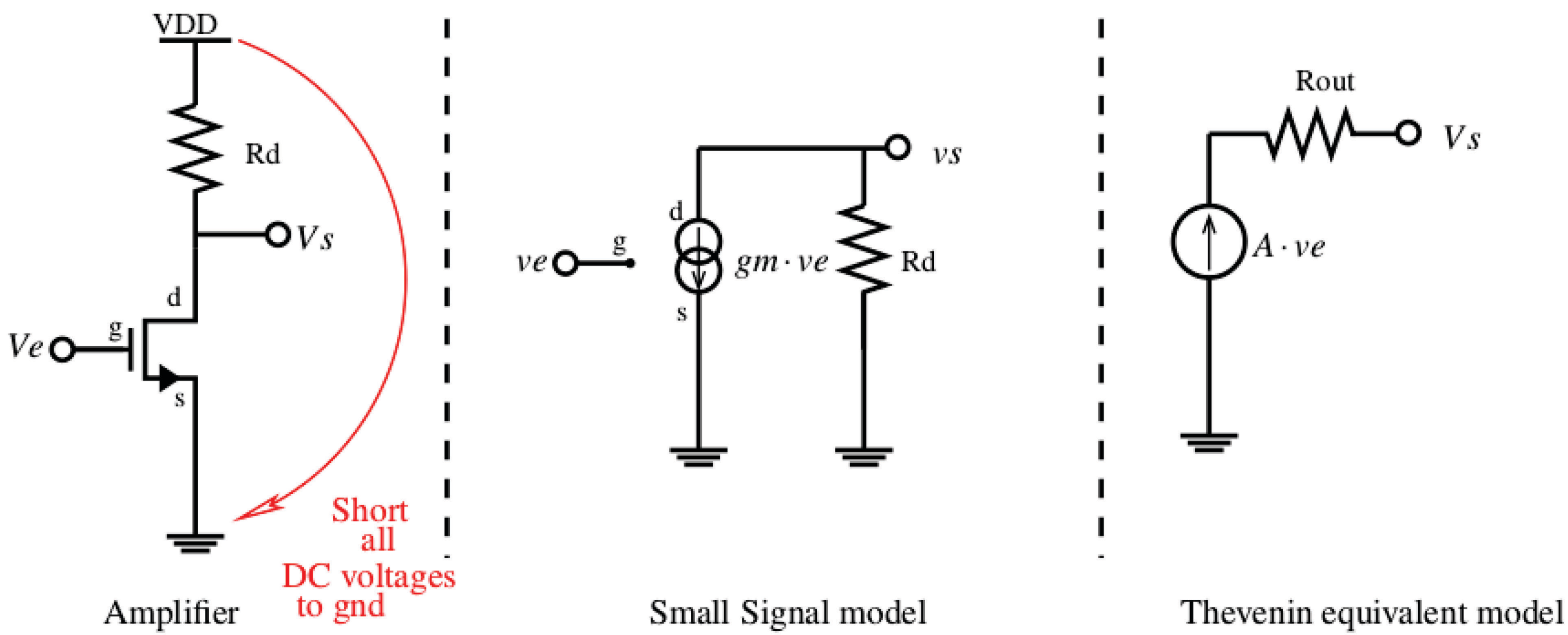




Small signal

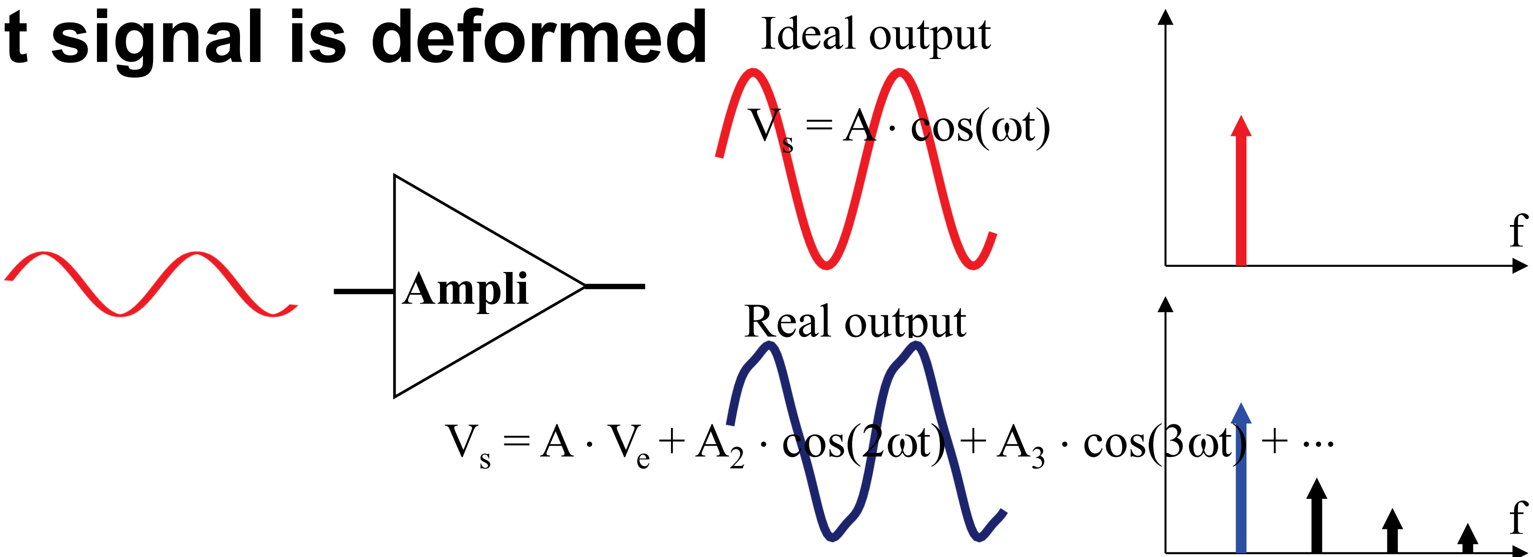
- Frequency response
- 3dB Bandwidth/Funity
- Output impedance





Distortion

Output signal is deformed



$$V_s = A \cdot \cos(\omega t)$$

$$V_s = A \cdot V_e + A_2 \cdot \cos(2\omega t) + A_3 \cdot \cos(3\omega t) + \cdots$$

