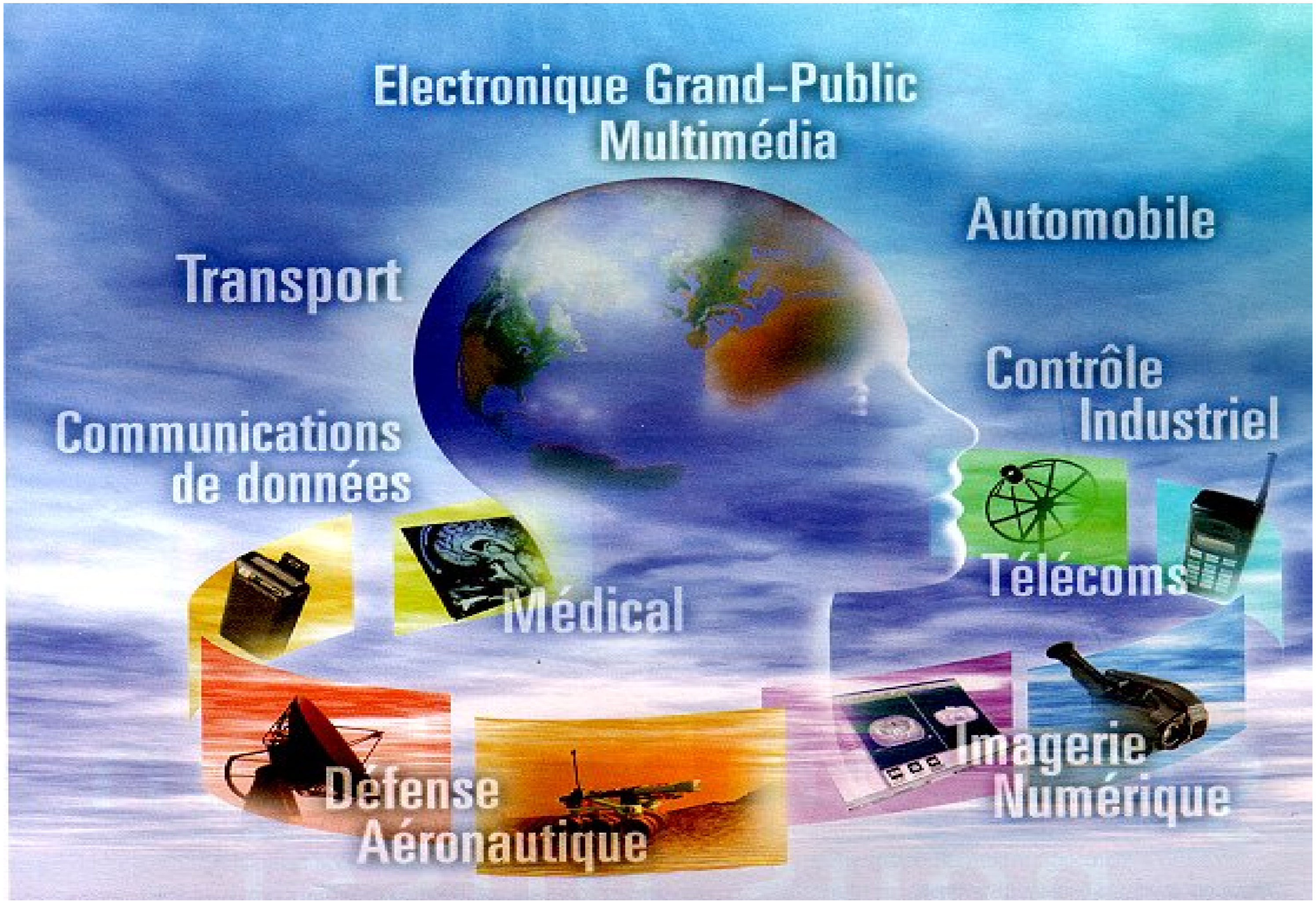
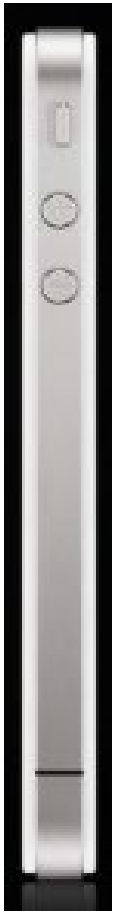
ELECTRONIQUE (ANALOGIQUE)

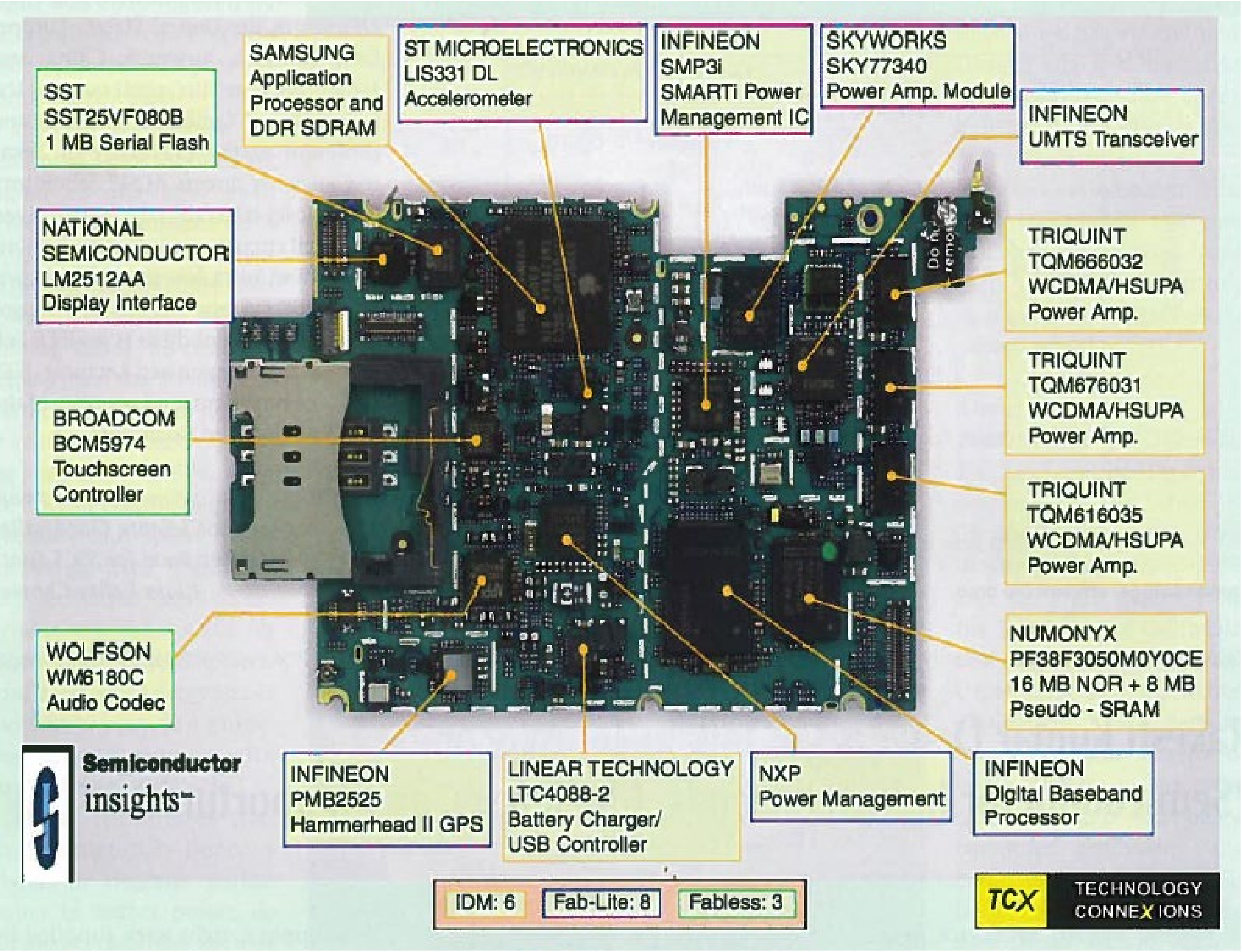


G. JACQUEMOD

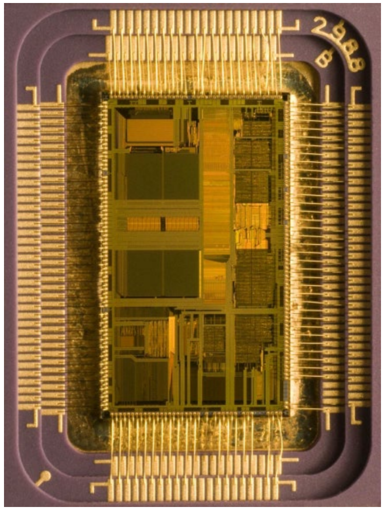
Métiers de l'électronique

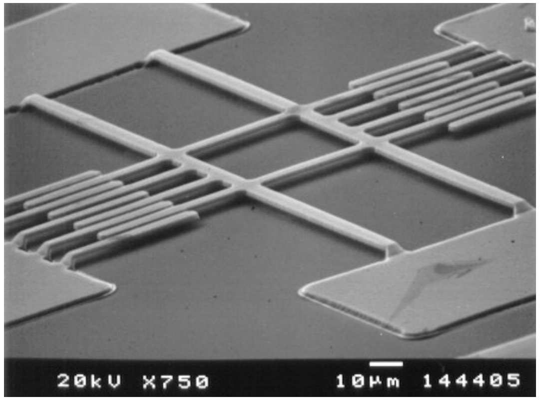
Métiers de l'électronique

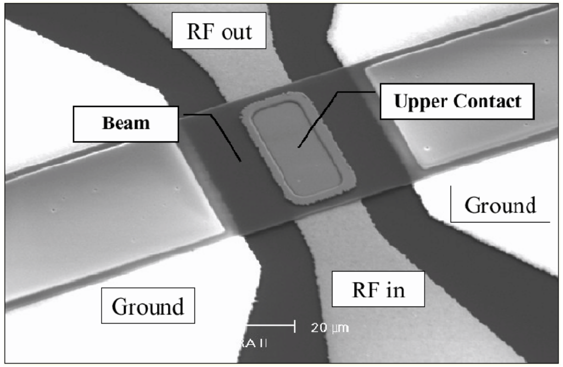


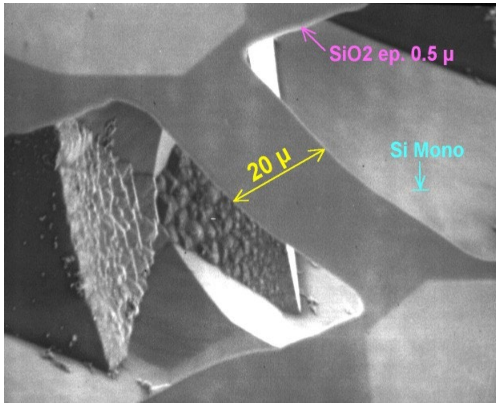


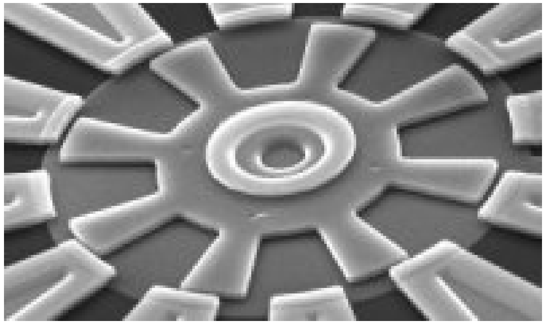
Métiers de l'électronique

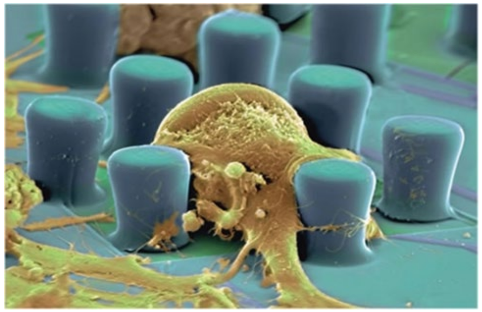












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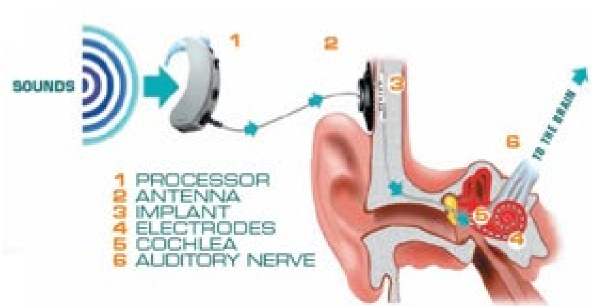

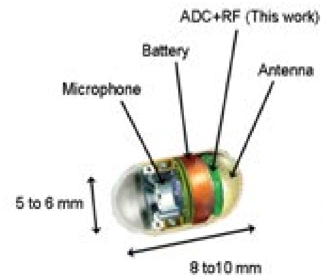

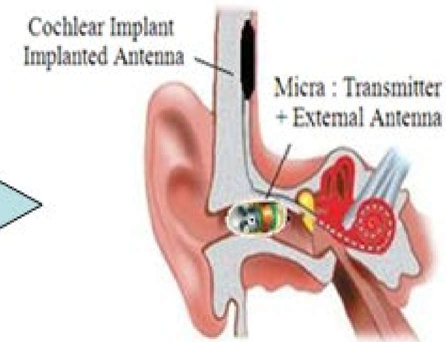

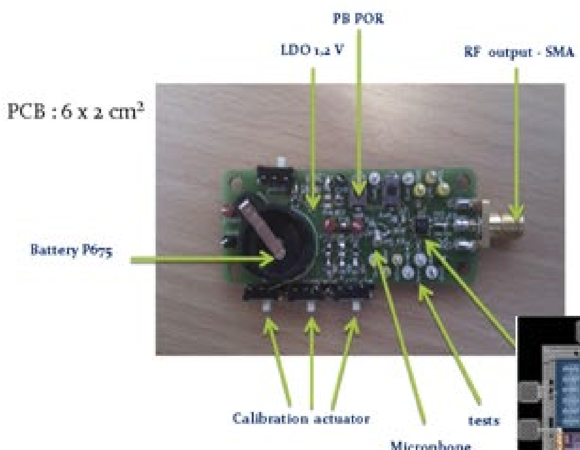

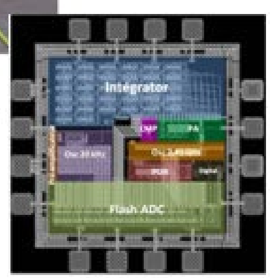

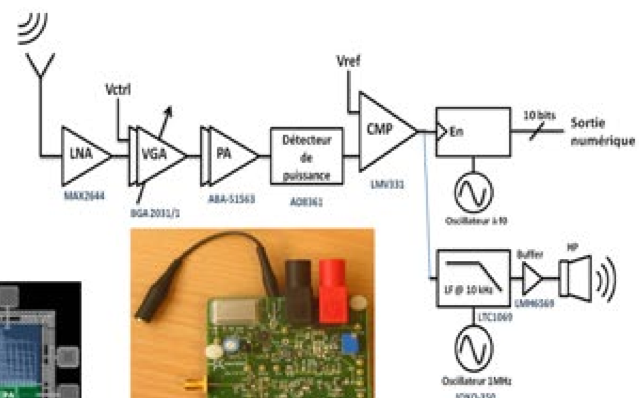

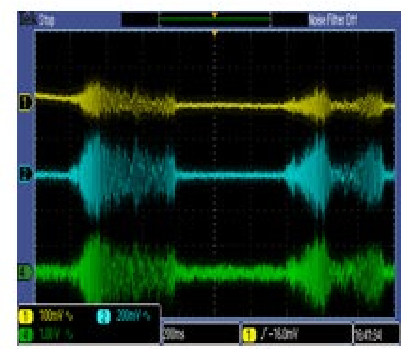

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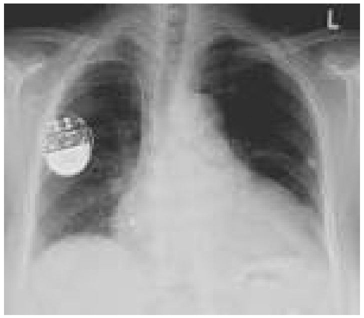

