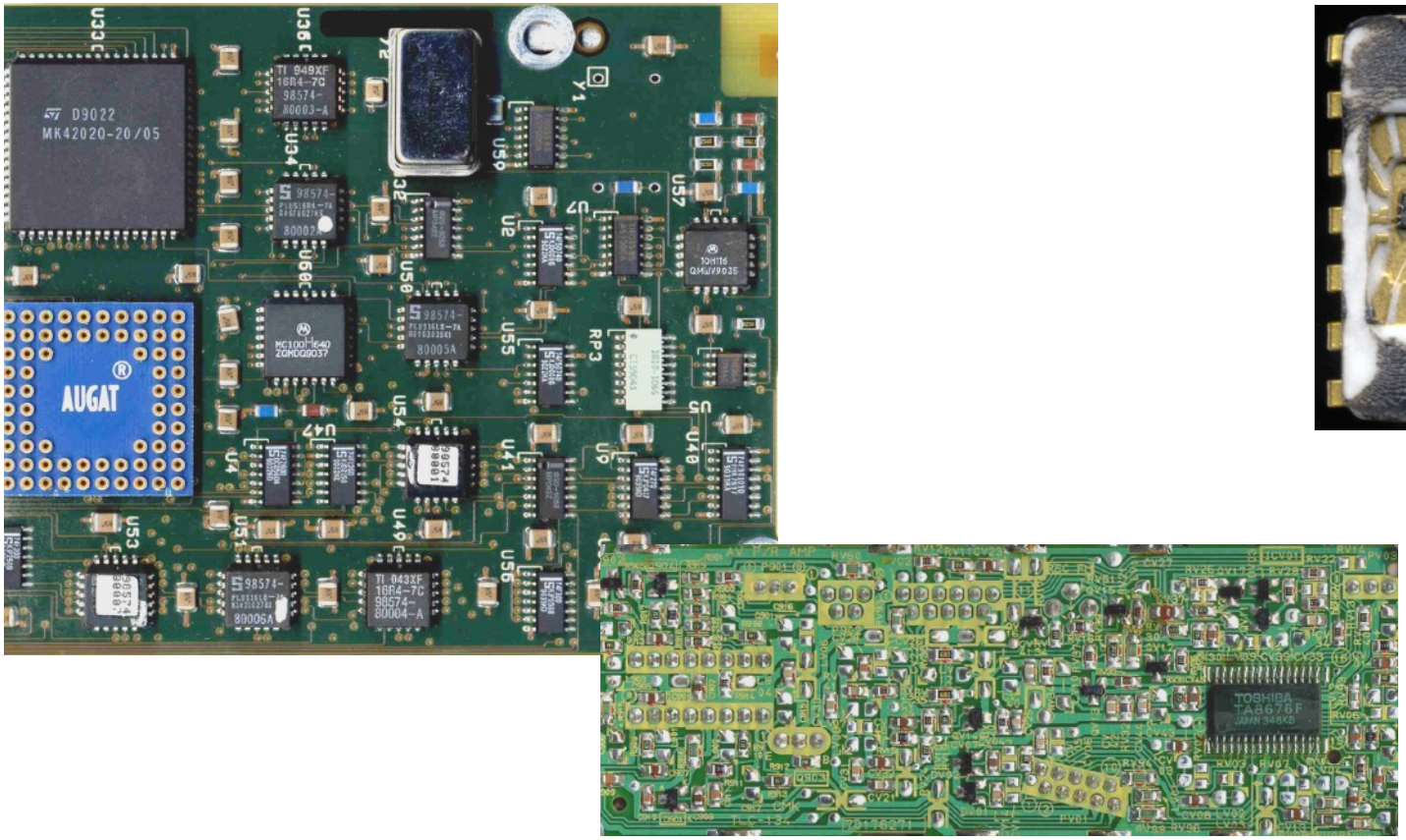
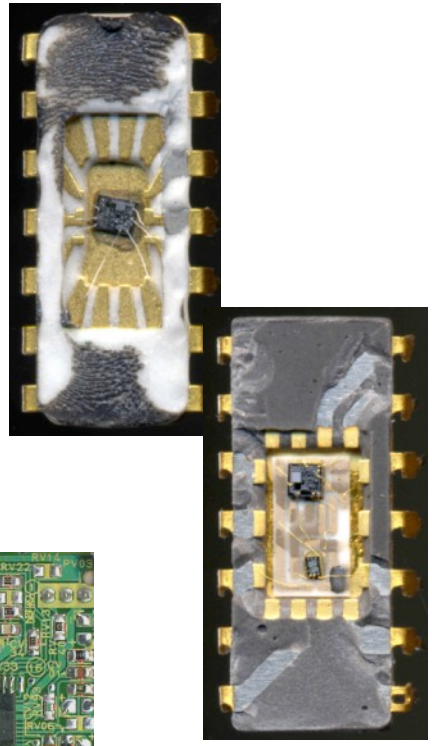
Circuits II - circuits électroniques et filtrage

D. Mari





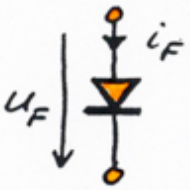
Circuits électroniques

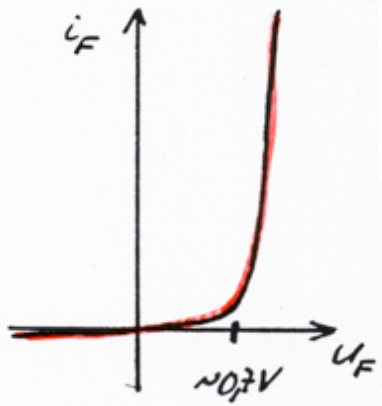
On appellera circuits électroniques des circuits électriques dans lesquels interviennent **des éléments non-linéaires et/ou des éléments actifs**.

Eléments non-linéaires

$$i = f_{ne}(u) \Rightarrow \text{résistance non linéaire}$$

Diodes

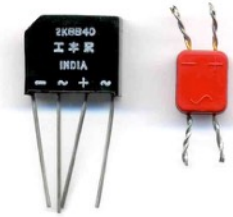




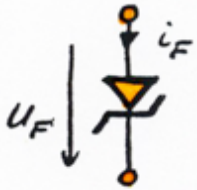
$$i_F = i_{so}\left[e^{\frac{eU_F}{kT}} - 1\right]$$

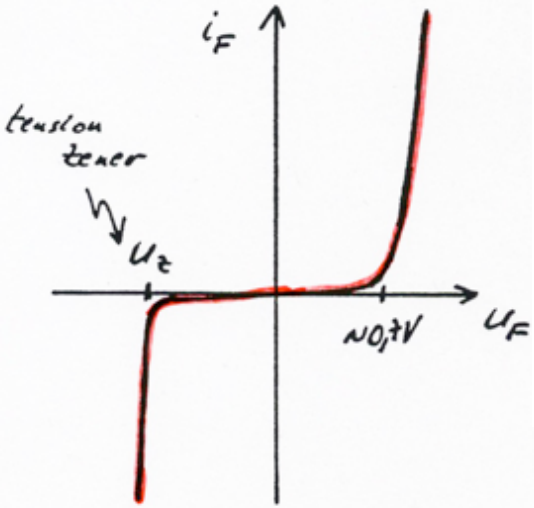
i_{so}= courant inverse de saturation

e=charge de l'électron



Diodes Zener





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$$u_z \in [2V, 100V]$$

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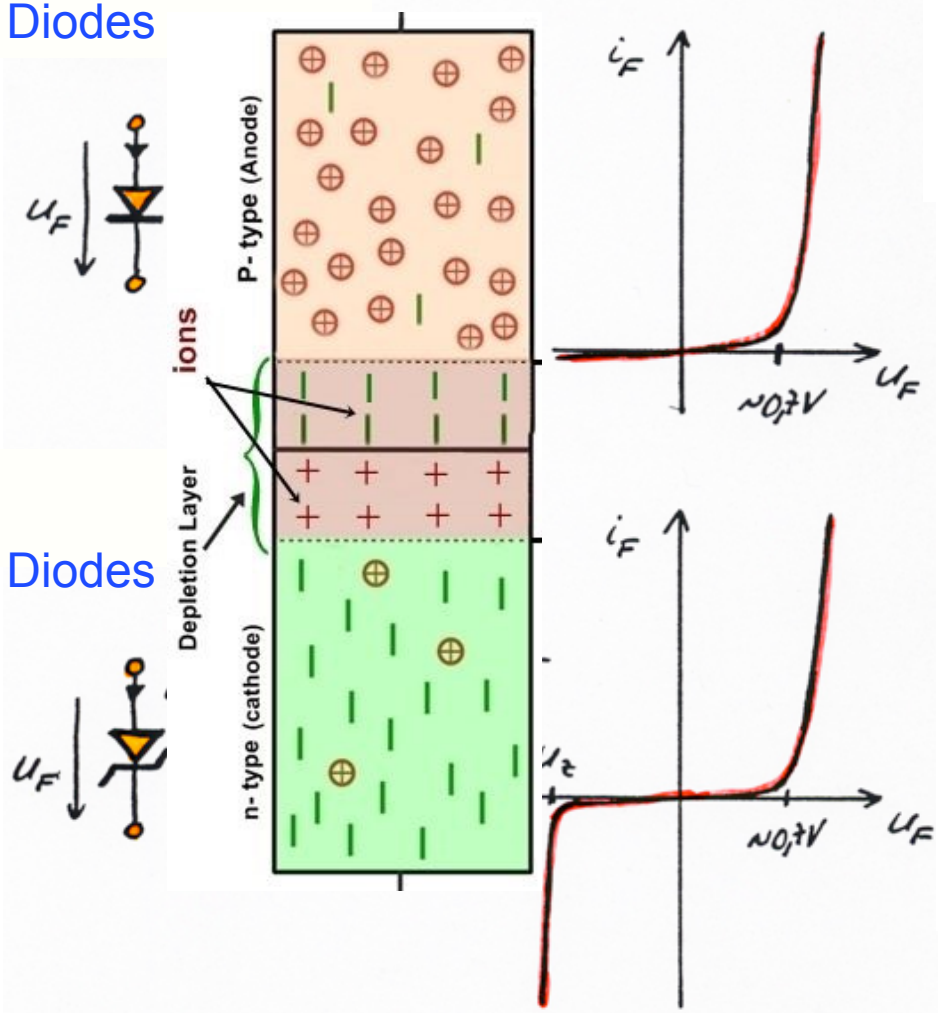