$A_2, A_3 \cdots$ parasite amplification gains

Distortion analysis

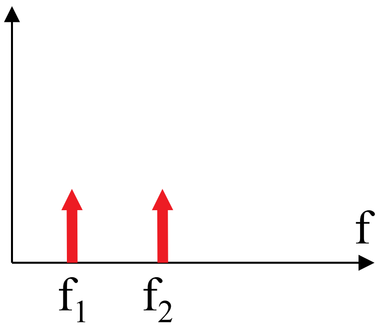
- Fourier analysis

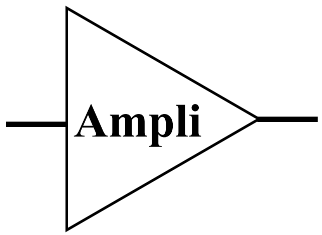
Distortion causes:

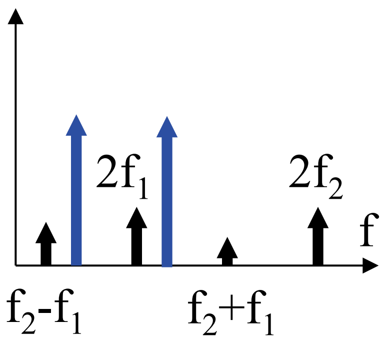
- Non linearity
- Saturation
- Slew-rate