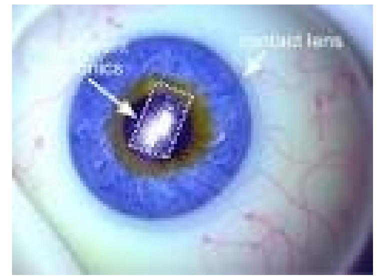

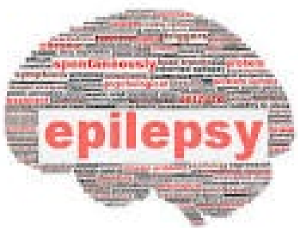

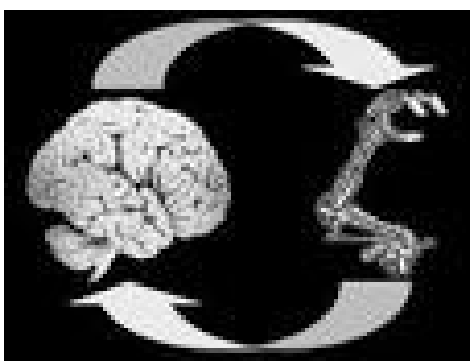

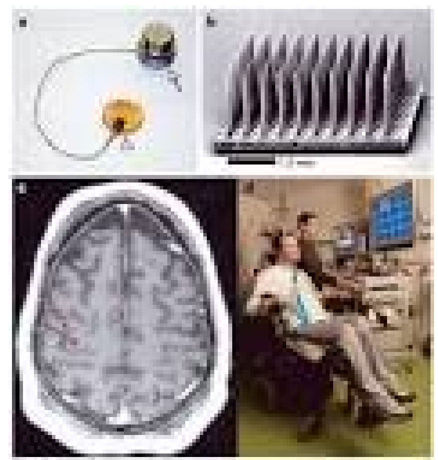

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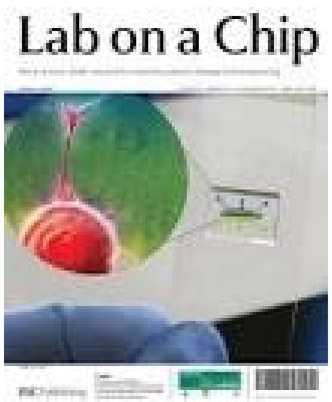
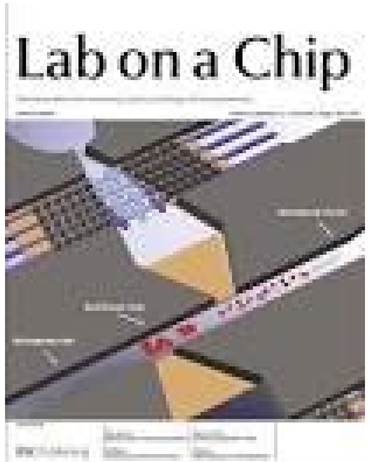
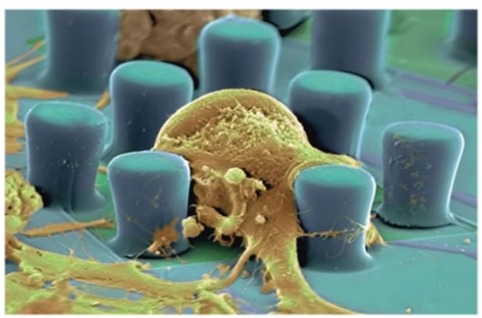
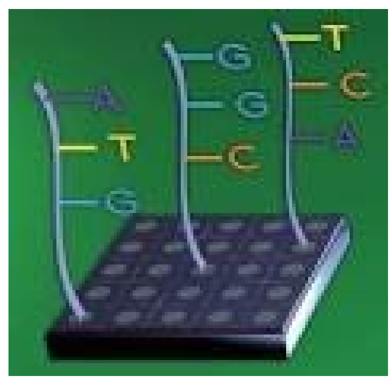
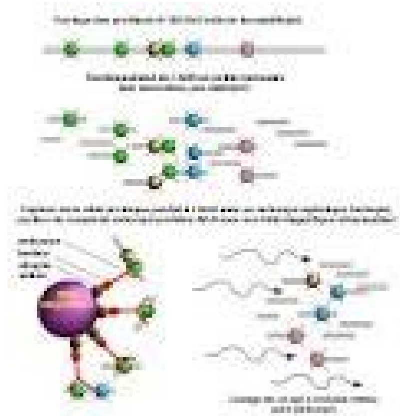


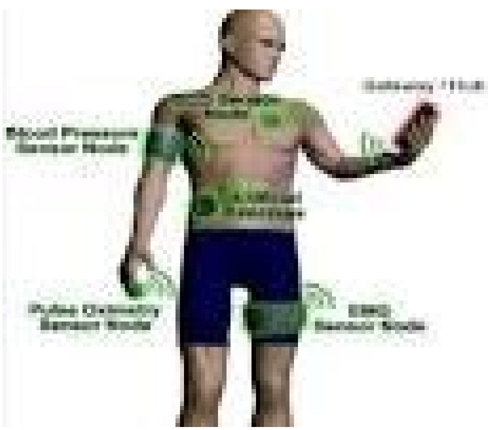


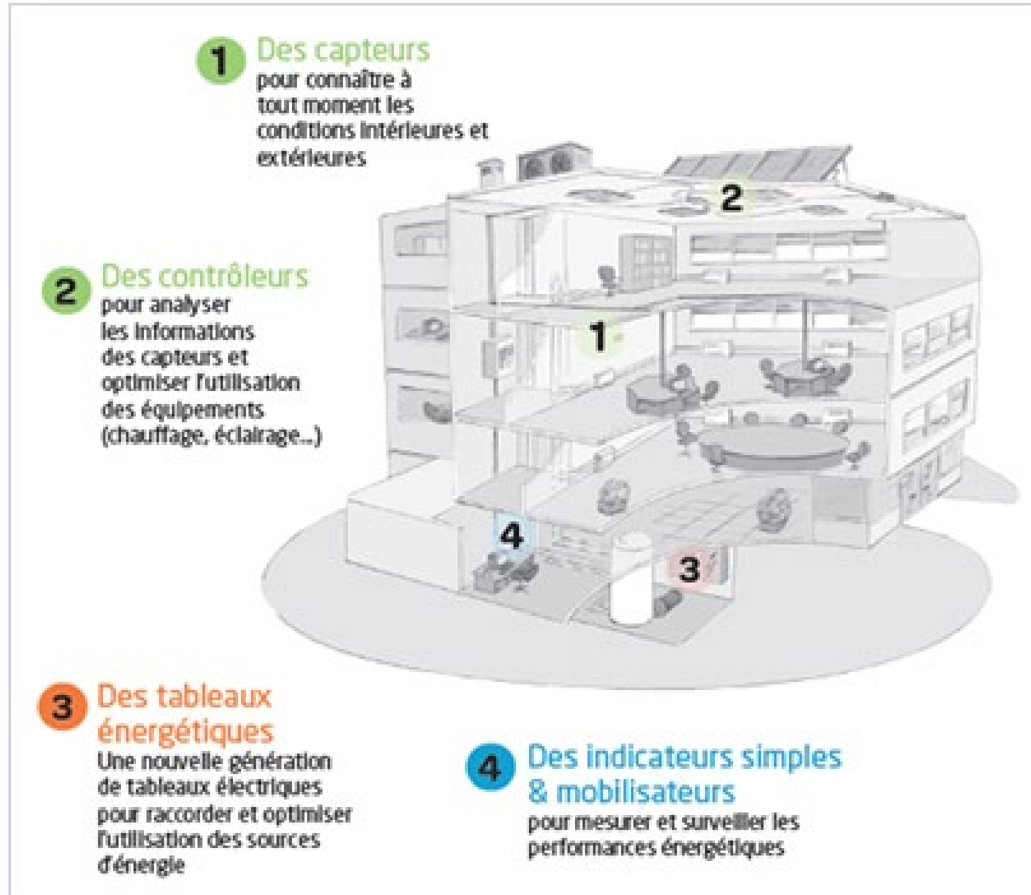






Métiers de l'électronique





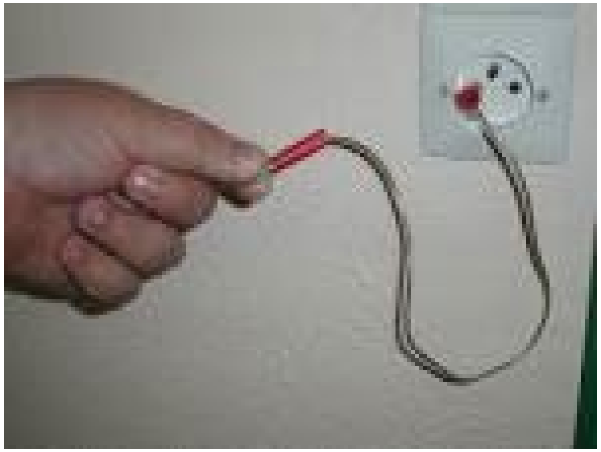
Quelle est la différence entre la phase et le neutre ?

A – Leur référence par rapport à la masse

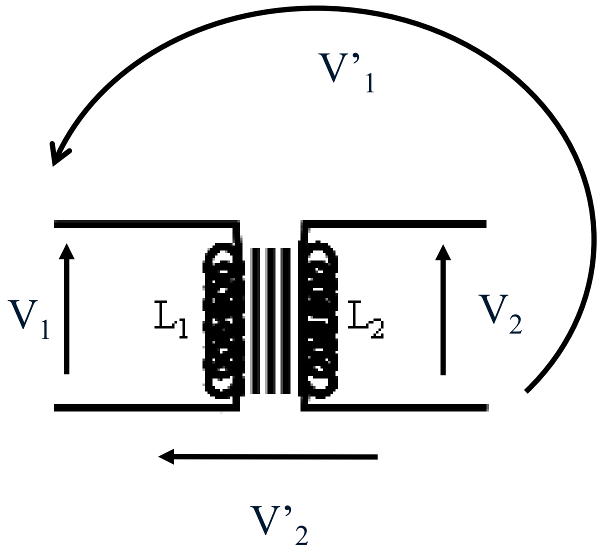
B – Leur référence par rapport à la terre

C – Pas de différence

D – 220.sin(2π50t) Volt



Transformateur ?



Si $L_1=L_2$ alors $V_1=V_2$, mais que vaut V'_1 ou V'_2?

A – $V'_1=V_1$

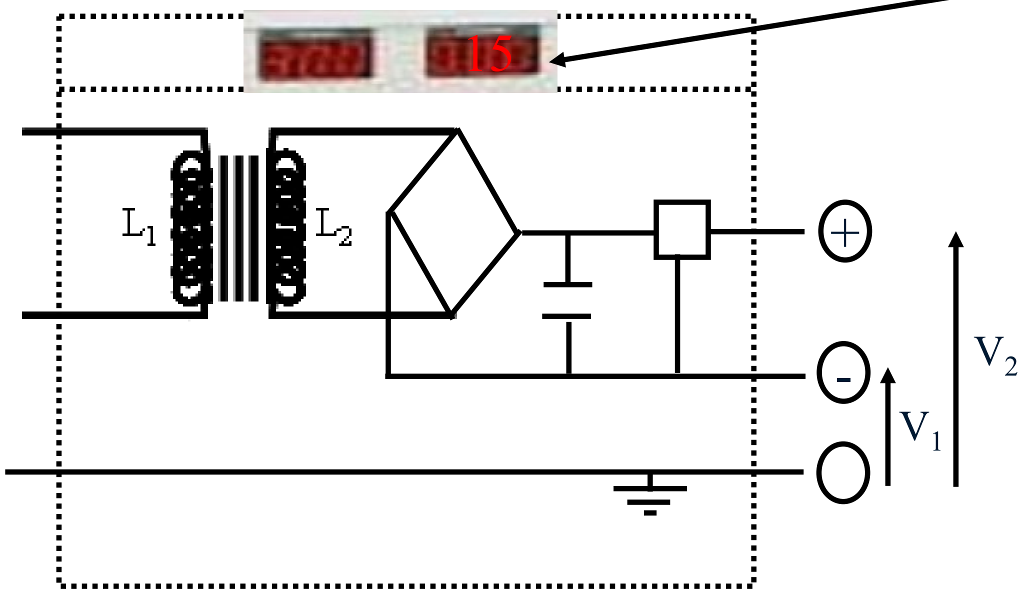
B – $V'_1=V_2$

C – $V'_2=V_1$

D – Aucune des trois propositions

Générateur de tension ?

Si E=15V, qu'a-t-on?



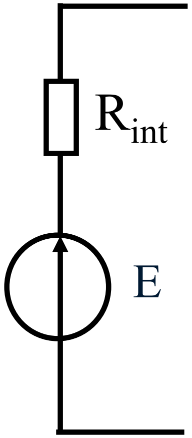
A – V_1=15V

B – V_1=-15V

C – V_2=-15V

D – Aucune des trois propositions

Quel est l'ordre de grandeur de R_{int} ?