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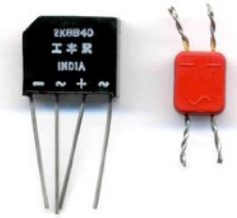

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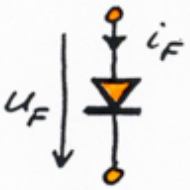
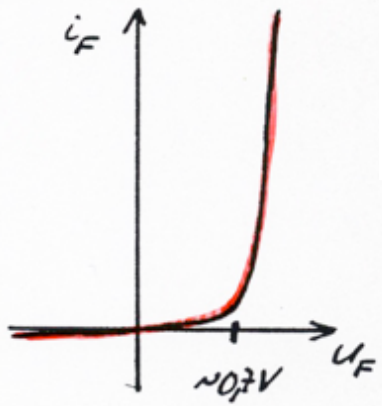
Diodes





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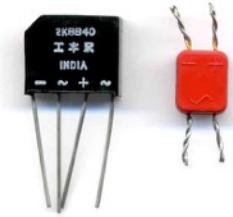

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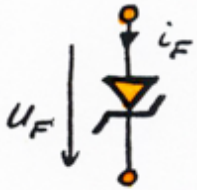

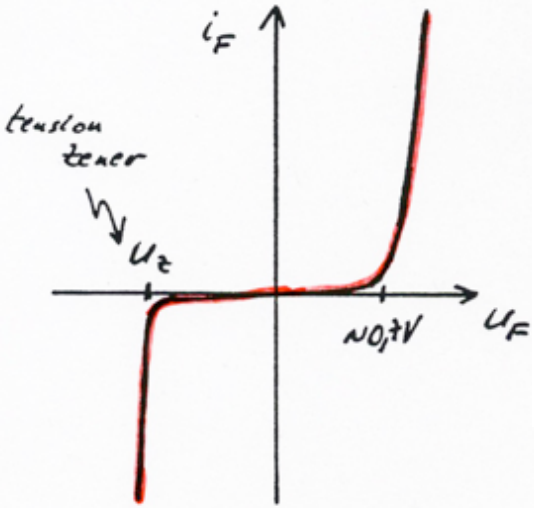

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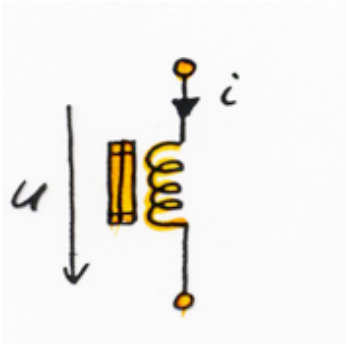
Eléments non-linéaires