Distortion

Intermodulation







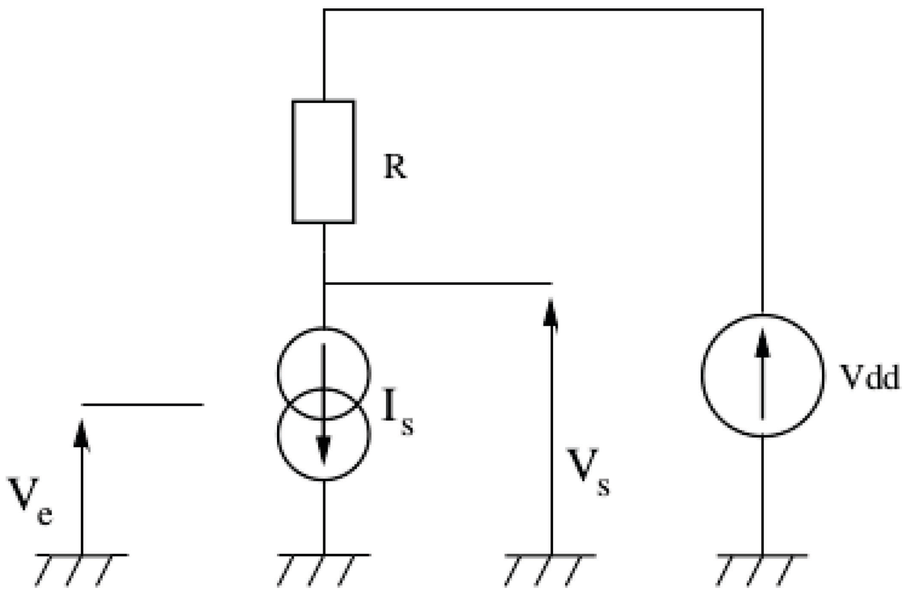
Distortion ratio

$$V_s = A \cdot V_e + A_2 \cdot \cos(2\omega t) + A_3 \cdot \cos(3\omega t) + \cdots$$

$$HD_2 = \left|\frac{A_2}{A}\right|$$

$$THD = \frac{\sqrt{A_2{}^2 + A_3{}^2 + \cdots}}{|A|}$$

Exercise: Harmonic decomposition



1. **Calculate the harmonic decomposition of the output signal.**
2. **What is the THD of the amplifier?**

SNR, SNDR and Noise Figure

- **SNR : signal to noise ratio $\Rightarrow$ quality of information transmission / parasites, noise**

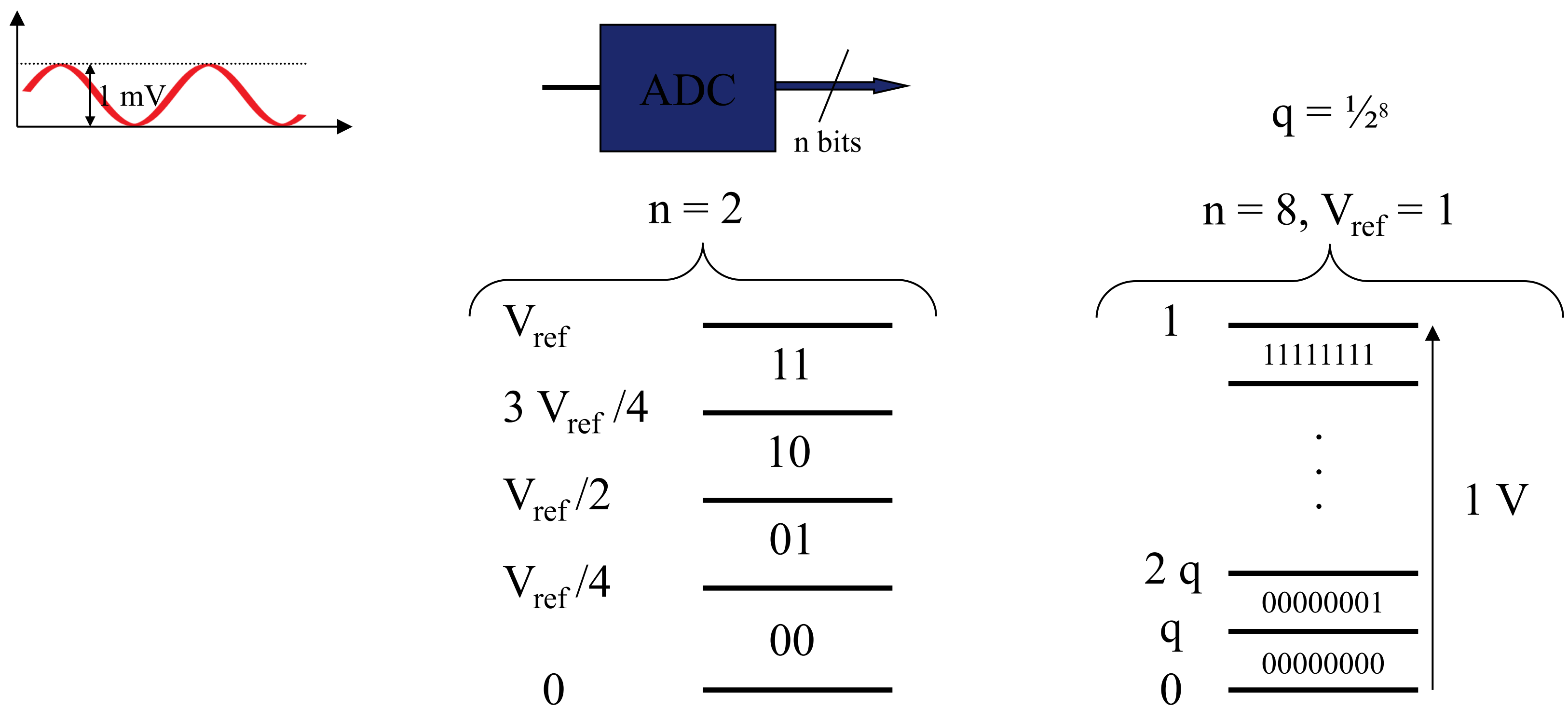
$$SNR = \left.\frac{\text{Signal power}}{\text{Noise power}}\right|_{dB}$$