A – qq mΩ

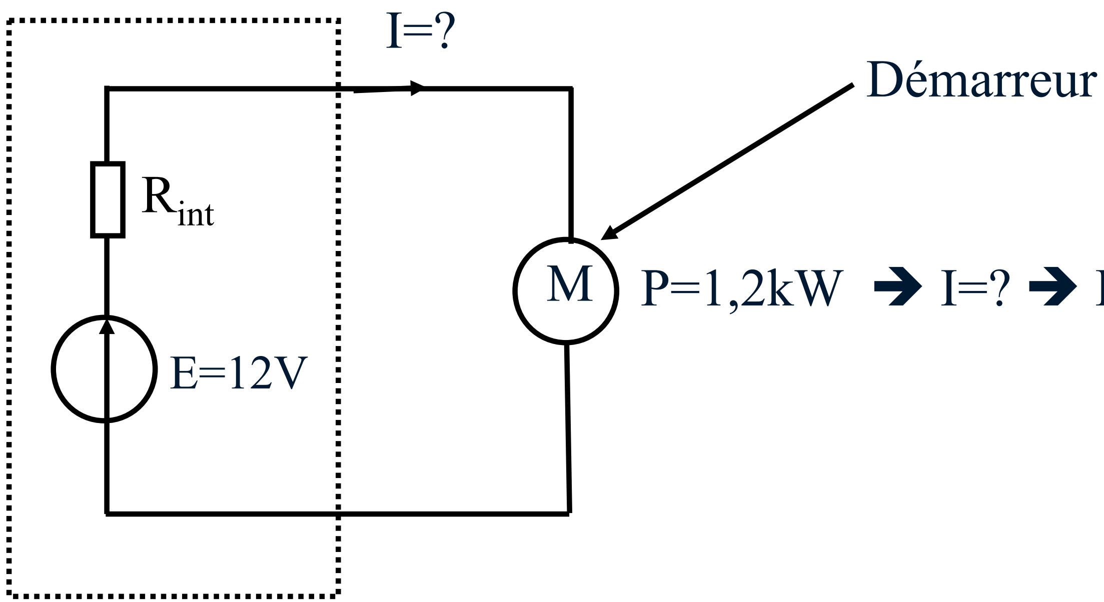
B – qq Ω

C – 50 Ω

D – qq kΩ

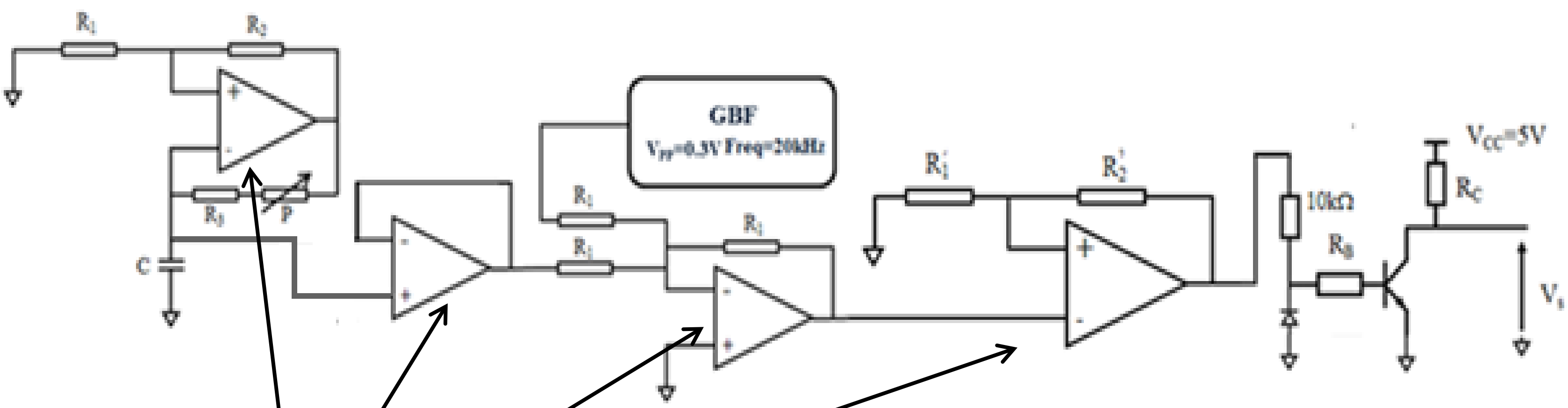
E – qq MΩ

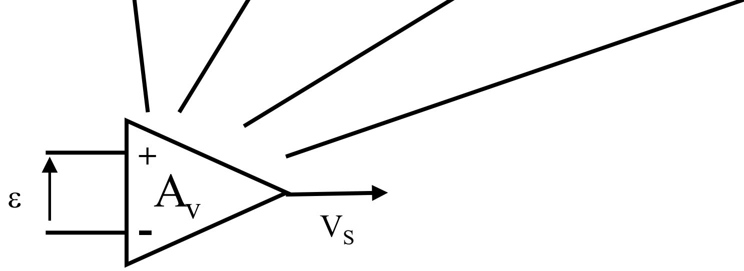
Quel est l'ordre de grandeur de R_{int} ? Batterie de voiture

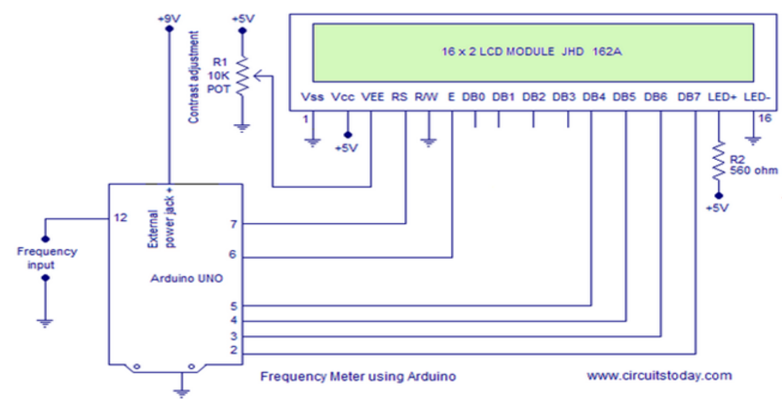


P=1,2kW ➔ I=? ➔ R_{int}.I=?

I – Générateur de fréquence



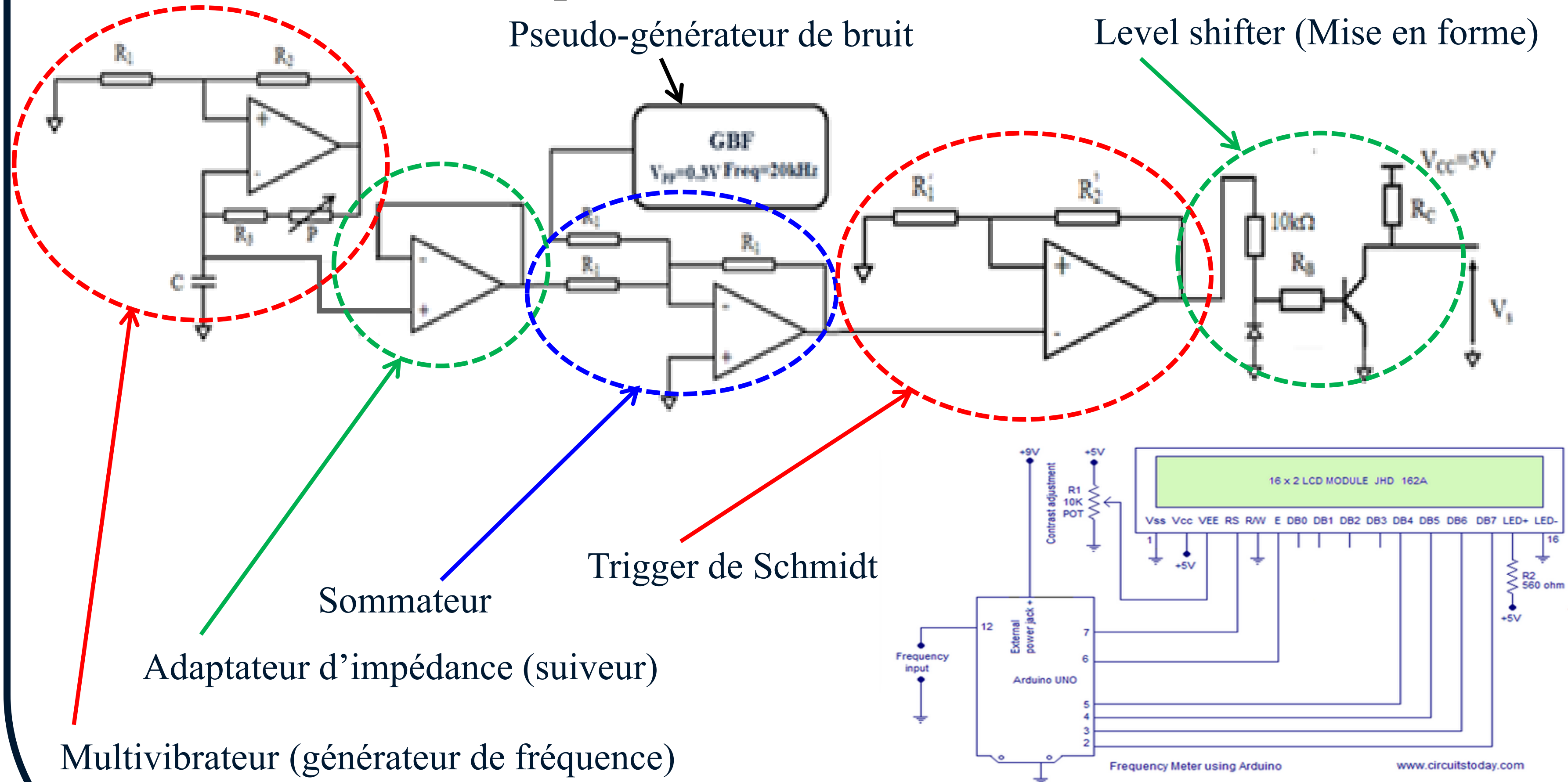




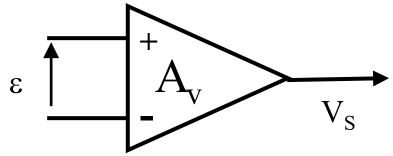
Amplificateur Opérationnel

Fréquencemètre

I – Générateur de fréquence



I – Amplificateur opérationnel idéal



$$v_s = v_{OUT} = V_{OUT_0} + A_{v_d} \cdot \varepsilon + A_{v_c} \cdot v_{in_c}$$

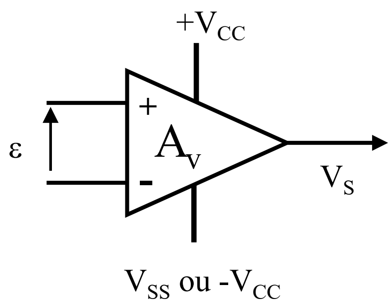
ε : Entrée différentielle
v_{in_c} : Entrée de mode commun
A_{v_d} : Gain différentiel
A_{v_c} : Gain de mode commun

__Remarque__ : Les sources de tensions v_{INc} et ε ne sont pas réelles. Elles sont issues d'un artifice mathématique pratique pour l'étude de l'étage différentiel.

$$\begin{cases} V_{OUT_0} : offset \\ v_{in_c} = \frac{1}{2}(e_+ + e_-) \\ \varepsilon = e_+ - e_- \end{cases} \quad Amplificateur\ idéal \Rightarrow \begin{cases} V_{OUT_0} = 0\ (tension\ \ d'offset) \\ A_{vd} = A_v \to \infty \\ A_{vc} = 0 \end{cases}$$

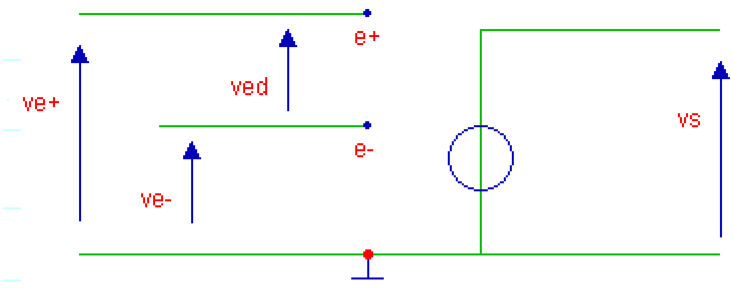
$$\begin{cases} e_+ = v_{in_c} + \varepsilon/2 \\ e_+ = v_{in_c} - \varepsilon/2 \end{cases}$$

Amplificateur Opérationnel



$$\text{Amplificateur idéal} \Rightarrow \begin{cases} V_{OUT_0} = 0 \\ A_{vd} = A_v \to \infty \\ A_{vc} = 0 \end{cases}$$

$$\text{Amplificateur idéal} \Rightarrow \begin{cases} i_+ = i_- = 0 \Rightarrow \text{Résistances d'entrée} \to \infty \\ A_{vd} = A_v \to \infty \\ R_S = 0 \end{cases}$$



$$\text{Amplificateur (linéaire)} \Rightarrow \begin{cases} V_s < V_{CC} \\ e_+ = e_- \end{cases}$$

$$\text{Comparateur} \Rightarrow \begin{cases} e_+ > e_- \Rightarrow V_s = +V_{CC} \\ e_+ < e_- \Rightarrow V_s = -V_{CC} \end{cases}$$

Amplificateur opérationnel réel

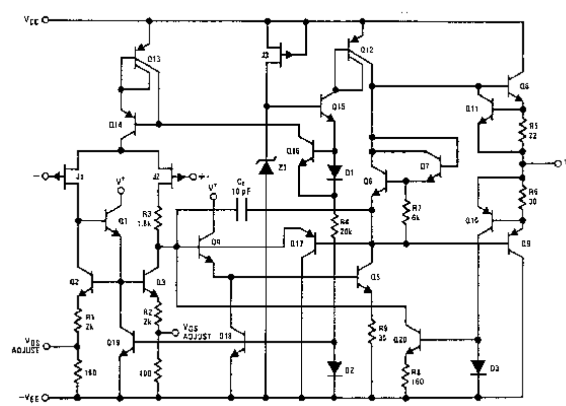
Tout comme il existe plusieurs types de transistors, il existe plusieurs types d'AOPs (logique, puisqu'un AOP est constitué de transistors) :

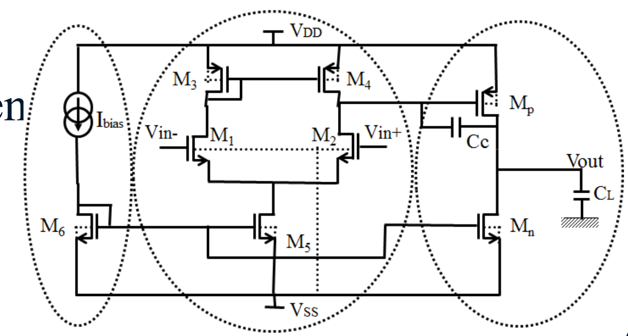
Bipolaire : constitué uniquement de transistors bipolaires (ex: 741, LM324 etc.)

BiFet : l’étage d’entrée est constitué de transistors à effet de champ JFET (ex : TL 071, TL072, TL074)

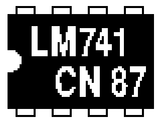
Bimos : l’étage d’entrée est constitué de transistors à effet de champ MOS (ex : CA3140)

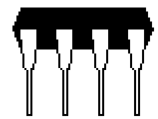
LinCMOS : constitués de transistors CMOS fonctionnant en zone linéaire (ex : TLV2432, LMC6035) particulièremen utilisés pour des systèmes fonctionnant sur batteries.