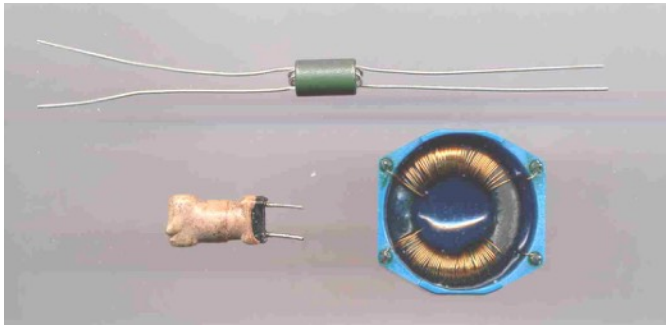
Selfs à noyau magnétique



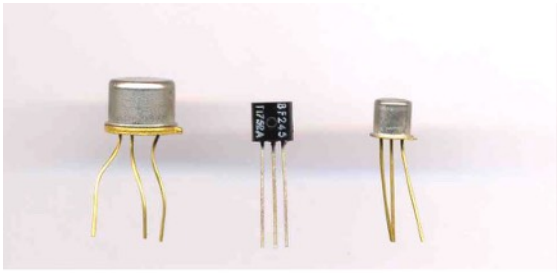
$$\boxed{\phi = f_{nl}(i)}$$

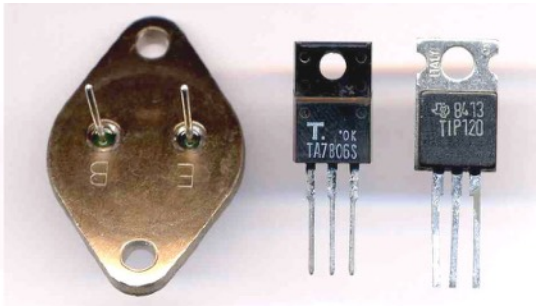
$$u = \frac{d\phi}{dt}$$

$\Rightarrow$ inductance non linéaire

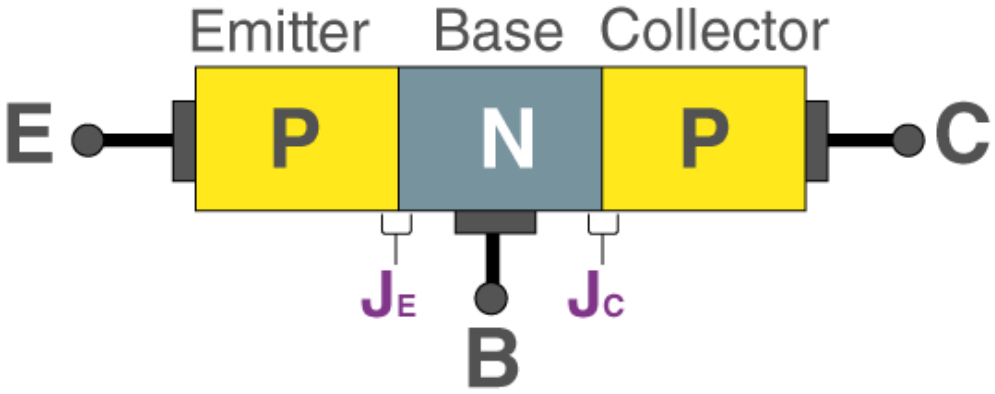


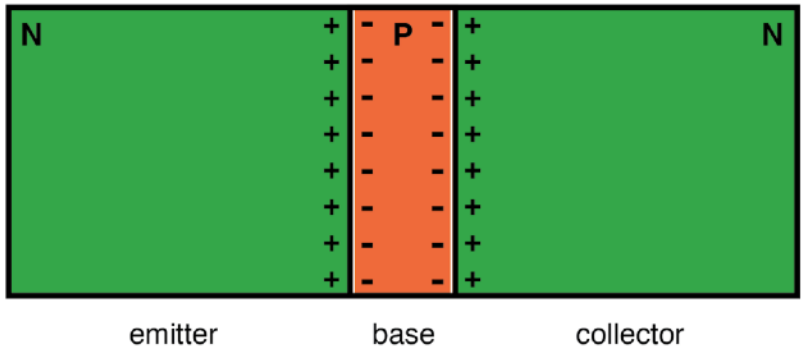
Eléments actifs

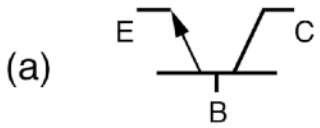




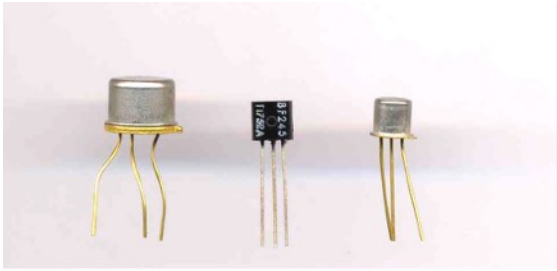
Transistors bipolaires PNP et NPN

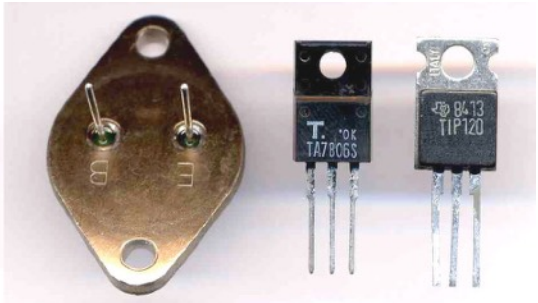




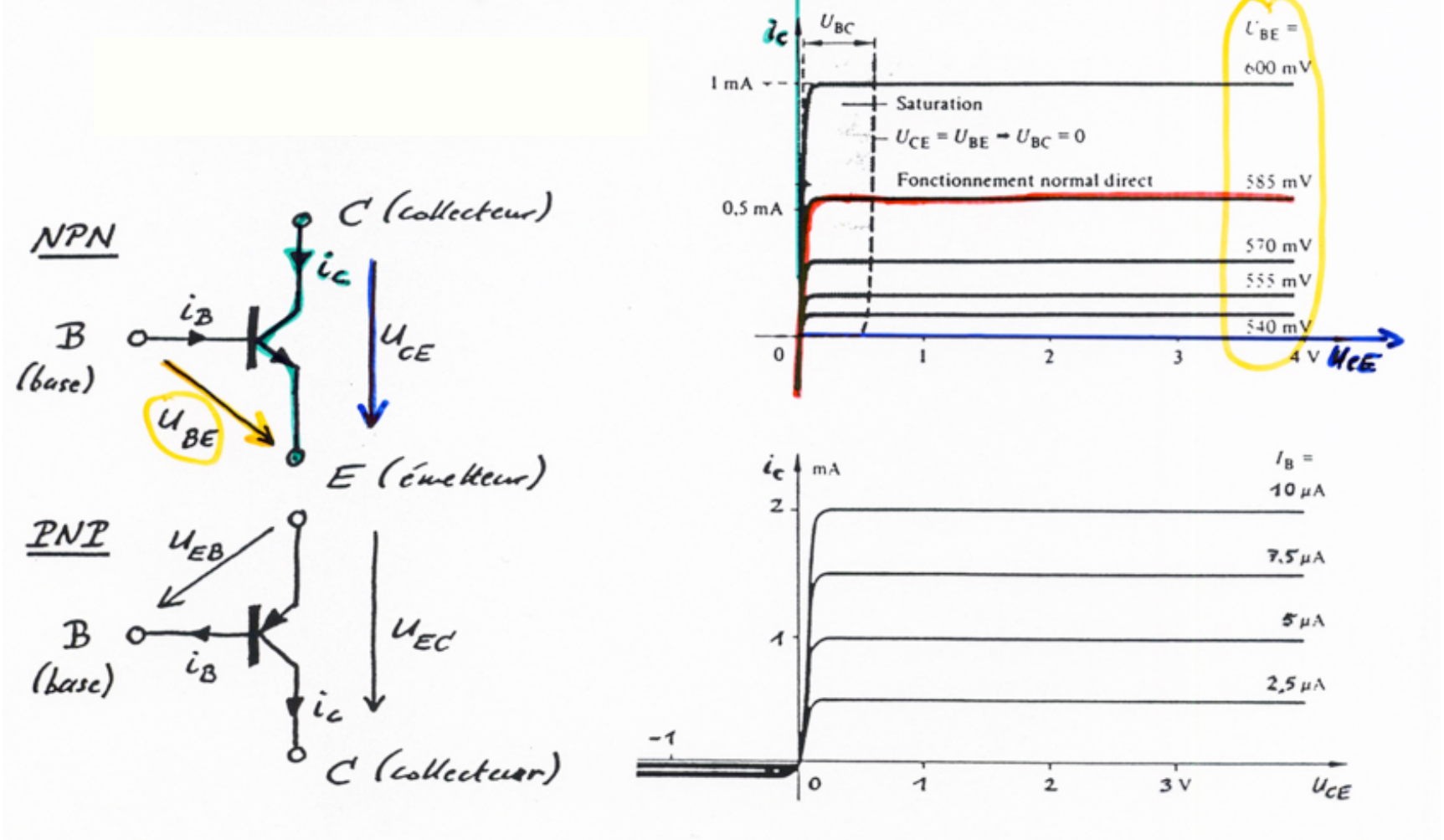


Eléments actifs

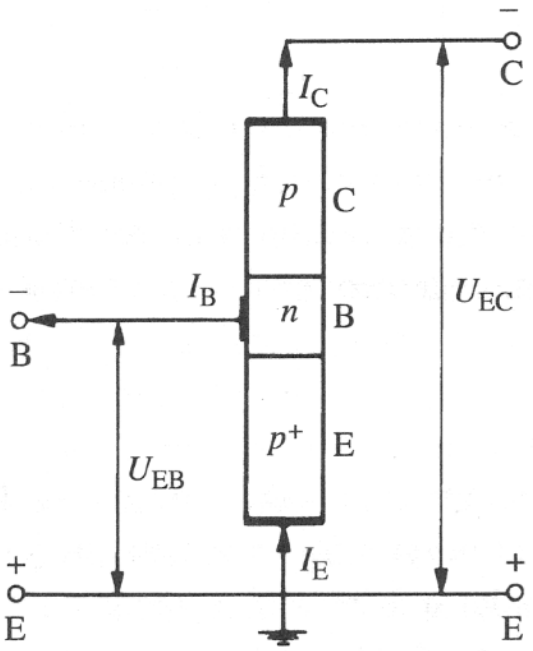