- **SNDR : signal to noise plus distortion ratio**

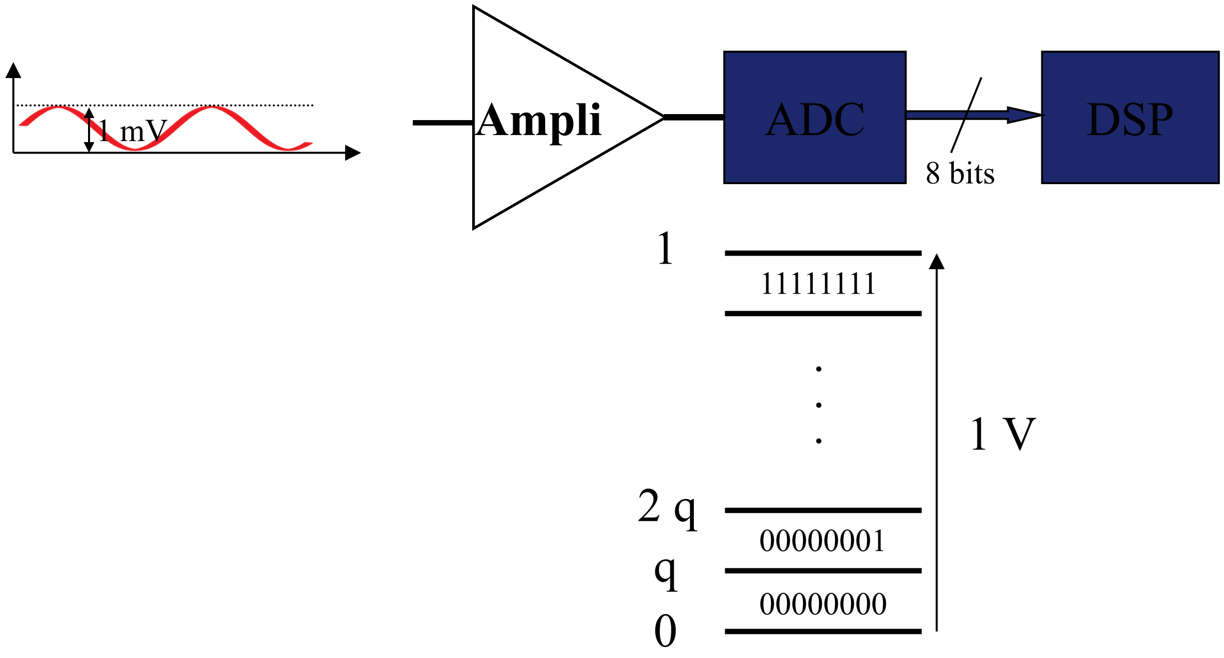
$$SNDR = \left.\frac{\text{Signal power}}{\text{noise} + \text{distortion power}}\right|_{dB}$$