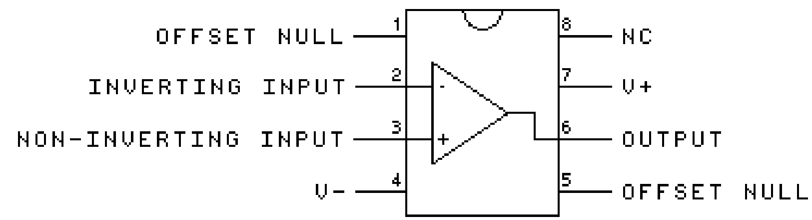




Amplificateur opérationnel réel







AD8541/AD8542/AD8544

FEATURES

Single-supply operation: 2.7 V to 5.5 V
Low supply current: 45 μA/amplifier
Wide bandwidth: 1 MHz
No phase reversal
Low input currents: 4 pA
Unity gain stable
Rail-to-rail input and output
Qualified for automotive applications

APPLICATIONS

ASIC input or output amplifiers
Sensor interfaces
Piezoelectric transducer amplifiers
Medical instrumentation
Mobile communications
Audio outputs
Portable systems

PIN CONFIGURATIONS

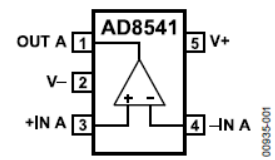


Figure 1. 5-Lead SC70 and 5-Lead SOT-23 (KS and RJ Suffixes)

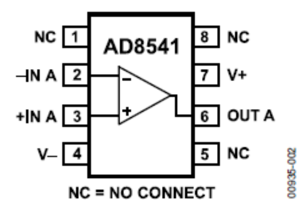
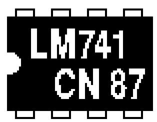
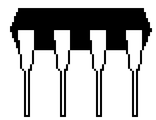
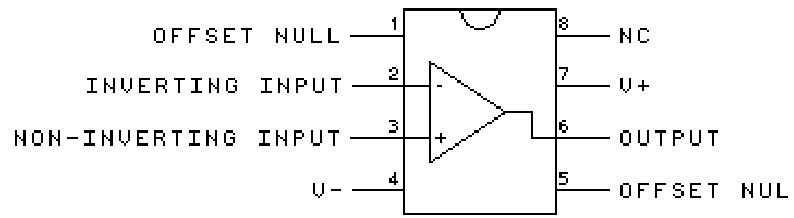


Figure 2. 8-Lead SOIC (R Suffix)

741


LM741
CN 87

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NC
V+
OUTPUT
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1
2
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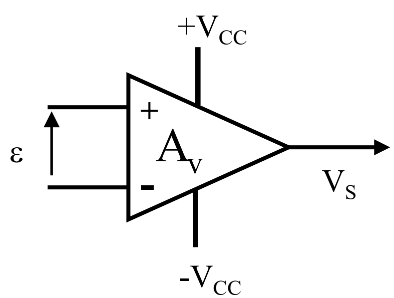
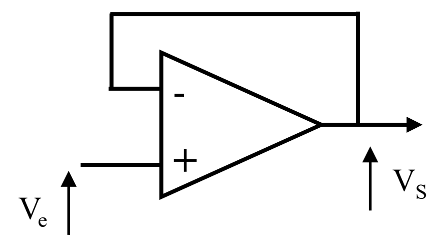
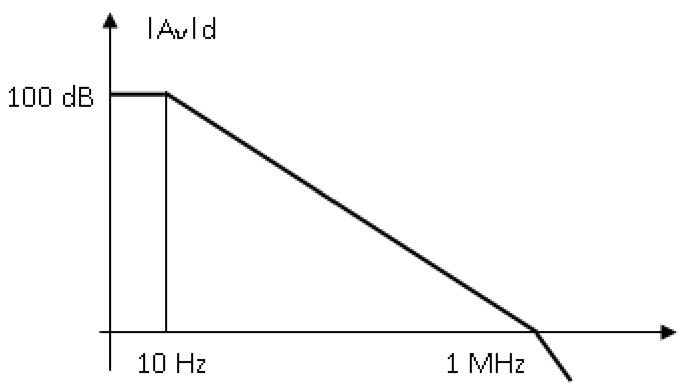

+VCC
-VCC
ε
Av
VS


Ve
VS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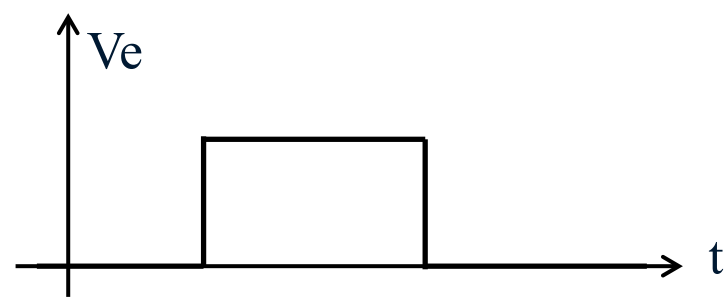
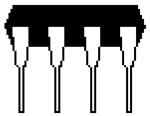
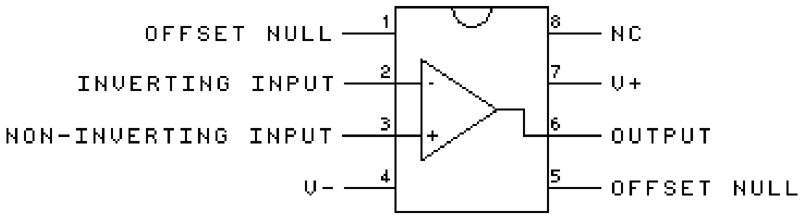
100 dB
10 Hz
1 MHz


Ve
t

741


LM741
CN 87

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V+
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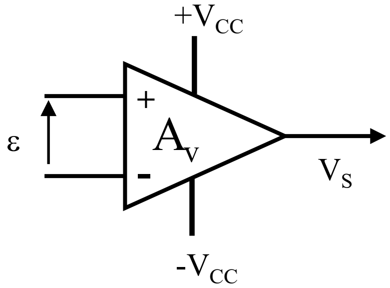
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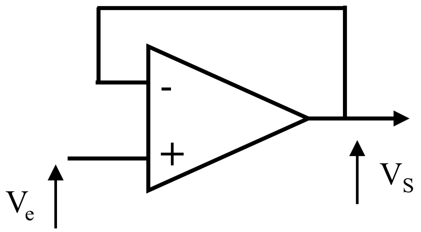
ε
Av
VS
-VCC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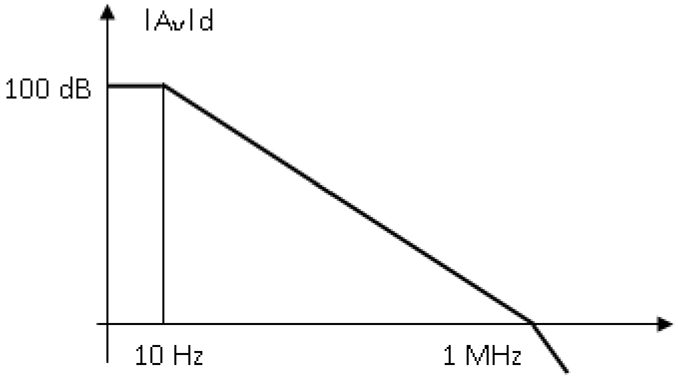
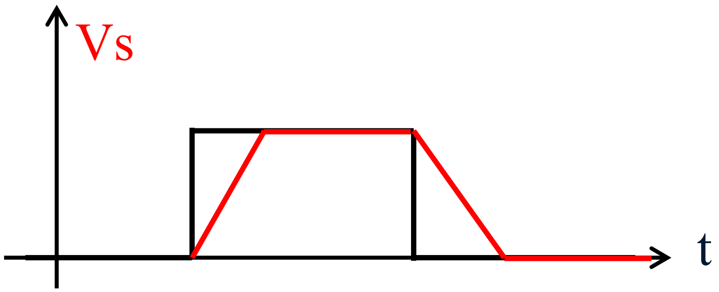
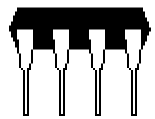
VS

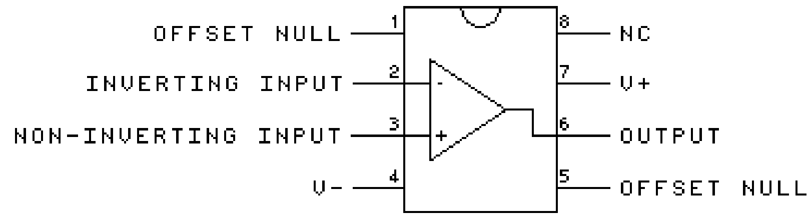

|Av|d
100 dB
10 Hz
1 MHz


Vs
t

741


LM741
CN 87

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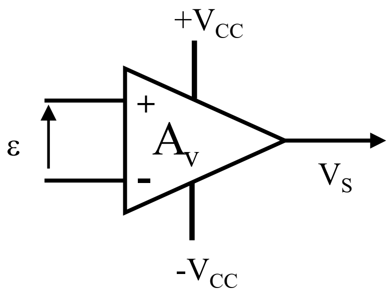
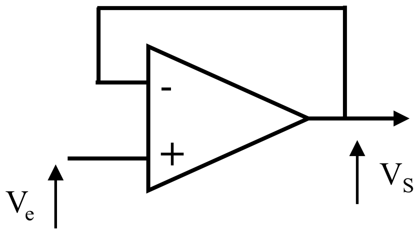
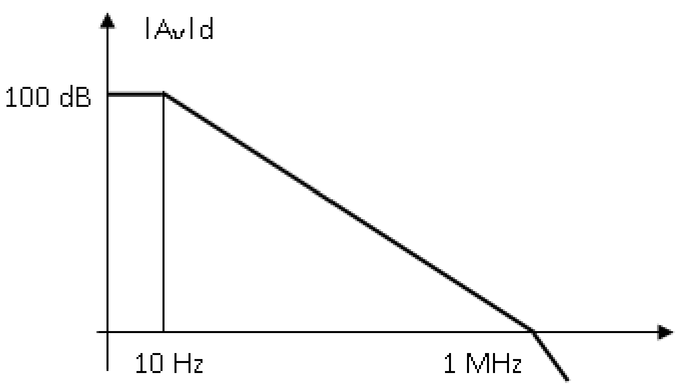
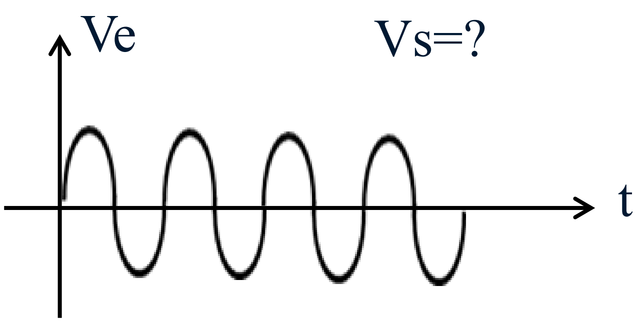
INVERTING INPUT
NON-INVERTING INPUT
V-
NC
V+
OUTPUT
OFFSET NULL
1
2
3
4
5
6
7
8


+VCC
ε
+
-
AV
VS
-VCC

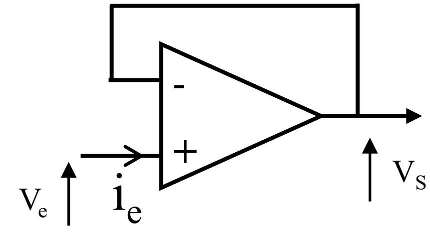

-
+
Ve
VS

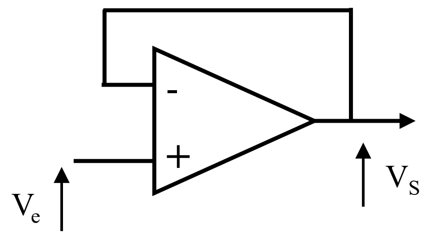

|Av|d
100 dB
10 Hz
1 MHz


Ve
Vs=?
t

II – Montage de base

$$V_s = V_e \text{ et } i_e = 0$$

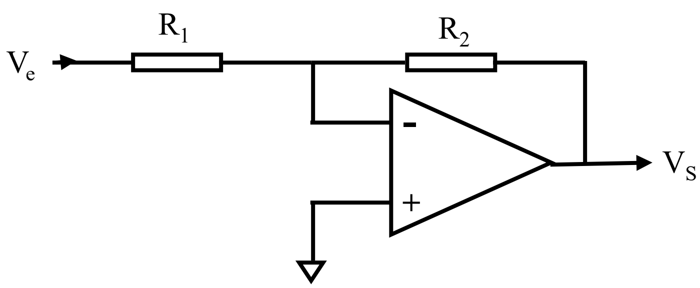




$$V_s = e_- = e_+ = V_e$$

- Montage suiveur (adaptation d'impédances)

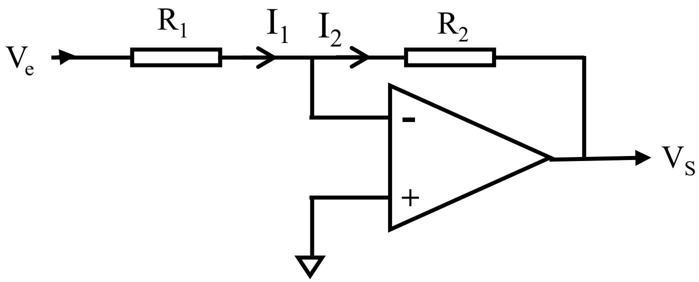
- Montage Inverseur



$$\frac{V_s}{V_e} = -\frac{R_2}{R_1}$$

Attention : $R_e = R_1$

➢ Montage Inverseur



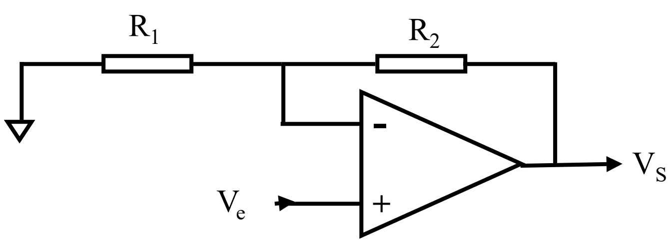
$$V_e - e_- = V_e - e_+ = V_e = R_1 I_1$$

$$I_2 = I_1$$

$$e_- - V_S = e_+ - V_S = -V = R_1 I_2$$

$$\frac{V_S}{V_e} = -\frac{R_2 I_2}{R_1 I_1} = -\frac{R_2}{R_1}$$

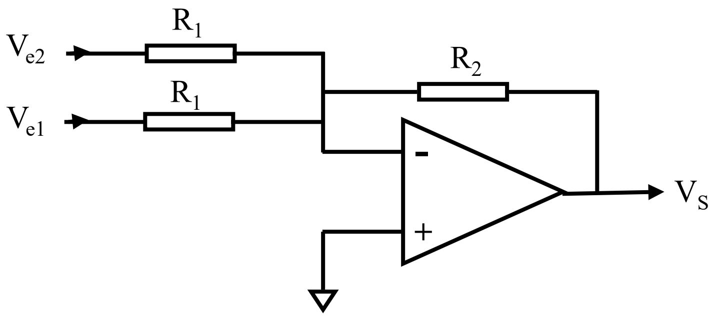
➢ Montage Non Inverseur



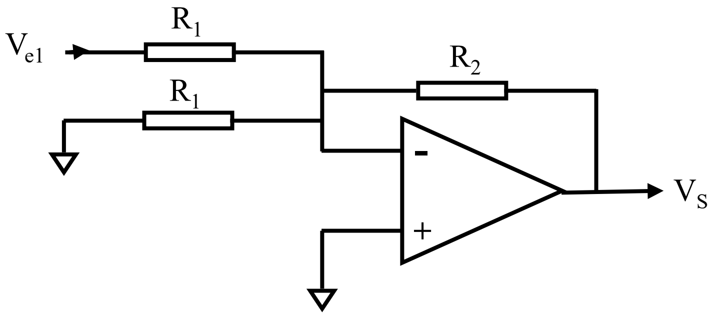
$$\frac{V_s}{V_e} = 1 + \frac{R_2}{R_1}$$

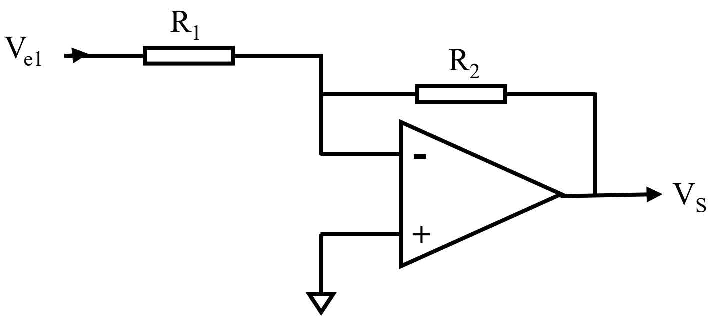
Attention : Contre-réaction sur l'entrée inverseuse (Patte -) et ici $R_e \rightarrow \infty$

- Montage Sommateur (Inverseur)