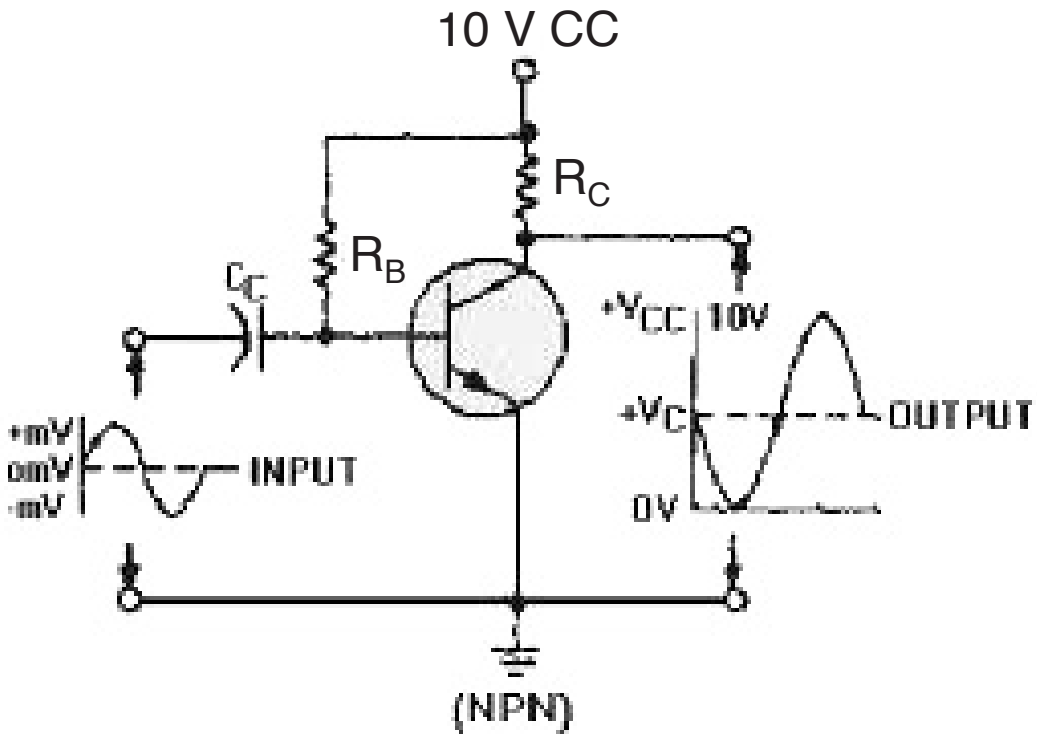


Transistors bipolaires NPN et PNP

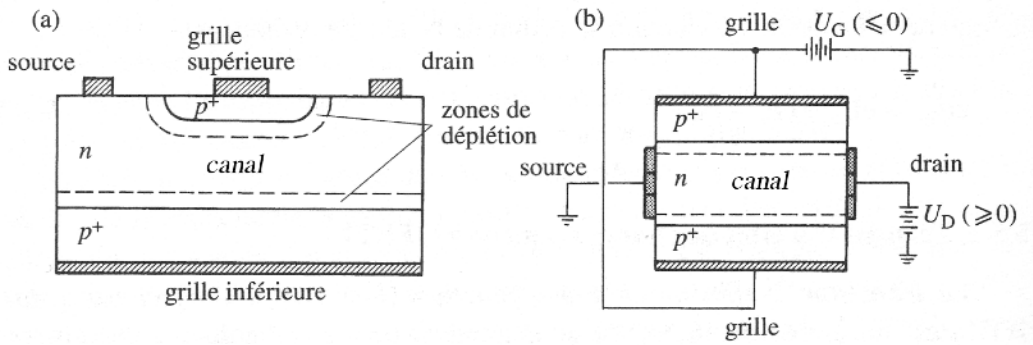


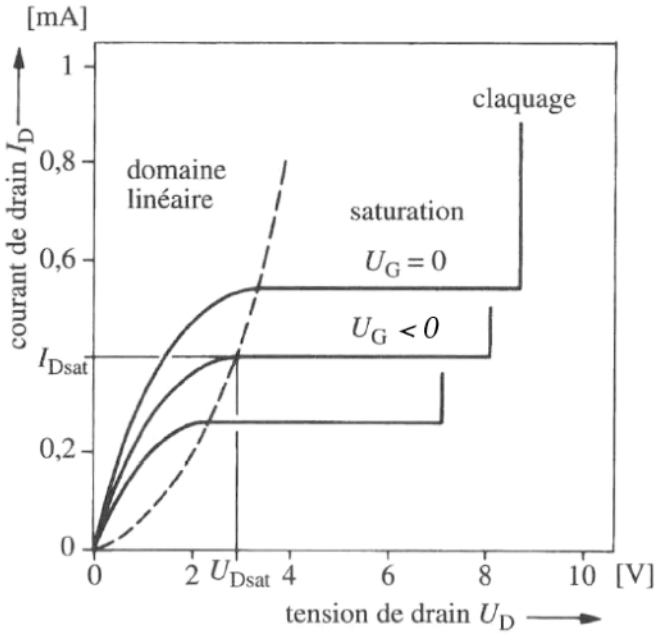
Le transistor comme amplificateur





Le transistor J-FET: caractéristiques





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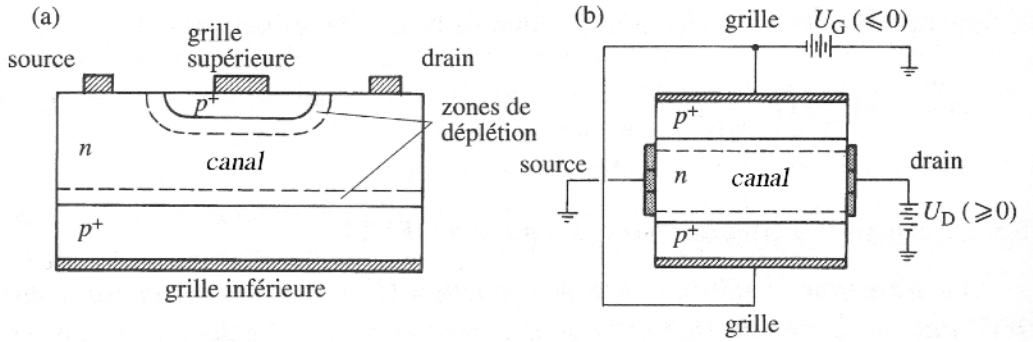
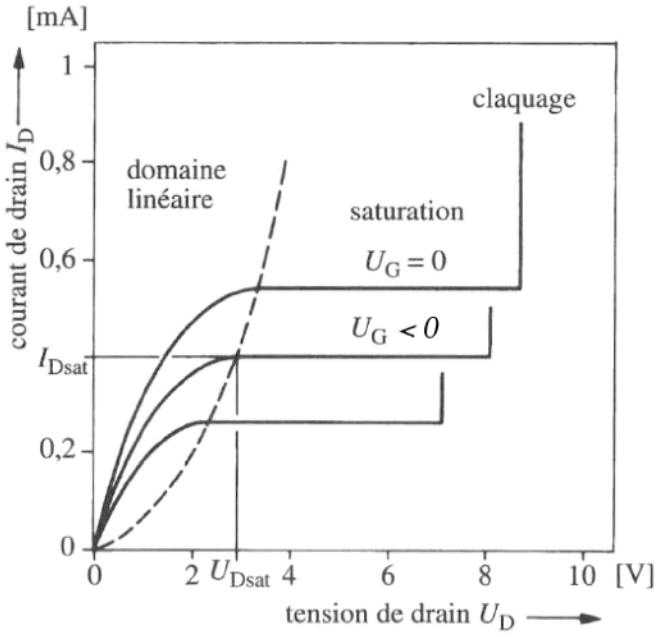
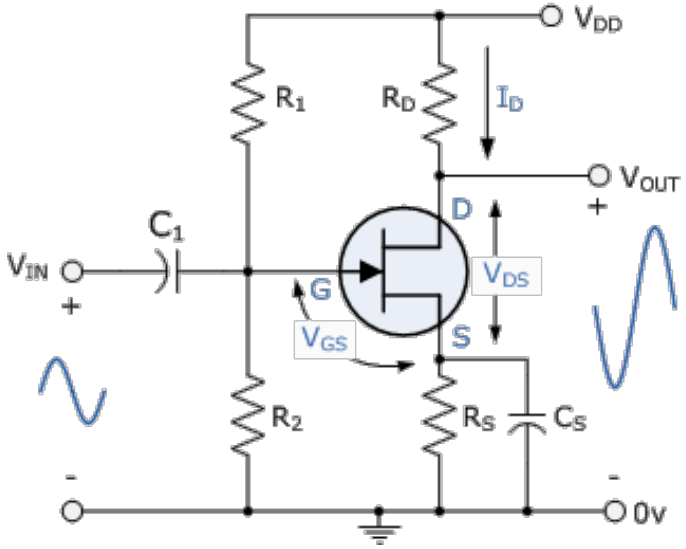




Montage amplificateur



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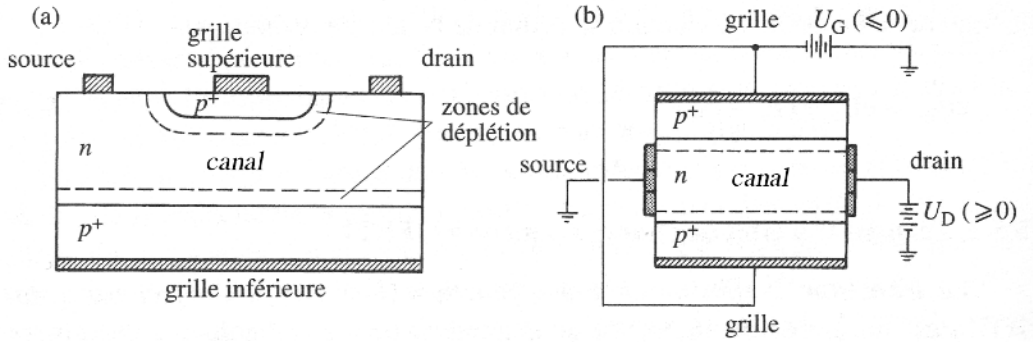
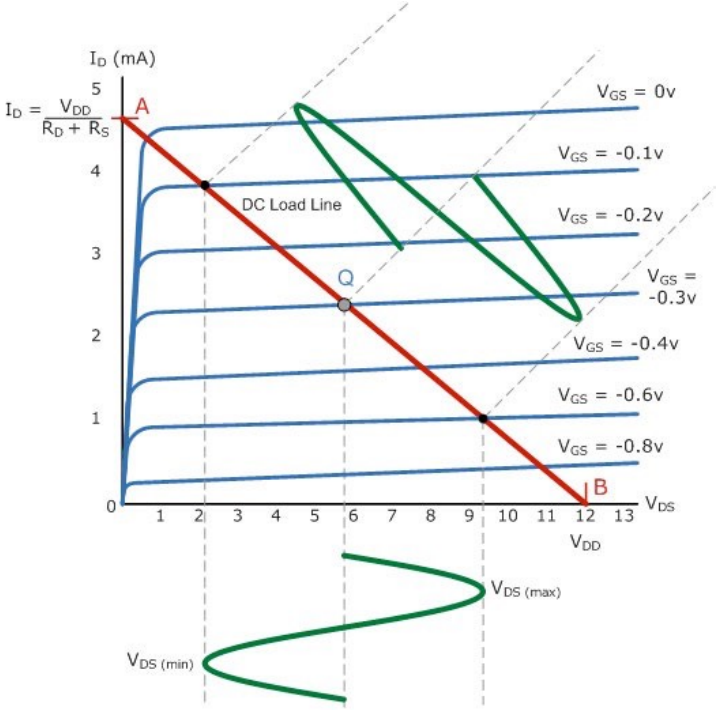
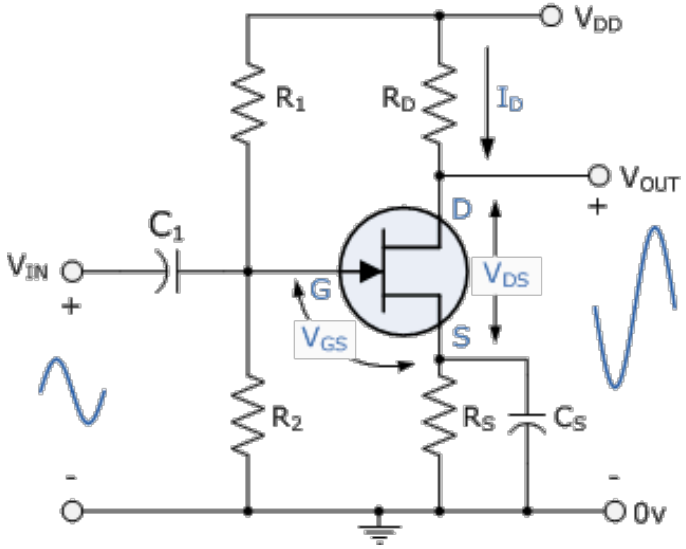