- **Noise figure : ratio between SNR at the output and SNR at the input**

Exercice: Gain, band. and distortion

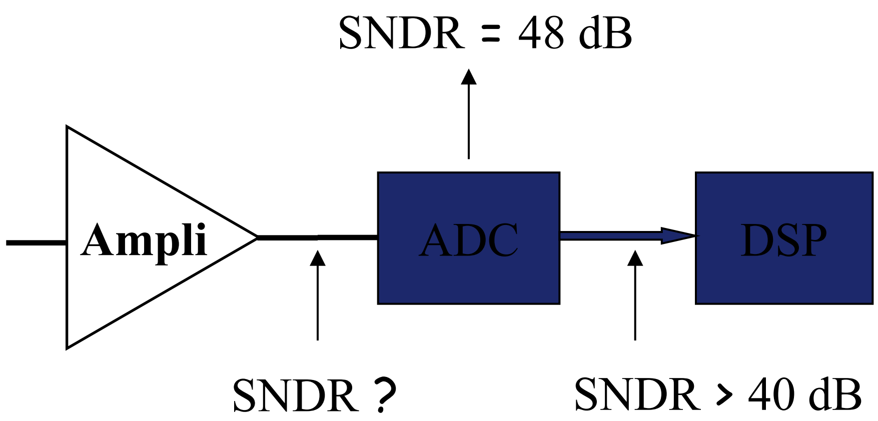


Exercice: Gain, band. and distortion



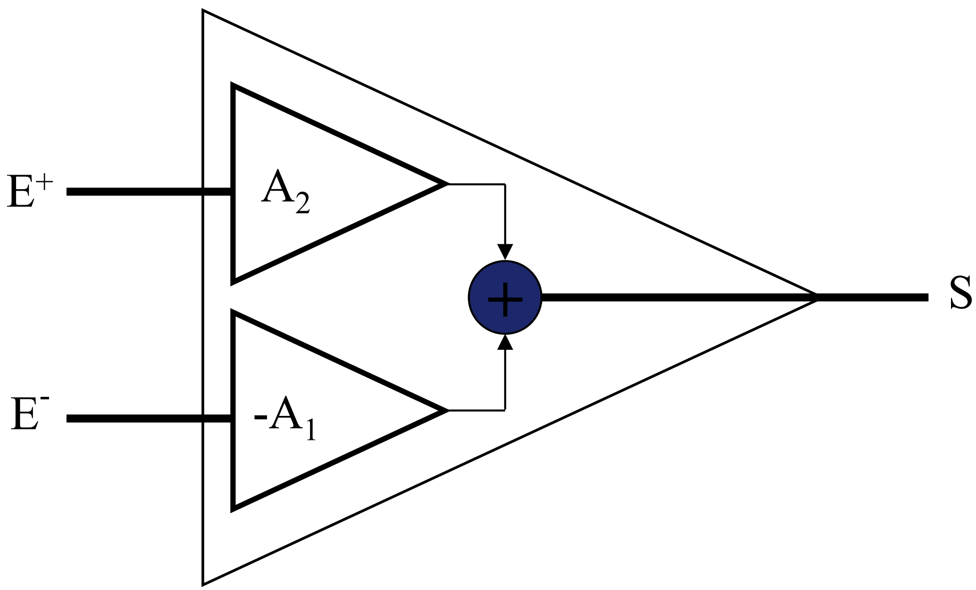
Gain et bandwidth ?

Exercice: Gain, band. and distortion



Maximum distorsion?