Théorème de superposition : V_{e1} seule



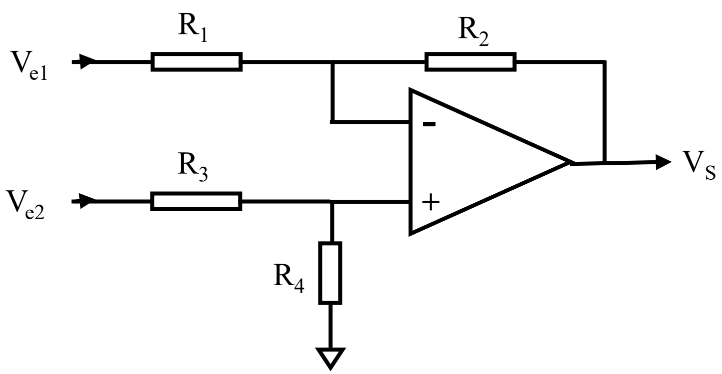


$$\frac{V_S}{V_{e1}} = -\frac{R_2}{R_1} \qquad V_S = -\frac{R_2}{R_1} V_{e1}$$

V_{e2} seule : identique ➔ $V_S = -\frac{R_2}{R_1} V_{e2}$

Total : V_{e1} et V_{e2} ➔ $V_S = -\frac{R_2}{R_1} V_{e1} - \frac{R_2}{R_1} V_{e2} = -\frac{R_2}{R_1}\left(V_{e1} + V_{e2}\right)$ $\qquad V_S = -\left(V_{e1} + V_{e2}\right)$

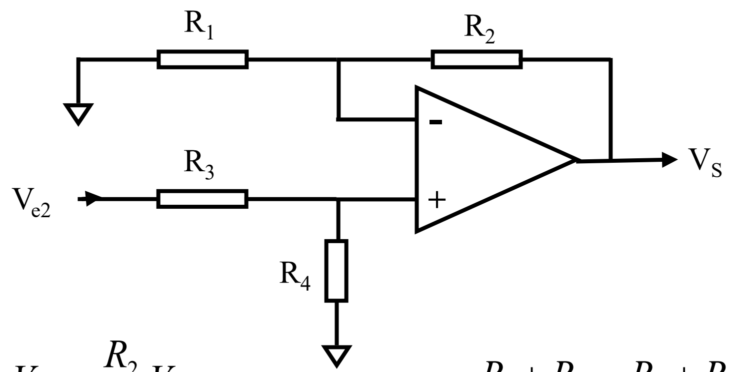
➢ Montage Soustracteur



Théorème de superposition : V_{e1} seule

$$\frac{V_S}{V_{e1}} = -\frac{R_2}{R_1} \qquad V_S = -\frac{R_2}{R_1} V_{e1}$$

V_{e2} seule



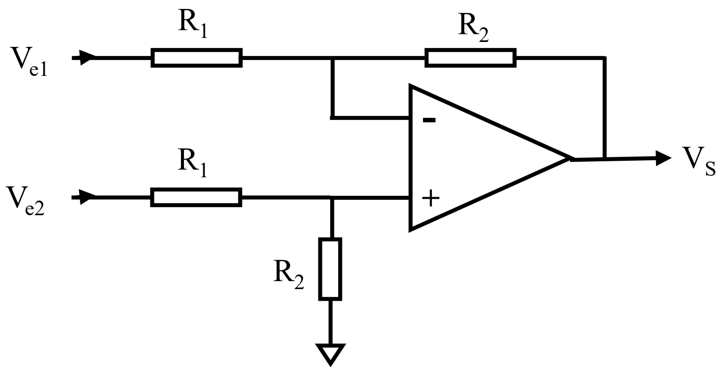
$$V_S = 1 + \frac{R_2}{R_1} e_+$$

$$e_+ = \frac{R_4}{R_3 + R_4} V_{e2} \qquad V_S = \left(\frac{R_1 + R_2}{R_1} \right) \frac{R_4}{R_3 + R_4} V_{e2} = \frac{R_2}{R_1} V_{e2}$$

$$R_1 + R_2 = R_3 + R_4 \quad et \quad R_2 = R_4$$
$$(R_1 = R_3)$$

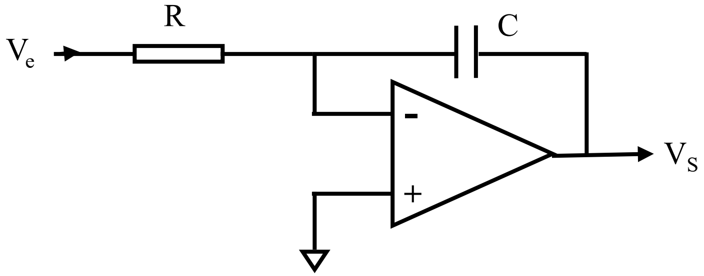
Total : V_{e2} et V_{e2} ➔ $V_S = -\frac{R_2}{R_1} V_{e1} + \frac{R_2}{R_1} V_{e1} = \frac{R_2}{R_1} (V_{e2} - V_{e1})$

- Montage Soustracteur



$$V_S = \frac{R_2}{R_1}\left(V_{e2} - V_{e1}\right)$$

- Montage Intégrateur

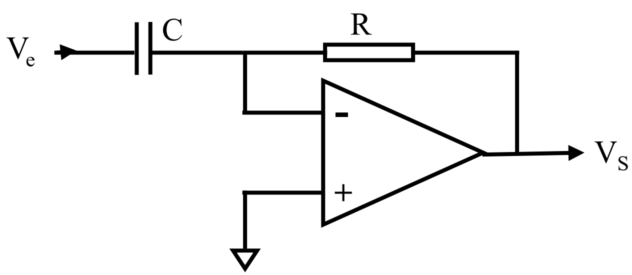


$$\frac{V_S}{V_e} = -\frac{Z_2}{Z_1} \qquad Z_2 = \frac{1}{jC\omega} \quad et \quad Z_1 = R$$

$$\frac{V_S}{V_e} = -\frac{1}{jRC\omega} \qquad i(t) = \frac{v_e(t) - e_-}{R} = C\frac{d(e_- - v_s)}{dt} = -C\frac{dv_s}{dt}$$

$$\frac{dv_s}{dt} = -\frac{v_e(t)}{RC} \Rightarrow v_S(t) = \frac{-1}{RC}\int_t v_e(u)du\left(+v_{s0}\right)$$

➢ Montage Différenciateur (ou Dérivateur)

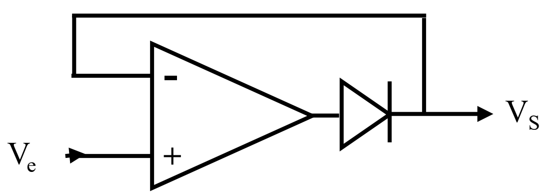


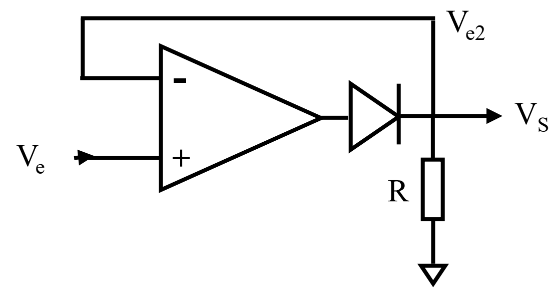
$$\frac{V_S}{V_e} = -\frac{Z_2}{Z_1} \qquad Z_1 = \frac{1}{jC\omega} \quad et \quad Z_2 = R$$

$$\frac{V_S}{V_e} = -jRC\omega \qquad i(t) = C\frac{d(v_e - e_-)}{dt} = \frac{e_- - v_S(t)}{R} = \frac{-v_S(t)}{R}$$

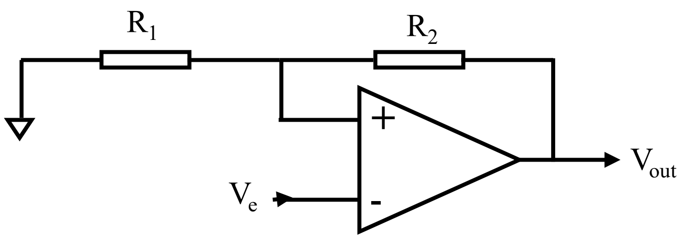
$$v_S(t) = -RC\frac{dv_e}{dt}$$

➢ Diode sans seuil





➢ Trigger de Schmitt

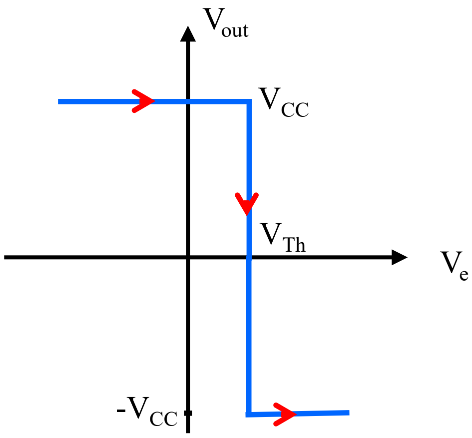


Contre-réaction sur l'entrée + : Comparateur

$$V_{out} = \mp V_{CC} \quad \Rightarrow \quad Deux\ seuils : \mp V_{Th} = \mp V_{CC} \frac{R_1}{R_1 + R_2}$$

Si à t=0 on a $V_e = e_- = -V_{CC}$ et $V_{out} = +V_{CC}$

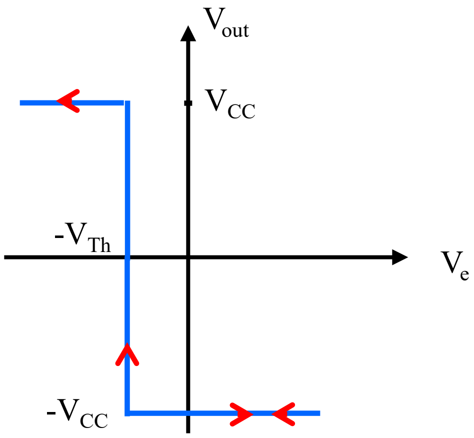
Alors : $e_+ = \dfrac{R_1}{R_1 + R_2} V_{cc} = V_{Th}$ et $e_+ > e_-$ ➔ $V_{out} = V_{cc}$



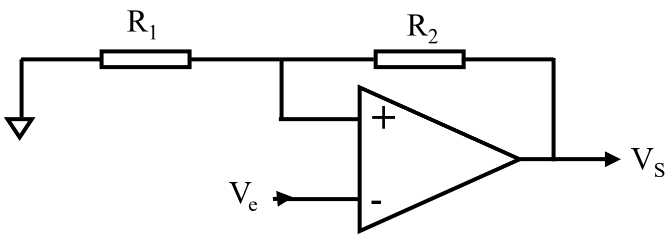
V_e ↗ et si $V_e \geq V_{Th}$ alors $e_- \geq e_+$

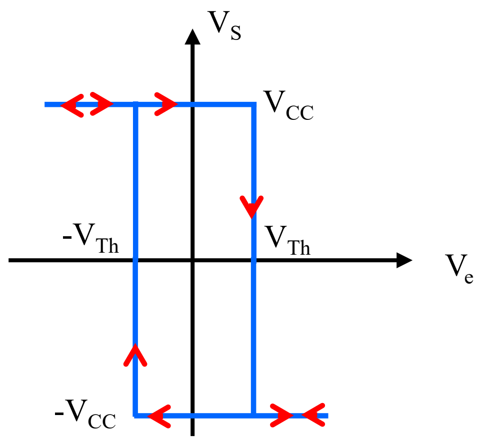
➔ $V_{out} = -V_{cc}$ et

$$e_+ = \frac{-R_1}{R_1 + R_2} V_{cc} = -V_{Th}$$



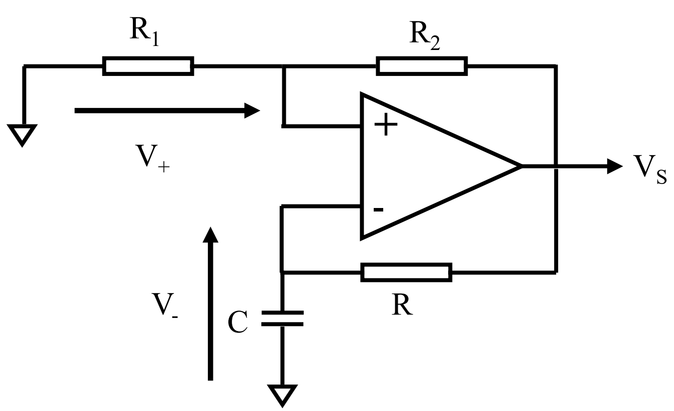
- Trigger de Schmitt





Application : fréquencemètre

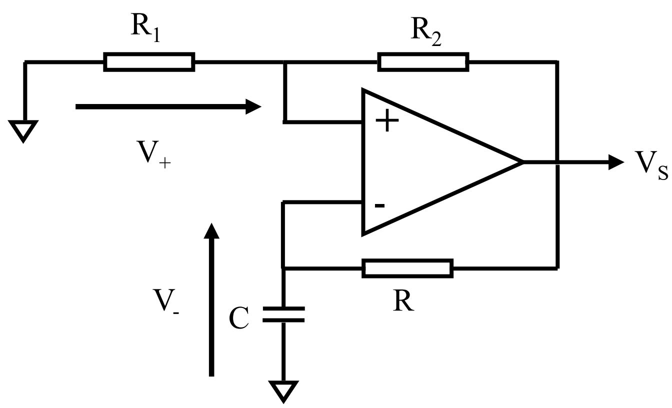
- Multivibrateur



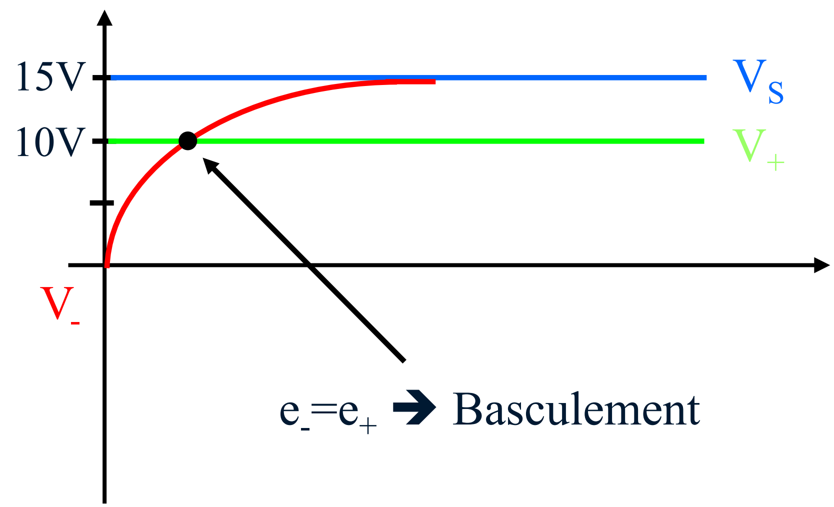
Prenons : V_{cc}=15 et V_S=10V $\left(Soit \quad \frac{R_1}{R_1+R_2} = \frac{1}{1,5} \right)$

On suppose à t=0, V_s=V_{cc} (donc V_+=V_{Th}=10V)
Et la capacité est déchargée ➔ V_-=0V
➔ Elle va vouloir se charger « jusqu'à V_{cc} »