Montage amplificateur



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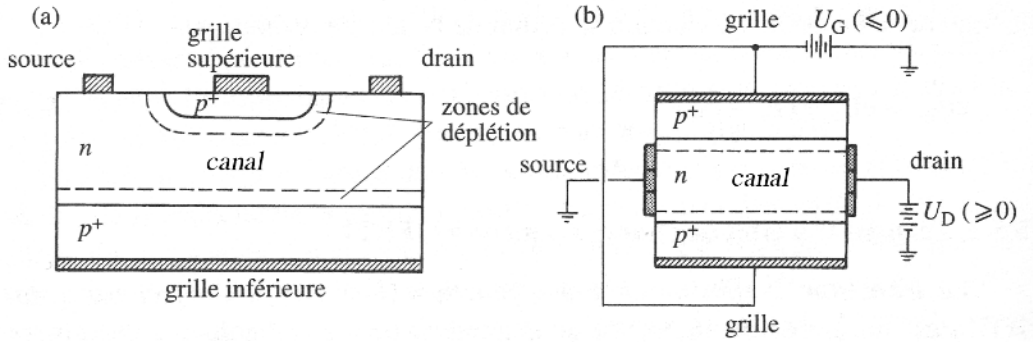

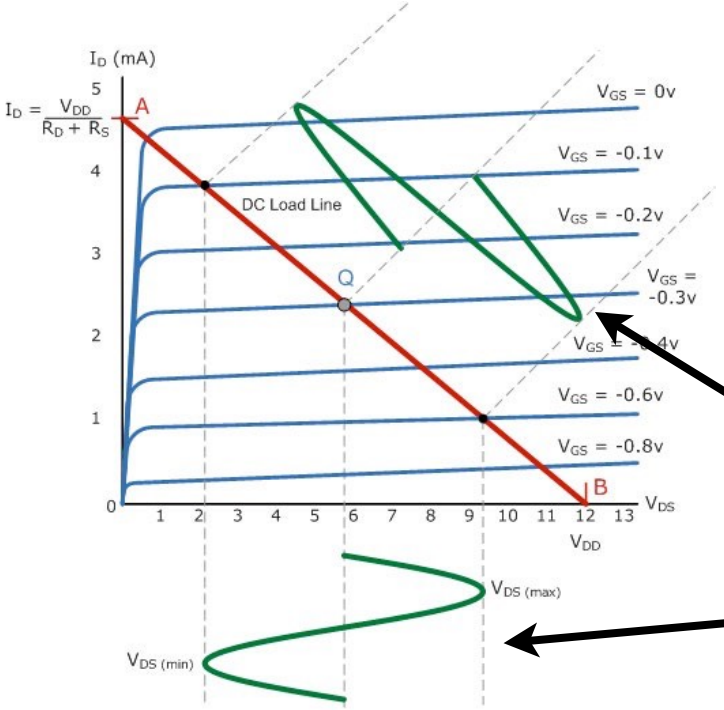

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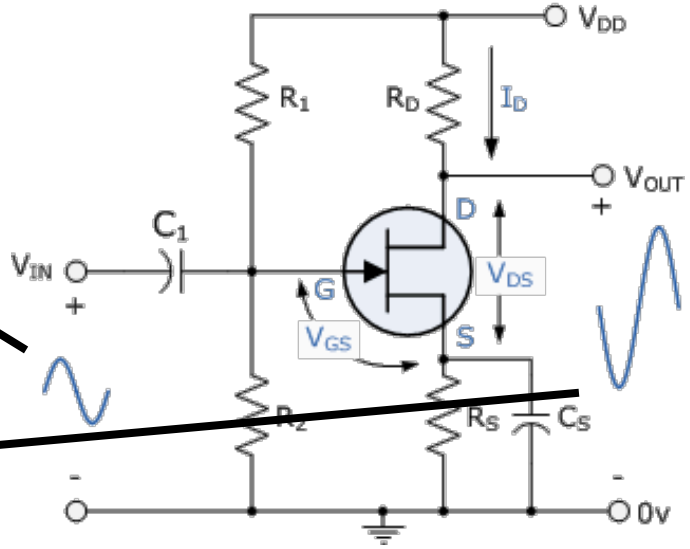
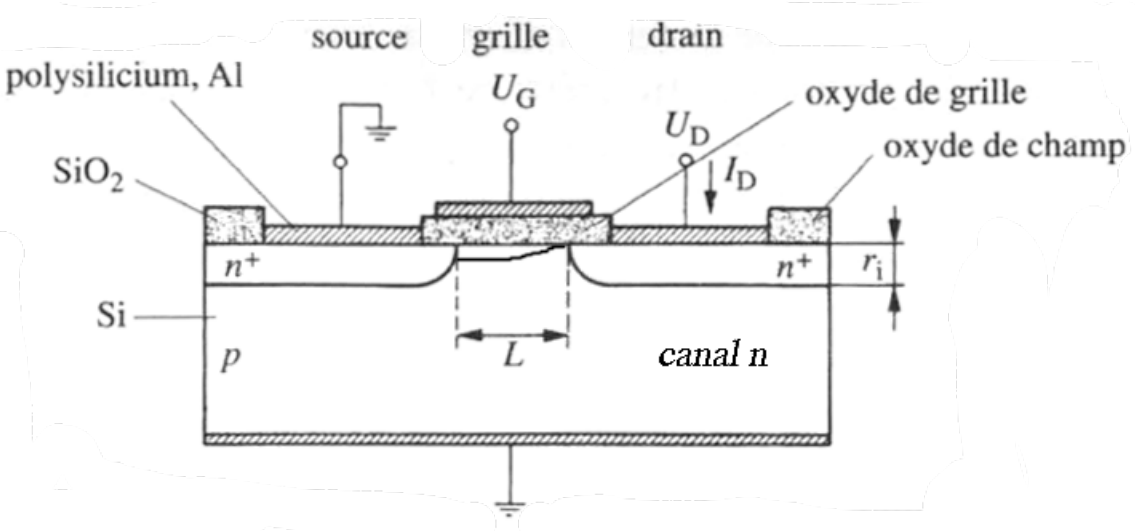


Le transistor MOS - FET



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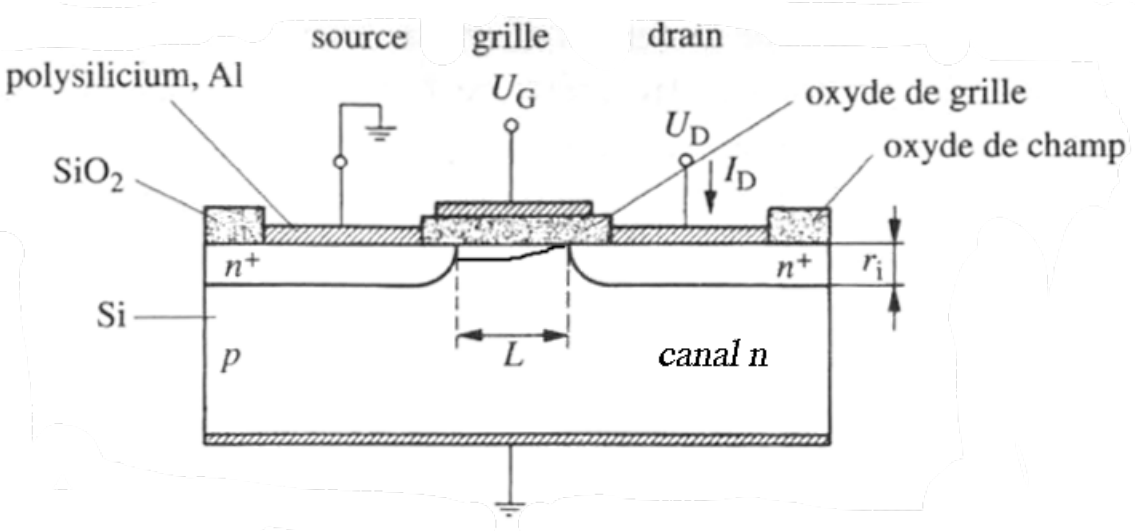