Differential amplifier



$$S = A_2 E^+ - A_1 E^-$$

$$E_d = E^+ - E^- \quad \text{et} \quad E_c = \frac{E^+ + E^-}{2}$$

$$A_d = \frac{A_1 + A_2}{2} \quad \text{et} \quad A_c = A_2 - A_1$$

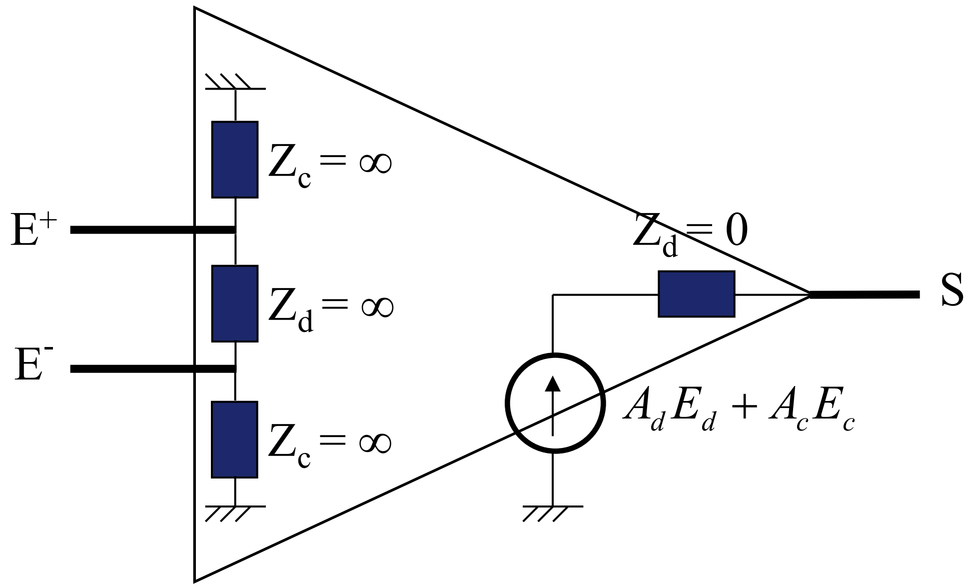
$$S = A_d E_d + A_c E_c$$

Common mode rejection ratio

$$CMRR\big|_{dB} = 20\log 10\left(\frac{A_d}{A_c}\right)$$

$$S = A_d\left(E_d + \frac{1}{CMRR} E_c\right)$$

Operational amplifier

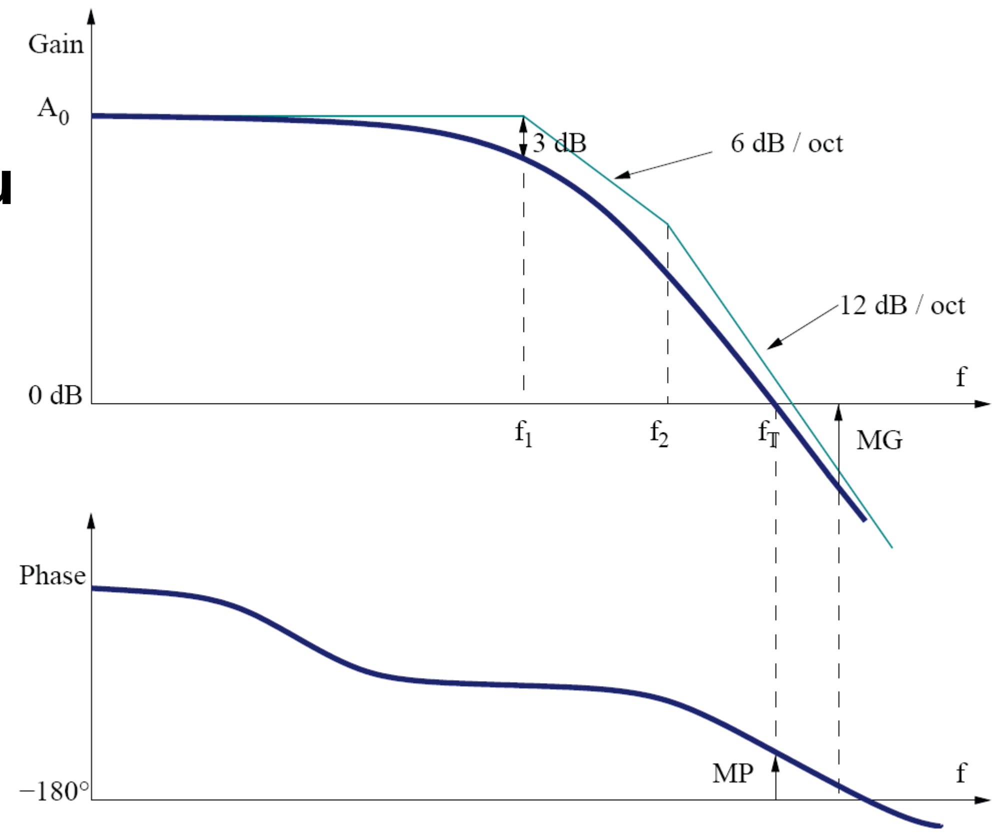


$$A_d = \infty \quad \text{and} \quad A_c = 0$$

$$A_d = \infty \text{ and } \text{finite } S \Rightarrow E_d = \varepsilon = 0$$

Characteristics

- Transition frequency : f_T
- Gain margin GM
- Phase margin PM
- Gain bandwidth produ



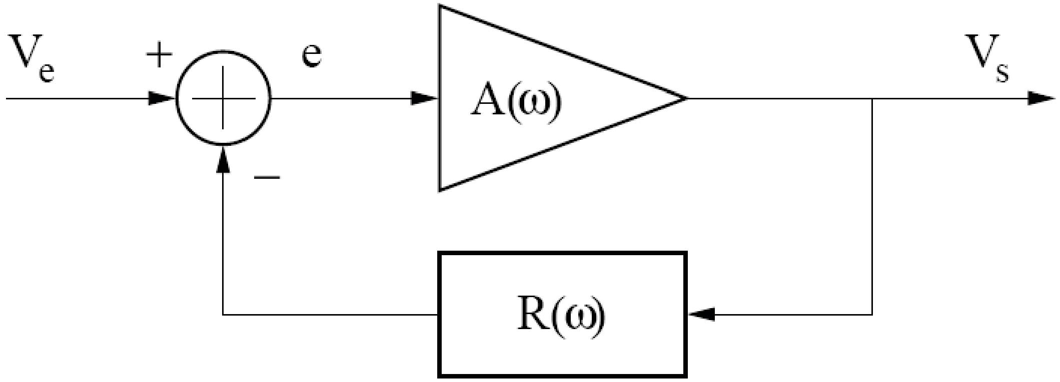