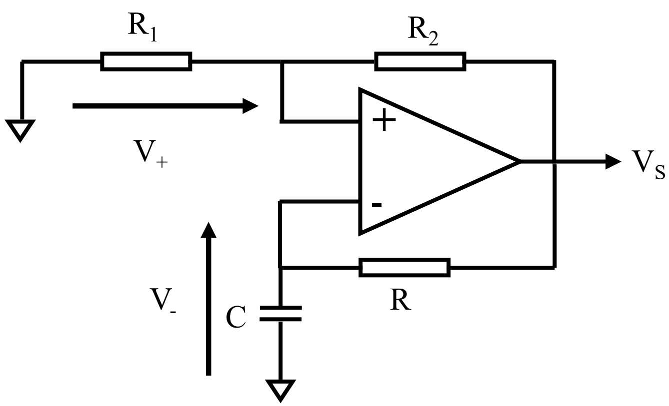
- Multivibrateur

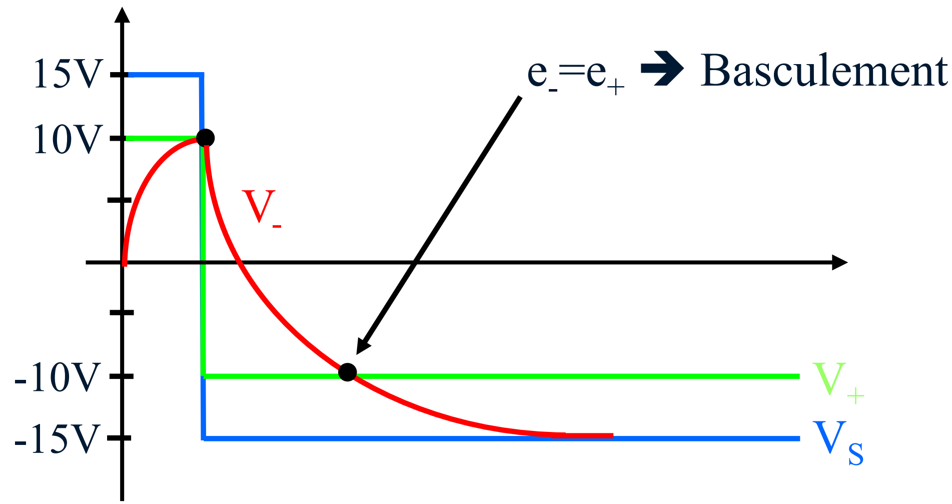


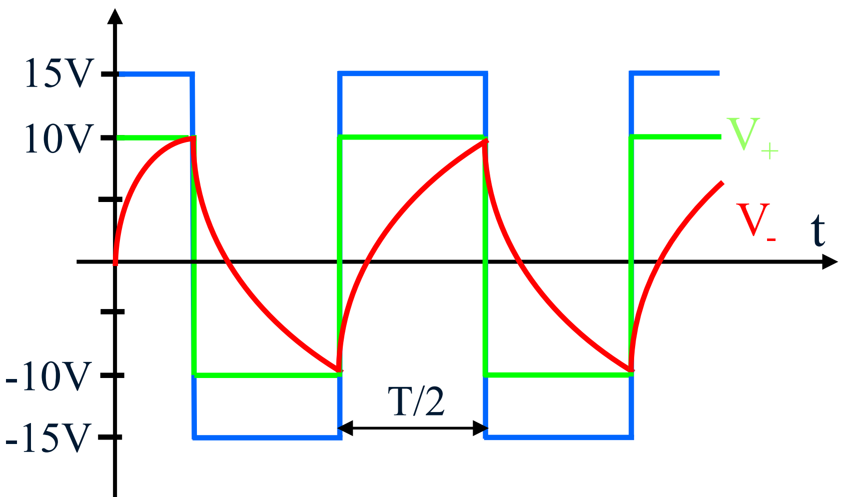
On suppose à t=0, $V_s=V_{cc}$ (donc $V_+=V_{Th}=10V$)
Et la capacité est déchargée ➔ $V_-=0V$
➔ Elle va vouloir se charger « jusqu'à V_{cc} »



- Multivibrateur





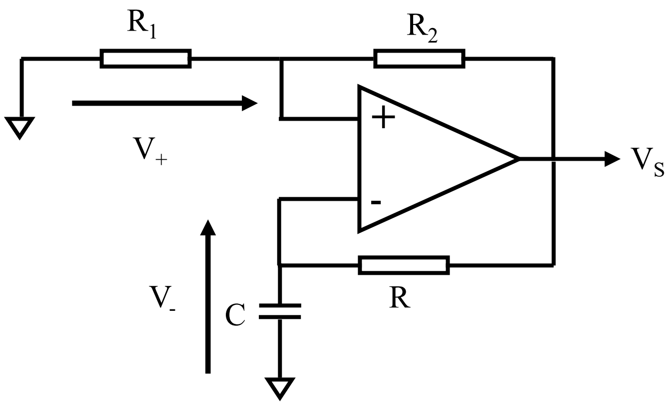


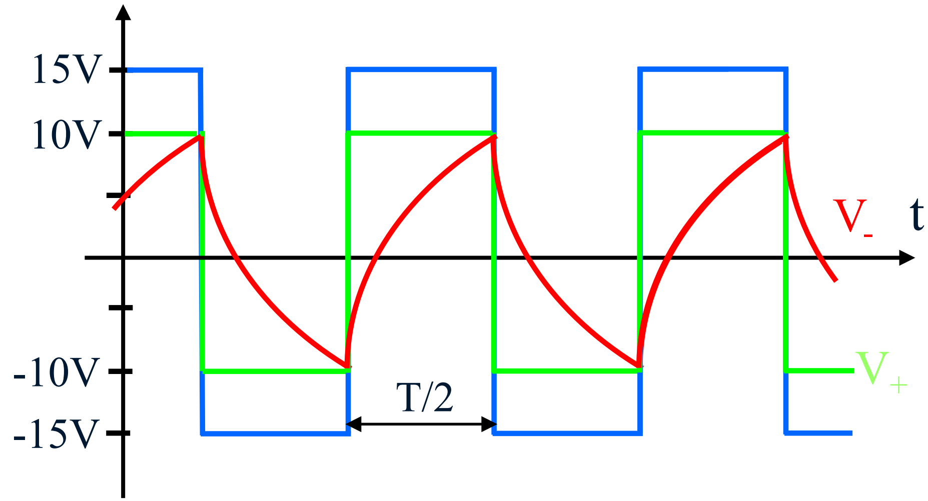
$$V_{cc} = 15V \quad V_i = V_{Th} = -10V = -V_{cc}\frac{R_1}{R_1+R_2}$$

$$V_-(t) = V_f\left(1-e^{-t/\tau}\right) + V_i e^{-t/\tau} \quad \tau = RC$$

$$V_f = V_{cc} \quad V_i = -V_{Th} = -V_{cc}\frac{R_1}{R_1+R_2}$$

- Multivibrateur





$$V_-(T/2) = V_{cc}(1 - e^{-T/2\tau}) - V_{cc}\frac{R_1}{R_1 + R_2}e^{-T/2\tau} = V_{Th} = V_{cc}\frac{R_1}{R_1 + R_2}$$

$$1 - e^{-T/2\tau} - \frac{R_1}{R_1 + R_2}e^{-T/2\tau} = \frac{R_1}{R_1 + R_2}$$

$$e^{-T/2\tau} + \frac{R_1}{R_1 + R_2}e^{-T/2\tau} = 1 - \frac{R_1}{R_1 + R_2}$$

$$e^{-T/2\tau}\left(\frac{R_1}{R_1 + R_2} + 1\right) = \frac{R_2}{R_1 + R_2}$$

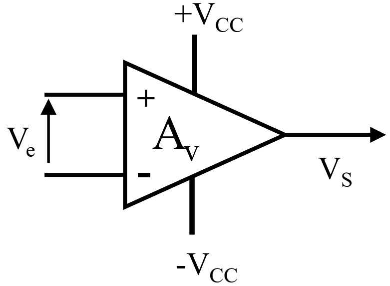
$$e^{-T/2\tau}\left(\frac{R_1}{R_1 + R_2} + 1\right) = \frac{R_2}{R_1 + R_2}$$

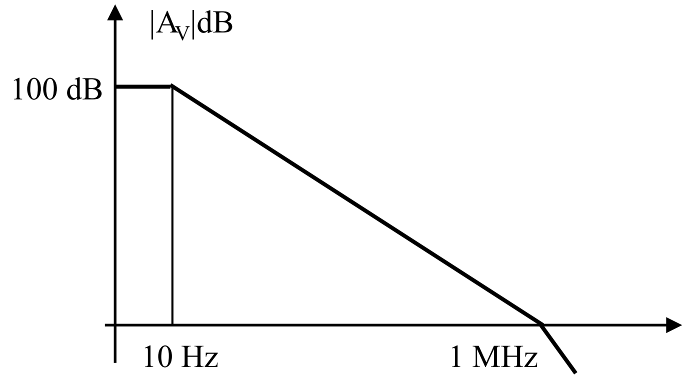
$$e^{-T/2\tau}\left(R_1 + R_1 + R_2\right) = R_2$$

$$-T/2\tau = \ln\left(\frac{R_2}{2R_1 + R_2}\right)$$

$$T = 2RC\ln\left(1 + \frac{2R_1}{R_2}\right)$$

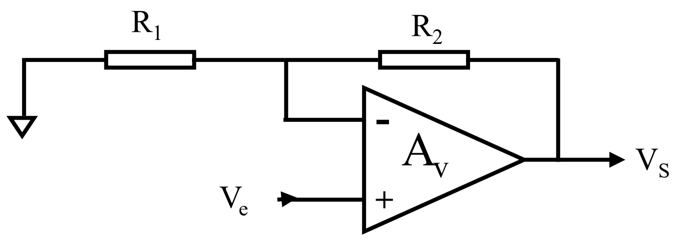
III – 741





$$A_v = \frac{A_0}{1 + j\dfrac{f}{f_c}}$$

$$\begin{cases} f_c = 10 Hz \\ A_O f_c = 1 MHz \end{cases}$$

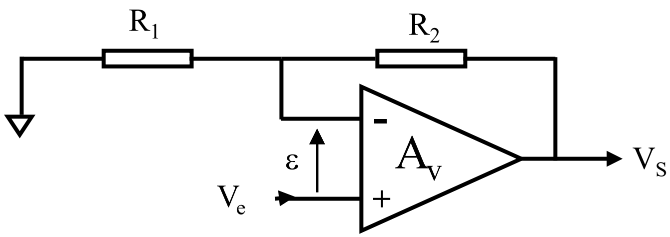


$$Si\ A_v \rightarrow \infty \ \ alors\ \frac{V_s}{V_e} = 1 + \frac{R_2}{R_1}$$

Que se passe-t-il si A_V est fini?

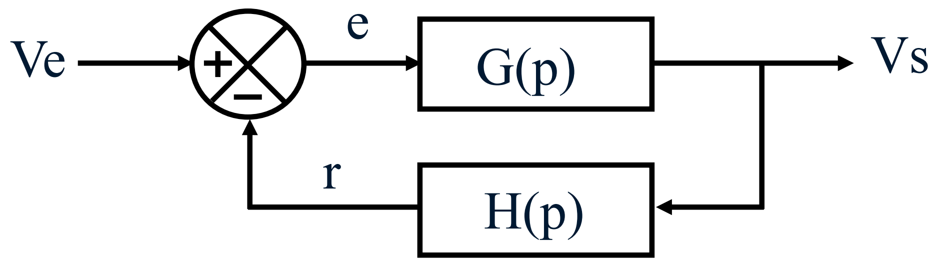
$$A_v = \frac{A_0}{1 + j\dfrac{f}{f_c}}$$

- Notions de contre-réaction

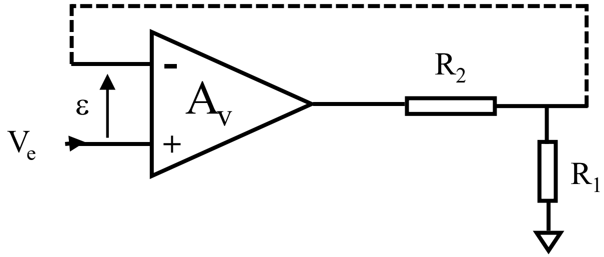


$$V_s = A_v(e_+ - e_-) = -A_v\varepsilon = A_v e$$

$$e_+ = V_e \quad e_- = \frac{R_1}{R_1+R_2}V_s = r$$

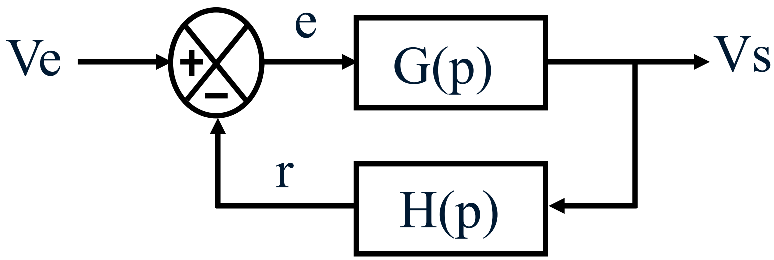


$$\left.\begin{array}{l} e = V_e - r \\ r = H.V_s \\ V_s = G.e \end{array}\right\} \Rightarrow \quad \frac{V_S}{V_e} = \frac{G}{1+GH}$$

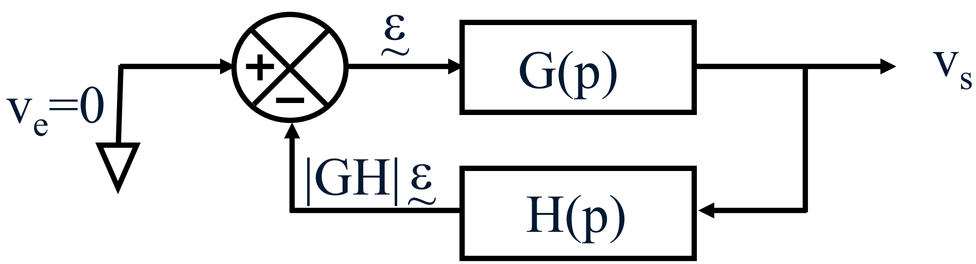


$$G = A_V \quad H = \frac{R_1}{R_1+R_2}$$

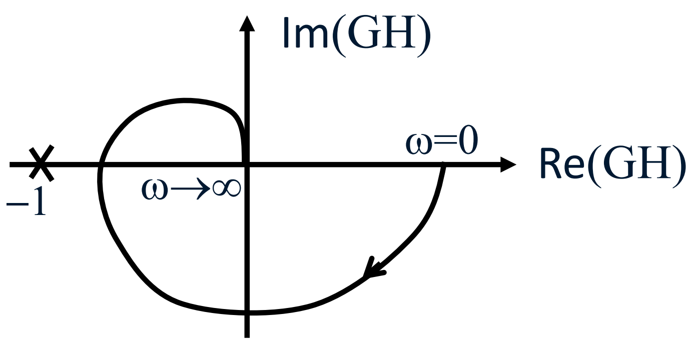
- stabilité d'un système contre-réactioné



G(p) : FT du système en boucle ouverte
H(p) : FT de la réaction
Q(p) : FT du système en boucle fermée
G(p)H(p) : FT de boucle

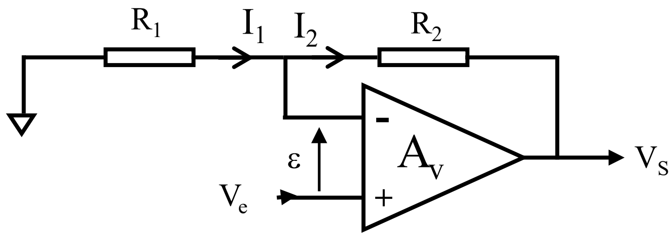


$$V_S = \frac{G}{1+GH} V_e \qquad |GH| \begin{cases} > \\ = \\ < \end{cases} 1$$



Critère de Nyquist !
Stable si les pôles sont à partie réelle négative (pôle dans D_-) : 1+GH(p)=0