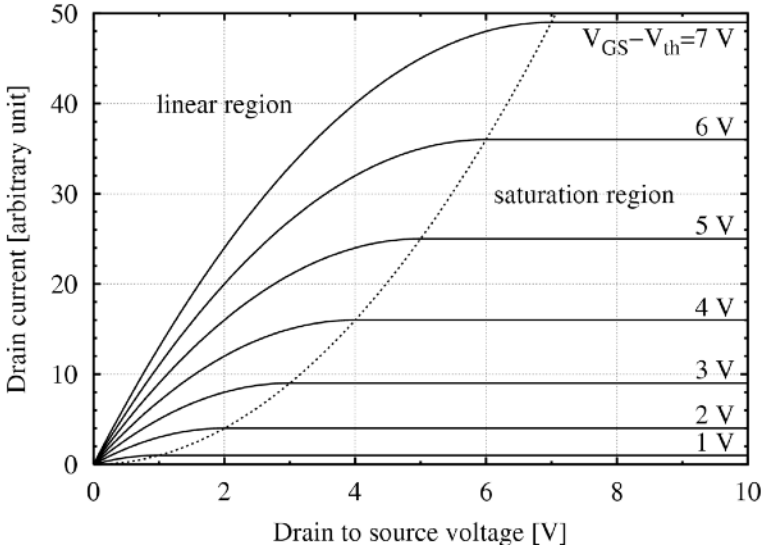

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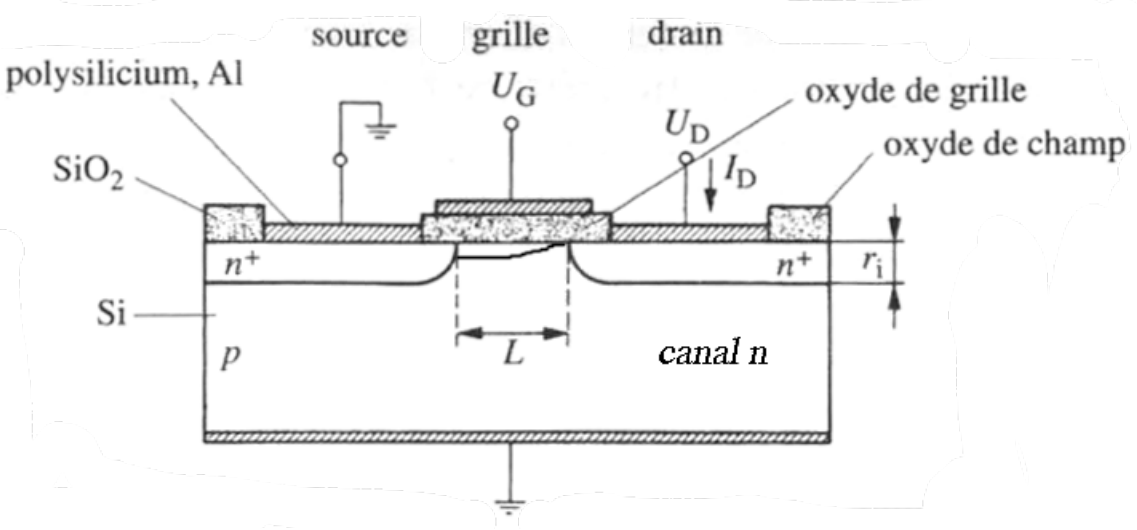
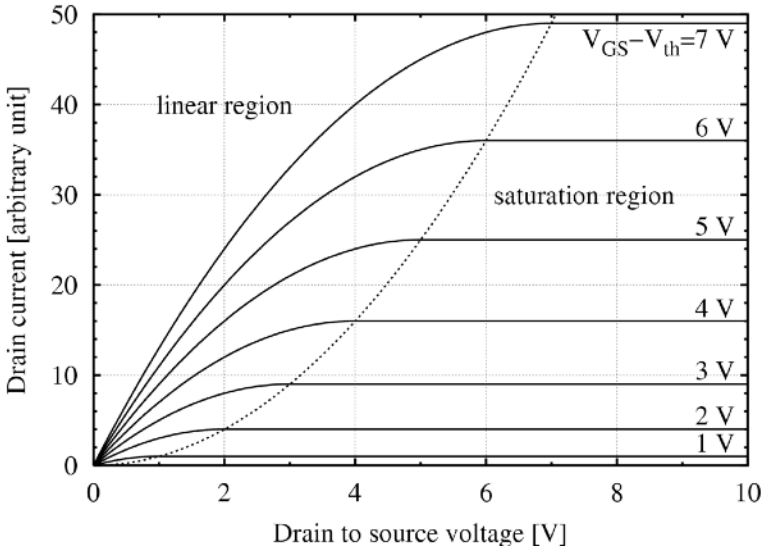
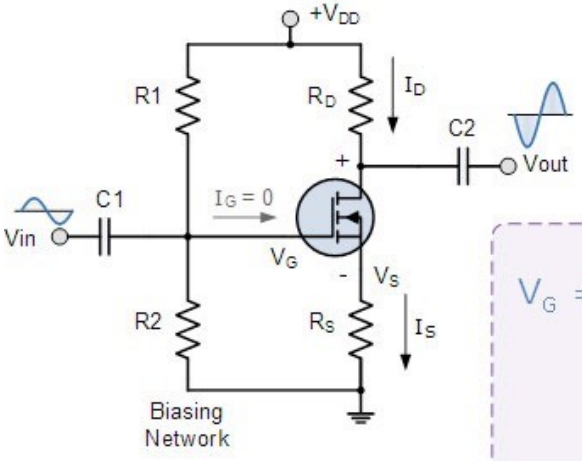


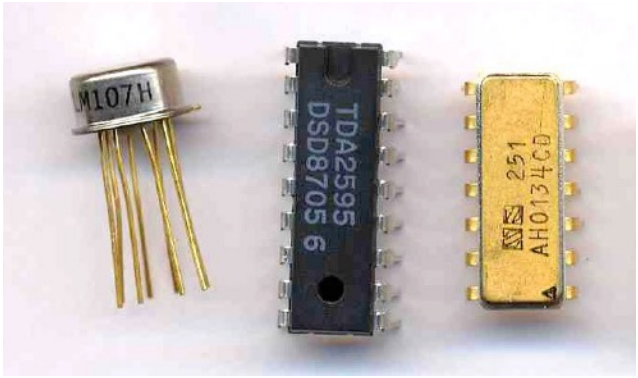




$$V_G = \left(\frac{R2}{R1+R2}\right) V_{DD}$$

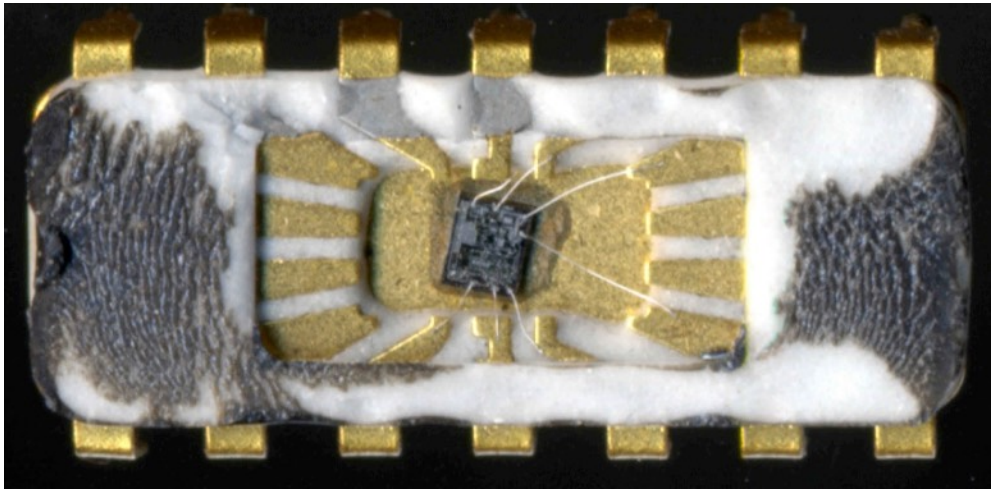
$$I_D = \frac{V_S}{R_S}$$

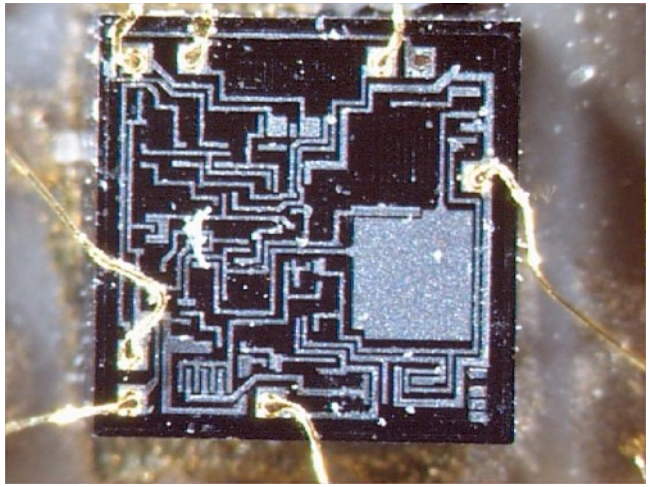
Fonctions analogiques et circuits intégrés