$$PGB = A_0 \cdot f_c$$

$$A = A_0 \frac{1}{1 + j\dfrac{\omega}{\omega_c}}$$

$$f >> f_c \Rightarrow |A| \cdot f = A_0 \cdot f_c$$

Feedback

Schema



$$H(\omega) = \frac{A(\omega)}{1 + A(\omega)R(\omega)}$$

Feedback ratio

$$H(\omega) \approx \frac{1}{R(\omega)} \quad \text{si} \quad A(\omega)R(\omega) >> 1$$

Feedback

Advantages : Increase the bandwidth

If $R(\omega) = R$ and $A(\omega) = \dfrac{A_0}{1 + j\dfrac{\omega}{\omega_c}}$

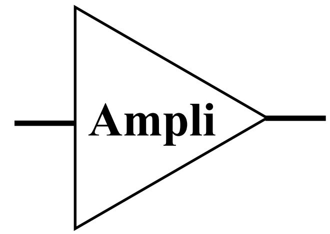
$$H(\omega) = \frac{A_0}{1 + R \cdot A_0} \; \frac{1}{1 + j\dfrac{\omega}{\omega_c\left(1 + R \cdot A_0\right)}}$$

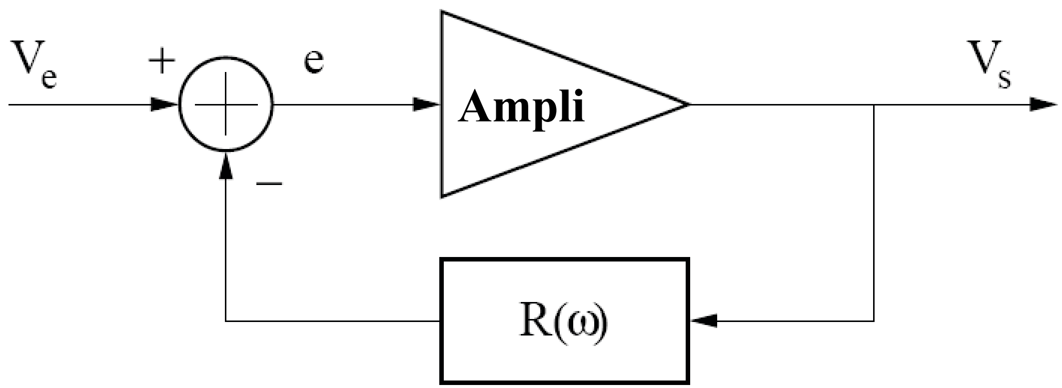
$$H_{BF0} = \frac{A_0}{1 + R \cdot A_0} \qquad \omega_{BFC} = \omega_c\left(1 + R \cdot A_0\right)$$