Amplificateur Opérationnel



On a toujours $I_1 = I_2$

$$V_s = A_v\left(e_+ - e_-\right) = -A_v\varepsilon \qquad \varepsilon = -V_s / A_v$$

$$e_+ = V_e \qquad e_- = V_e + \varepsilon$$

$$I_1 = \frac{0 - e_-}{R_1} = \frac{-V_e - \varepsilon}{R_1} = I_2 = \frac{V_e + \varepsilon - V_s}{R_2}$$

$$\left(-V_e + \frac{V_S}{A_v}\right)R_2 = \left(V_e - \frac{V_S}{A_v} - V_s\right)R_1$$

$$V_S\left(\frac{R_2}{A_v} + \frac{R_1}{A_v} + R_1\right) = V_e\left(R_1 + R_2\right)$$

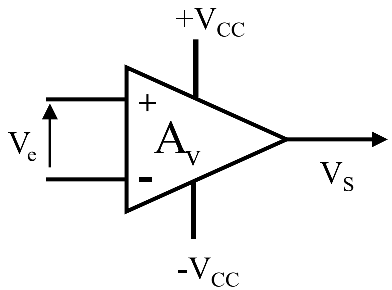
$$\frac{V_S}{V_e} = \frac{R_1 + R_2}{\frac{R_2}{A_v} + \frac{R_1}{A_v} + R_1} = \frac{A_v\left(R_1 + R_2\right)}{R_1 + R_2 + A_v R_1} = \frac{A_v}{1 + A_v \frac{R_1}{R_1 + R_2}} = \frac{G}{1 + GH}$$

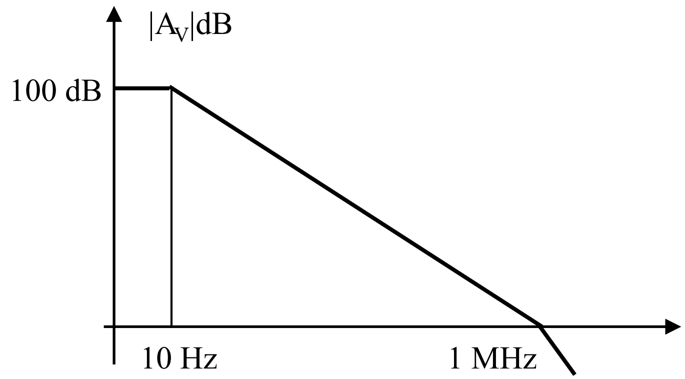
$$\begin{cases} G = A_v \\ GH = A_v \dfrac{R_1}{R_1 + R_2} \end{cases}$$

$$\frac{V_S}{V_e} = \frac{G}{1 + GH} \qquad H = \frac{R_1}{R_1 + R_2} \qquad \frac{1}{H} = 1 + \frac{R_2}{R_1}$$

Amplificateur Opérationnel

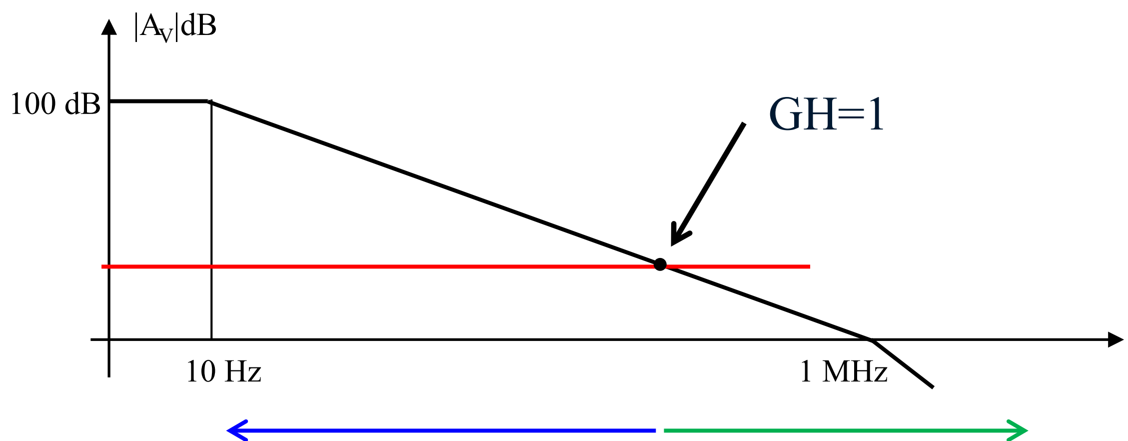
741





$$A_v = \frac{A_0}{1 + j\dfrac{f}{f_c}}$$

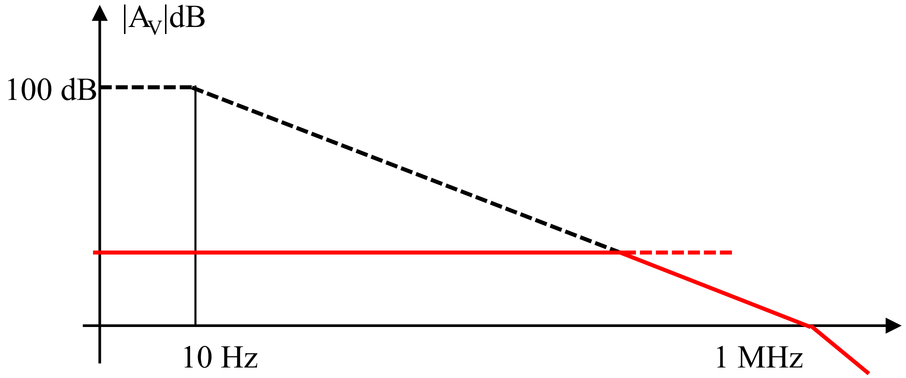
$$\begin{cases} f_c = 10Hz \\ A_O f_c = 1MHz \end{cases}$$

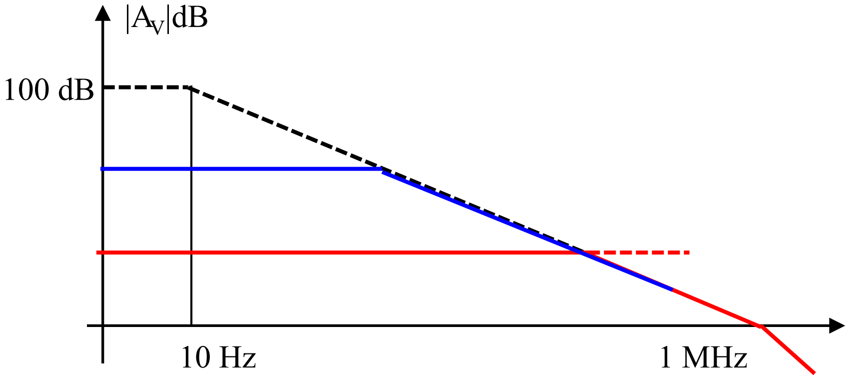


$$\frac{V_S}{V_e} = \frac{G}{1 + GH}$$

$G >> \dfrac{1}{H}$ GH>>1 $G << \dfrac{1}{H}$ GH<<1

Amplificateur Opérationnel



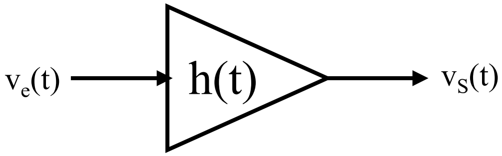


➔ G.BW=Cste

I – Théorie échantillonnage

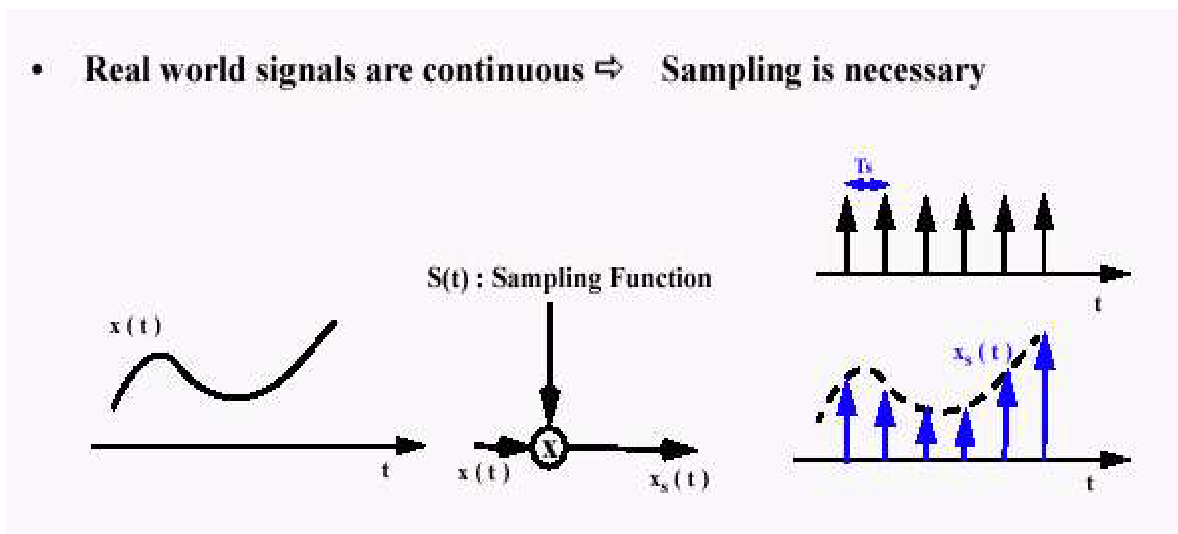
- Rappel Filtre LI

$$v_s(t) = h(t) * v_e(t) = \int h(t-\theta).v_e(\theta)d\theta \qquad v_s(t) = h(t) * \delta(t) = h(t)$$



$$V_s(f) = H(f).V_e(f) \qquad H(f) = \frac{V_s(f)}{V_e(f)}$$

- Echantillonnage



Echantillonnage

➢ Echantillonnage

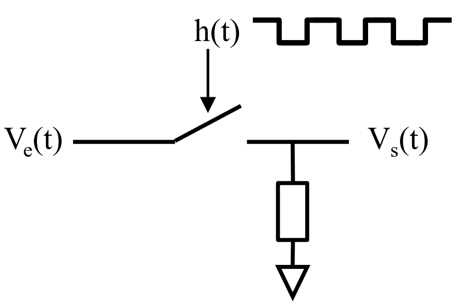
$$v_s(t) = v_e(t).\sum_{k=-\infty}^{+\infty}\delta(t-kT_e) = v_e(t).Ш_{T_e}(t) \qquad Ш_{T_e}(t) \rightleftharpoons \frac{1}{T_e}Ш_{\frac{1}{T_e}}(f)$$

$$V_s(f) = V_e(f)*\frac{1}{T_e}\sum_{k=-\infty}^{+\infty}\delta\left(f-\frac{k}{T_e}\right) = \frac{1}{T_e}V_e(f)*Ш_{\frac{1}{T_e}}(f)$$

Echantillonnage dans le domaine temporel ➔ Périodisation dans le Domaine fréquentiel (Exemple cos et modulation amplitude)

➔ Shannon : Echantillonner à deux fois la fréquence maximale du signal

➔ Filtre anti-repliement (anti-aliasing) : Filtre Passe-Bas

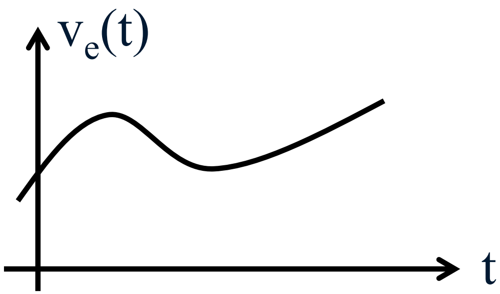


On pose : $\begin{cases} Interrupteur\ \ fermé: h(t)=1 & \Rightarrow v_s(t) = v_e(t).1 = v_e(t).h(t) \\ Interrupteur\ ouvert: h(t)=0 & \Rightarrow v_s(t) = v_e(t).0 = v_e(t).h(t) \end{cases}$

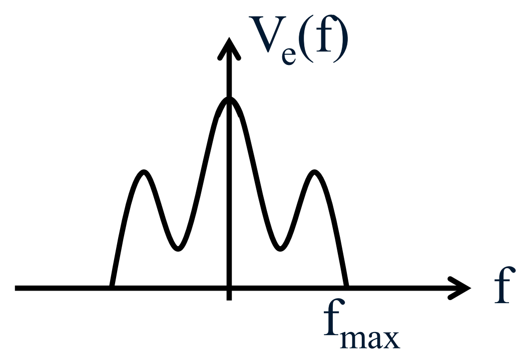
Dans la pratique ➔ Echantillonneur-bloqueur

Echantillonnage

- ➔ Echantillonnage ➔ Périodisation du spectre

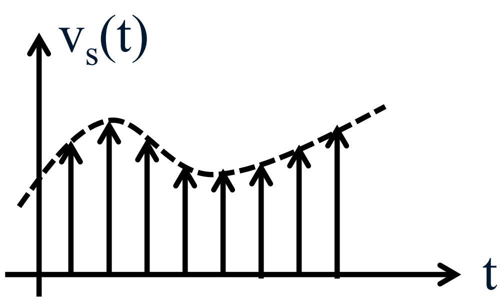


$\rightleftharpoons$

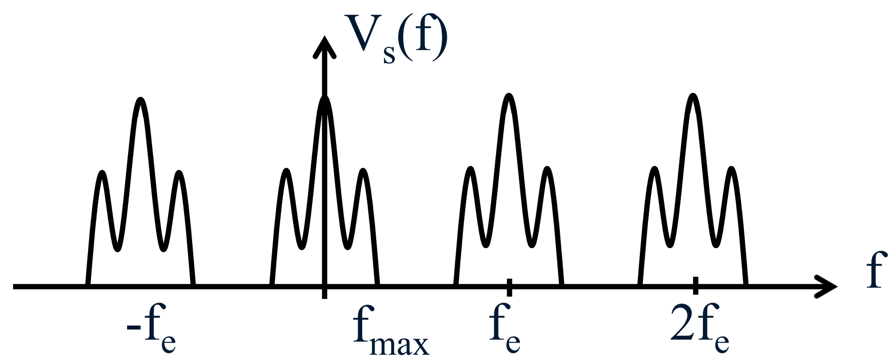


$$v_s(t) = v_e(t).\sum_{k=-\infty}^{+\infty}\delta(t-kT_e) = v_e(t).Ш_{T_e}(t)$$

$$V_s(f) = V_e(f) * \frac{1}{T_e}\sum_{k=-\infty}^{+\infty}\delta(f-\frac{k}{T_e}) = \frac{1}{T_e}V_e(f) * Ш_{\frac{1}{T_e}}(f)$$