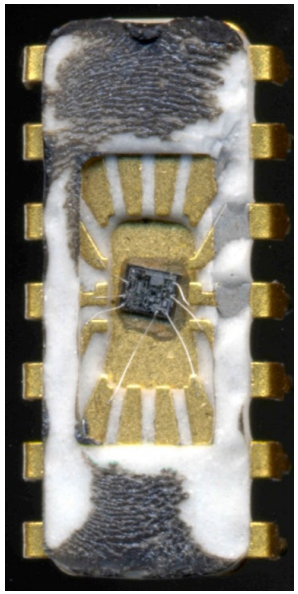
La combinaison d'éléments linéaires (résistances, capacités, inductances), non-linéaires (diodes,...) et actifs (transistors,...) permet de réaliser des circuits électroniques avec des **fonctions analogiques** précises, comme amplificateurs, comparateurs, oscillateurs, modulateurs, etc.

Actuellement, de nombreuses fonctions analogiques sont réalisées par intégration des divers éléments sur un seul substrat de silicium. Ce sont les **circuits intégrés analogiques**.

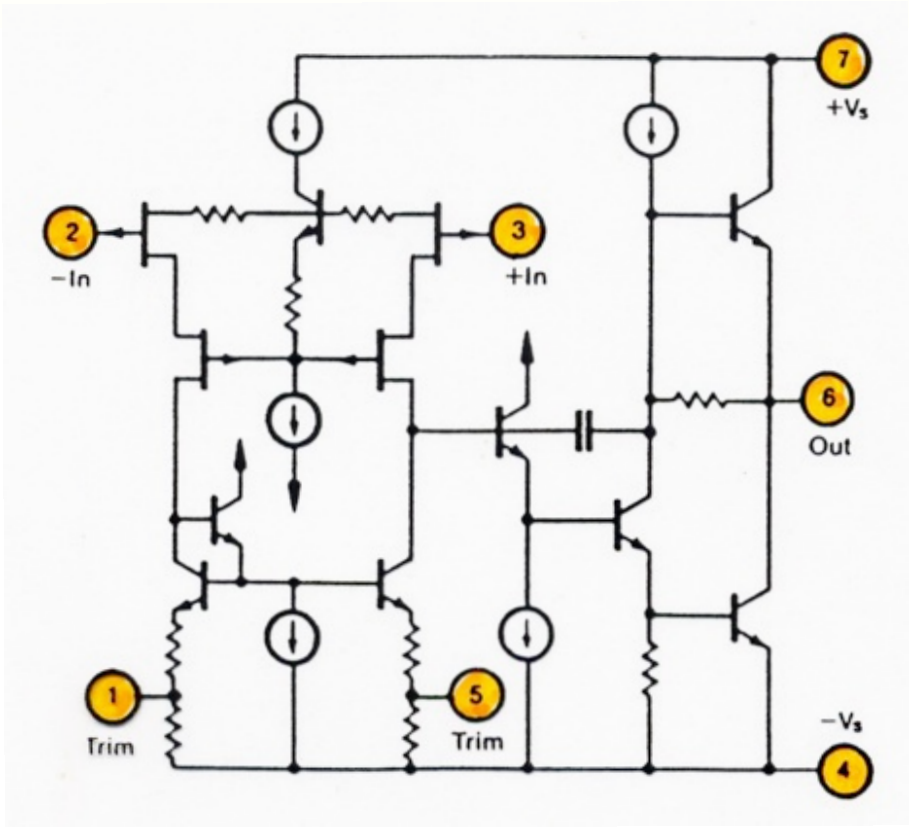


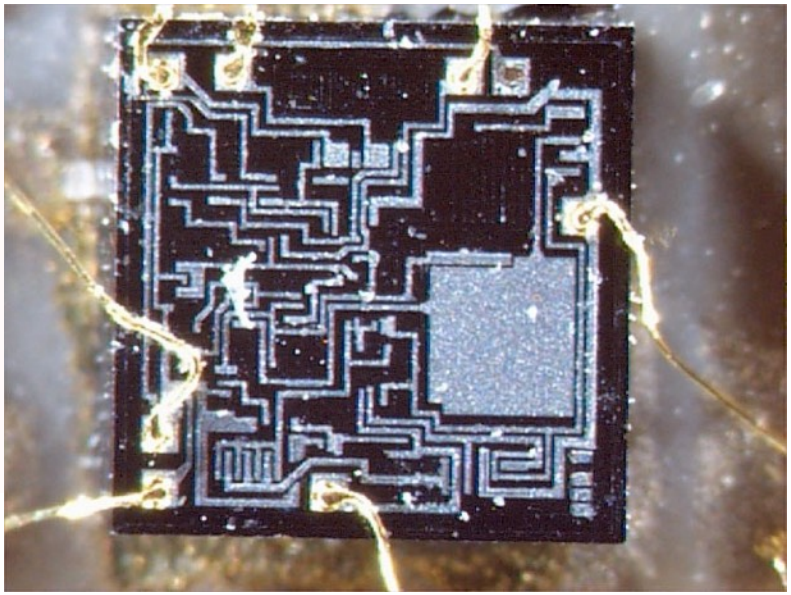


Fonctions analogiques et circuits intégrés

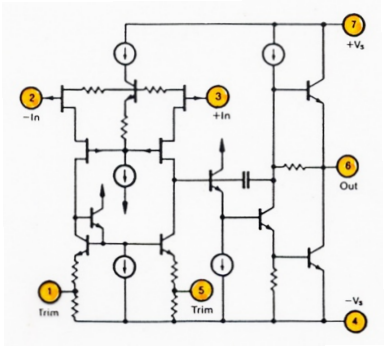


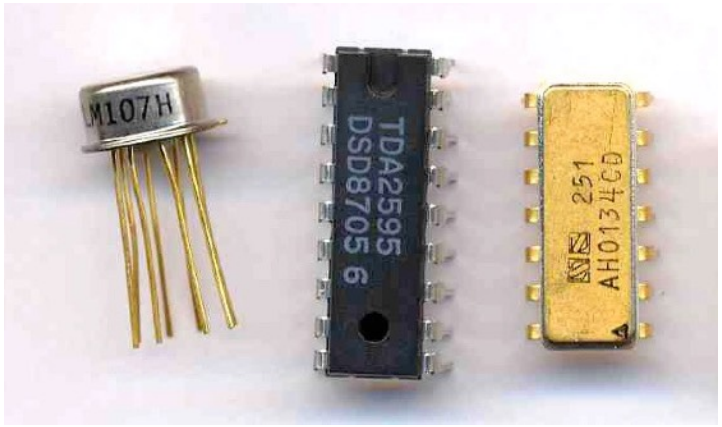
Exemple: ampli opérationnel à entrées FET

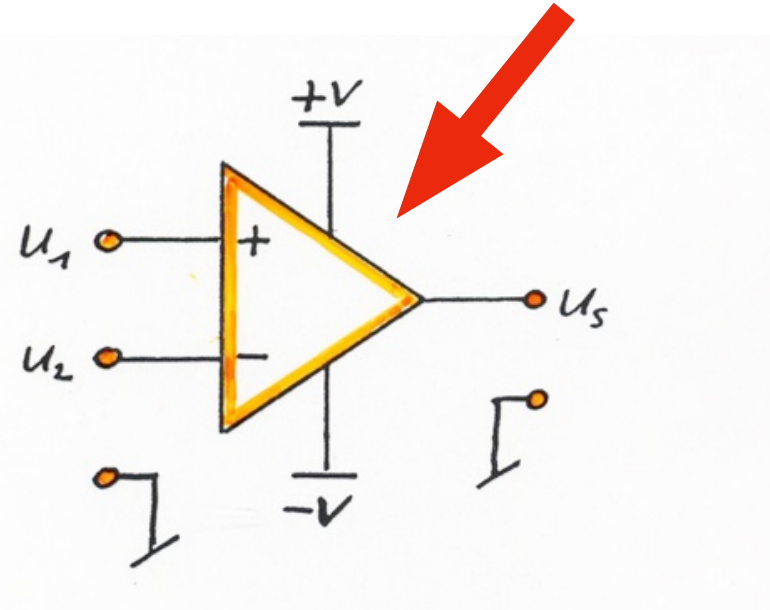




Amplis opérationnels







G = gain de l'amplificateur opérationnel

$$u_s = G(u_1 - u_2)$$

G est très grand (10^4 to 10^6)