Feedback

Advantages : Distortion reduction

$$Y(\omega) = X(\omega) \cdot A(\omega) + u$$



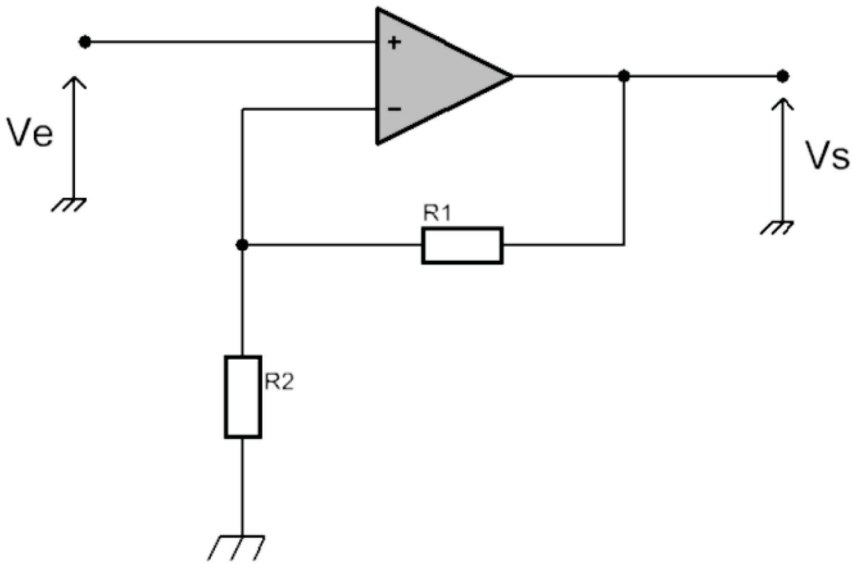


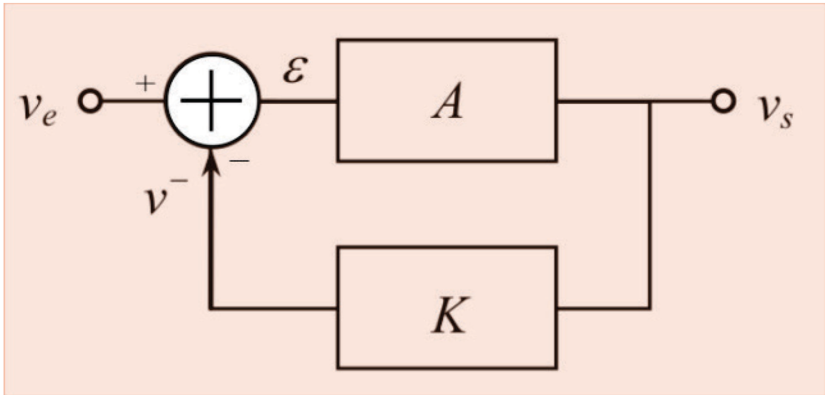
$$\left(V_e(\omega) - R \cdot V_s(\omega)\right)A(\omega) + u = V_s(\omega)$$

$$V_s(\omega) = \frac{A(\omega)}{1 + R \cdot A(\omega)} V_e(\omega) + \frac{1}{1 + R \cdot A(\omega)} u$$

$<< u$

Exercice





1. **Calculate the transfer function H=Vs/Ve for an ideal OpAmp**
2. **What becomes H for a real OpAmp with a gain A**
3. **Plot the Bode Diagram**
4. **How should we chose tau2 to have a MP of π/4?**