$\rightleftharpoons$

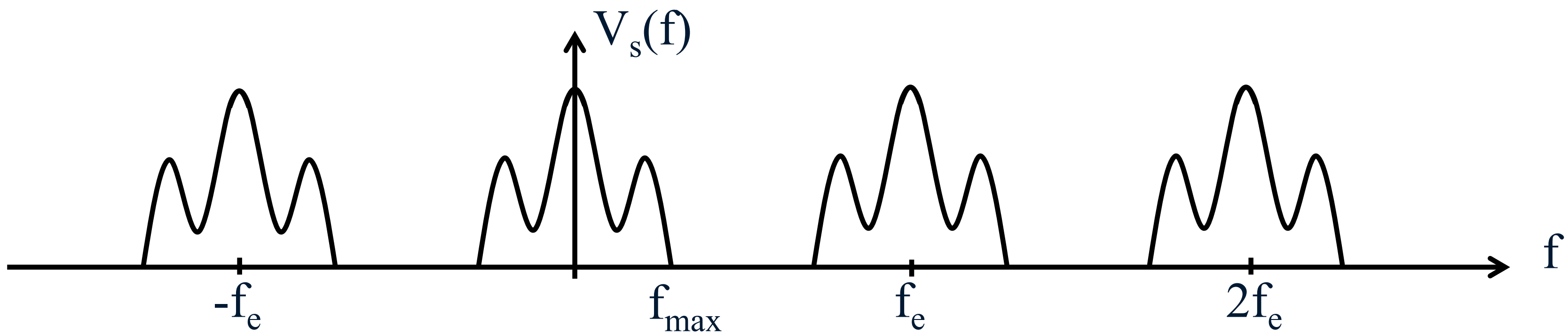


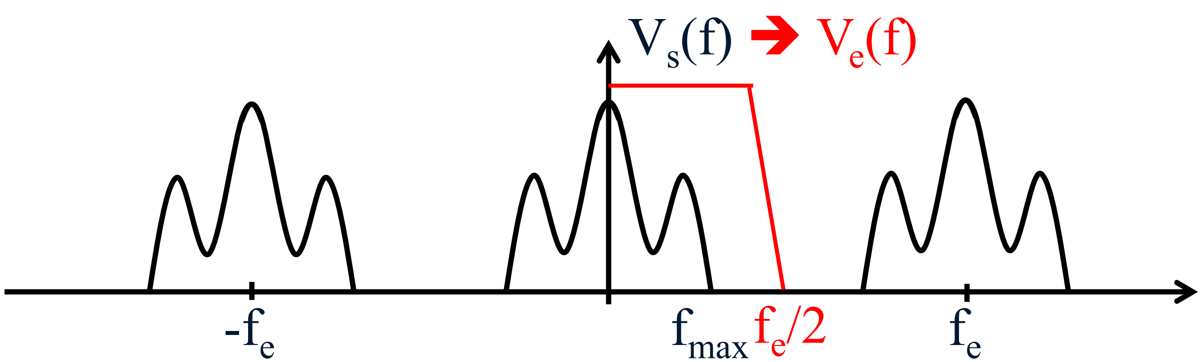
Echantillonnage

- Echantillonnage ➔ Périodisation du spectre

  ➔ Shannon : Echantillonner à deux fois la fréquence maximale du signal

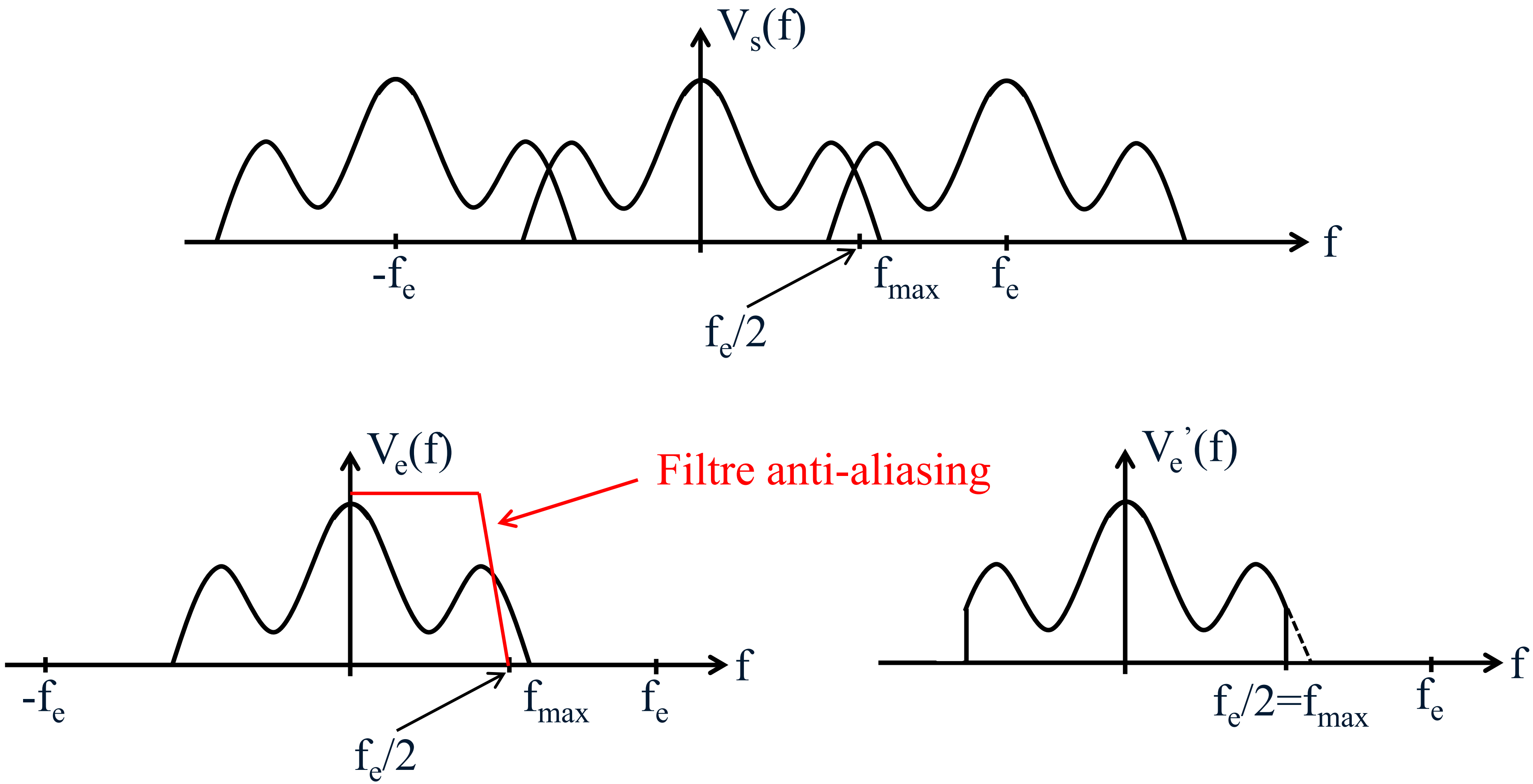
  ➔ Filtre anti-repliement (anti-aliasing) : Filtre Passe-Bas





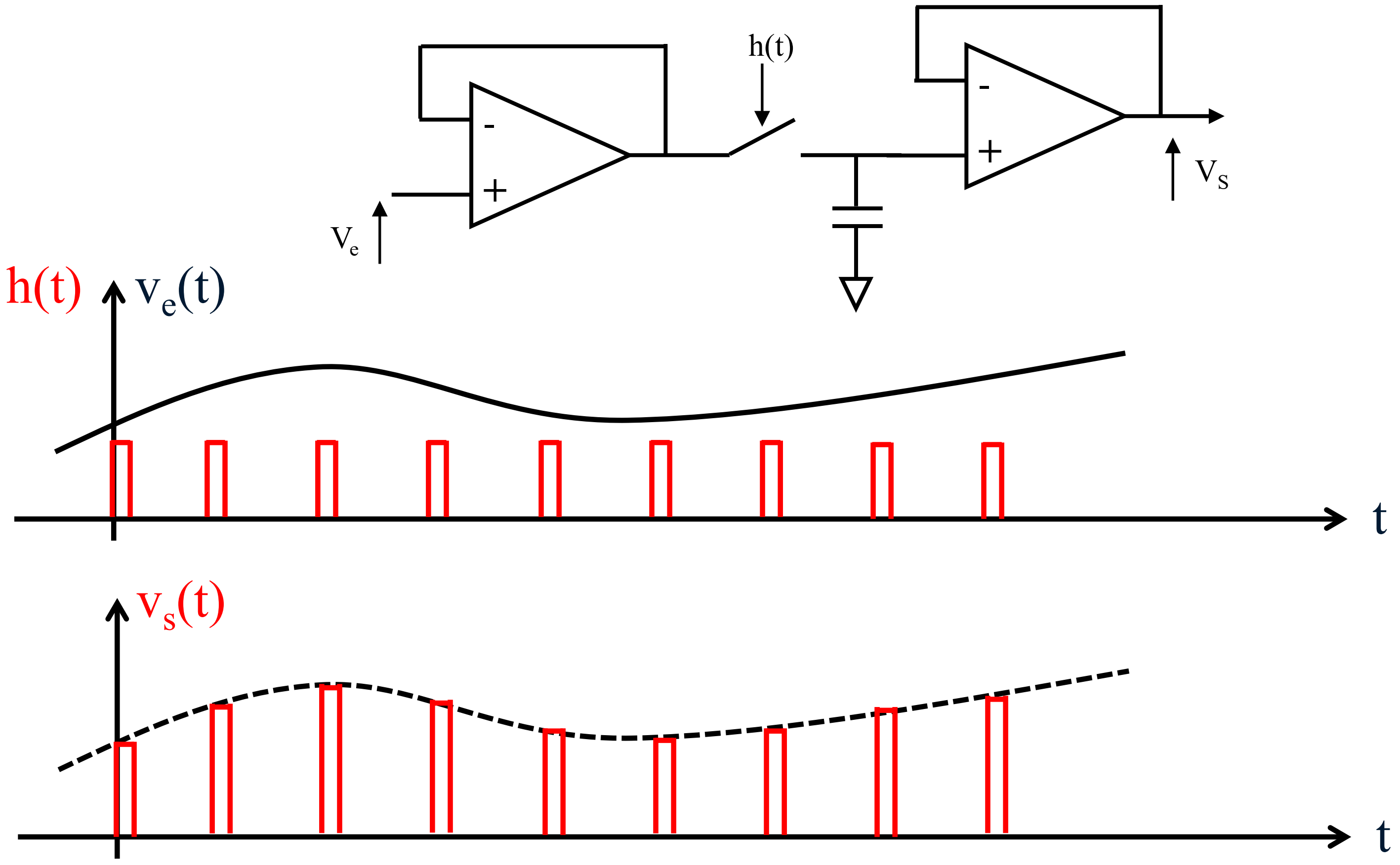
$$f_{\max} \leq \frac{f_e}{2} \quad \Rightarrow \quad f_e \geq 2 f_{\max}$$

Echantillonnage



Echantillonnage

➢ Echantillonneur-bloqueur : Sample and Hold

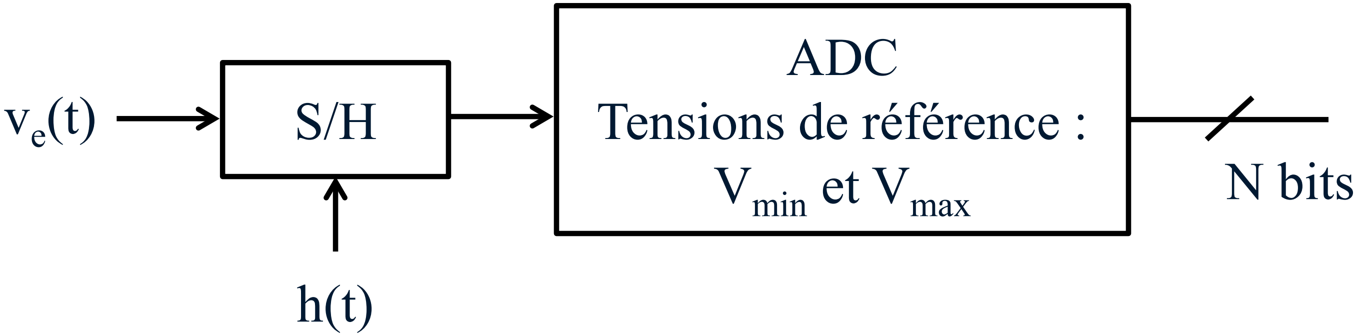


Echantillonnage

- Quantification

Attention échantillonnage différent de quantification (électronique analogique échantillonnée : filtres à capacités commutées, dispositifs à transfert de charges, …)

Signal numérique = signal échantillonné puis quantifié
➔ Convertisseur analogique-numérique (CAN ou ADC en anglais)

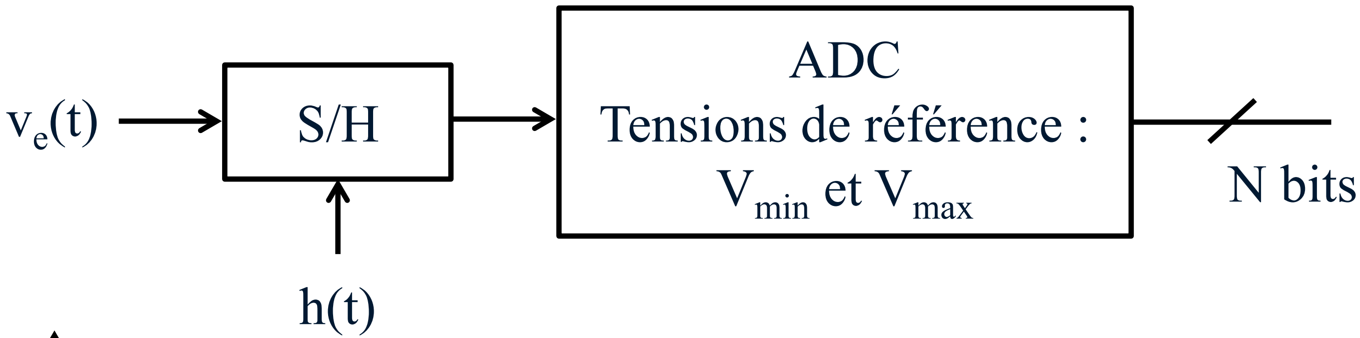


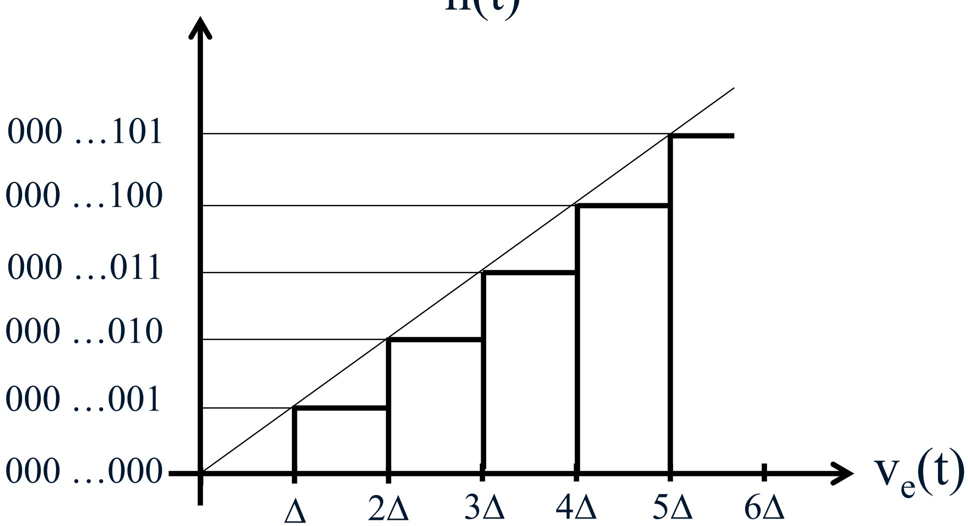
➔ Pas de quantification (erreur de conversion) : $\Delta = \frac{V_{max} - V_{min}}{2^N}$

Exemple : V_{max}-V_{min}=5-0=5V et N=8 bits ➔ Δ=19,5 mV

Echantillonnage

➔ ADC idéal (erreur de conversion ➔ bruit)





➔ Possibilité de codage en sortie

- Entier signé ou non
- Codage de Gray
- BCD
- …

➔ Bruit de quantification : $\pm\Delta/2$ (Puissance : $\Delta^2/12$)

Echantillonnage

➔ ADC : Exemple Convertisseur Simple Rampe

Conception Mixte : Projet Elec5