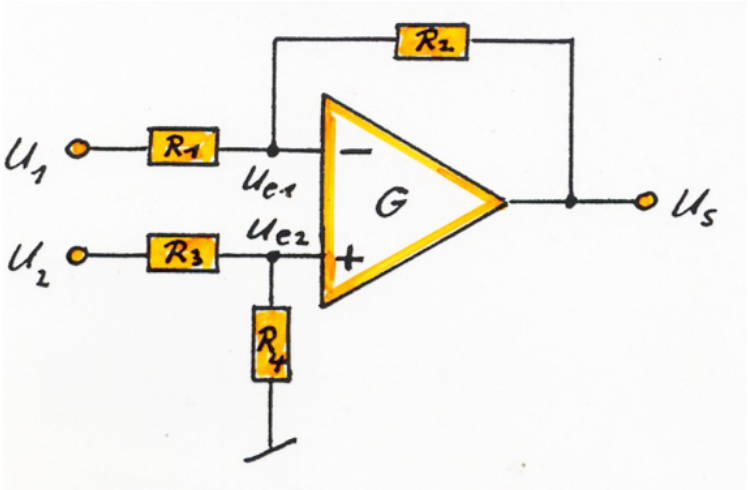
L'impédance d'entrée (z_i) est très grande

(10^6 to $10^9\ \Omega$)

L'ampli opérationnel permet de réaliser très simplement, en utilisant exclusivement les équations de Kirchhoff, les équations constitutives des éléments passifs et l'équation de l'ampli opérationnel, une très grande variété de fonctions analogiques, dont on va donner quelques exemples dans la suite.

Circuits linéaires

Amplificateur de tension



Impédance d'entrée $z_i >> R_i \Rightarrow$

$$u_{e2} = \frac{R_4}{R_3 + R_4} u_2$$

$$u_{e1} = u_1 + \frac{R_1}{R_1 + R_2}(u_s - u_1)$$

Gain G $\Rightarrow$ $u_s = G(u_{e2} - u_{e1})$

$$u_s = G\left(\frac{R_4}{R_3 + R_4} u_2 - u_1 - \frac{R_1}{R_1 + R_2}(u_s - u_1) \right)$$

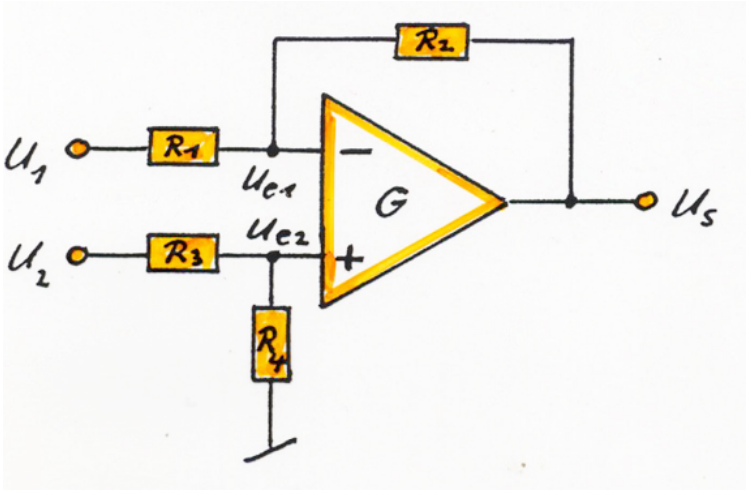
$$\Rightarrow u_s = \frac{\left(\frac{R_4}{R_3 + R_4} u_2 - \frac{R_2}{R_1 + R_2} u_1 \right) G}{1 + \frac{GR_1}{R_1 + R_2}}$$

G très grand $\Rightarrow$

$$u_s \cong \frac{R_4(R_1 + R_2)}{(R_3 + R_4)R_1} u_2 - \frac{R_2}{R_1} u_1$$

Circuits linéaires

Amplificateur de tension



Impédance d'entrée $z_i >> R_i \Rightarrow$

$$u_{e2} = \frac{R_4}{R_3 + R_4} u_2$$

$$u_{e1} = u_1 + \frac{R_1}{R_1 + R_2}(u_s - u_1)$$

Gain G $\Rightarrow$ $u_s = G(u_{e2} - u_{e1})$

$$u_s = G\left(\frac{R_4}{R_3 + R_4} u_2 - u_1 - \frac{R_1}{R_1 + R_2}(u_s - u_1) \right)$$

$$\Rightarrow u_s = \frac{\left(\frac{R_4}{R_3 + R_4} u_2 - \frac{R_2}{R_1 + R_2} u_1 \right) G}{1 + \frac{GR_1}{R_1 + R_2}}$$

G très grand $\Rightarrow$

$$u_s \cong \frac{R_4(R_1 + R_2)}{(R_3 + R_4)R_1} u_2 - \frac{R_2}{R_1} u_1$$

Amplificateur différentiel

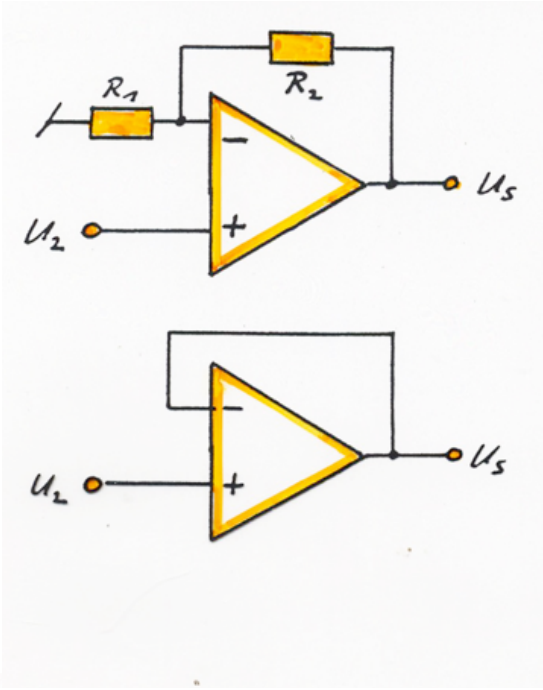
$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \Rightarrow$$

$$u_s = \frac{R_2}{R_1}(u_2 - u_1)$$

Circuits linéaires

$$u_s \cong \frac{R_4(R_1+R_2)}{(R_3+R_4)R_1}u_2 - \frac{R_2}{R_1}u_1$$

Amplificateur non-inverseur



$$\left.\begin{array}{l} R_3 = 0 \quad \text{and} \quad R_4 \to \infty \\ u_1 = 0 \end{array}\right\} \Rightarrow$$

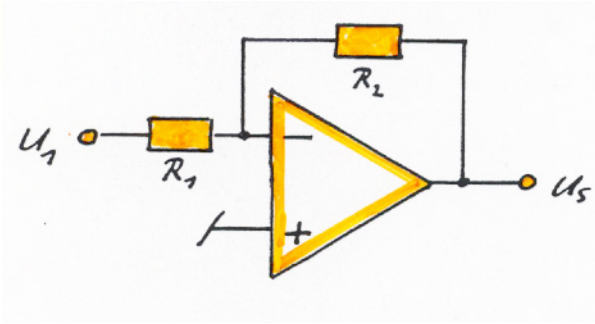
$$u_s = \frac{R_1+R_2}{R_1}u_2$$

$$R_1 \to \infty \quad \text{and} \quad R_2 = 0 \quad \Rightarrow$$

$$u_s = u_2$$

Ces deux amplificateurs ont
une grande impedance d'entrée (!)

Amplificateur inverseur

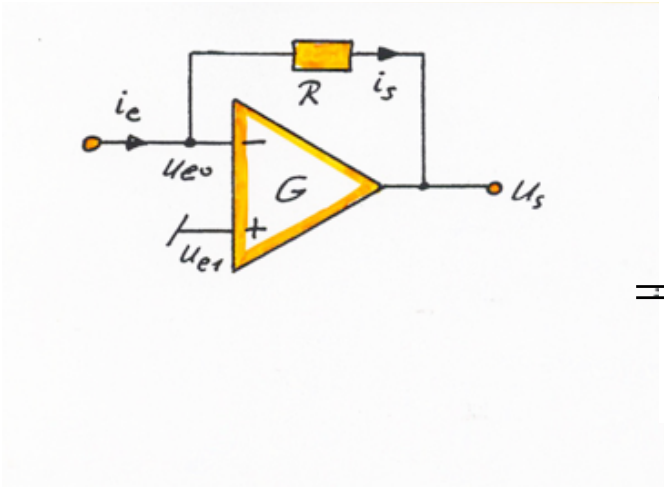


$$R_3 = R_4 = 0 \quad \text{and} \quad u_2 = 0 \quad \Rightarrow$$

$$u_s = -\frac{R_2}{R_1}u_1$$

Circuits linéaires

“Amplificateur piloté en courant”



Impédance d’entrée : $z_i >> R \Rightarrow$

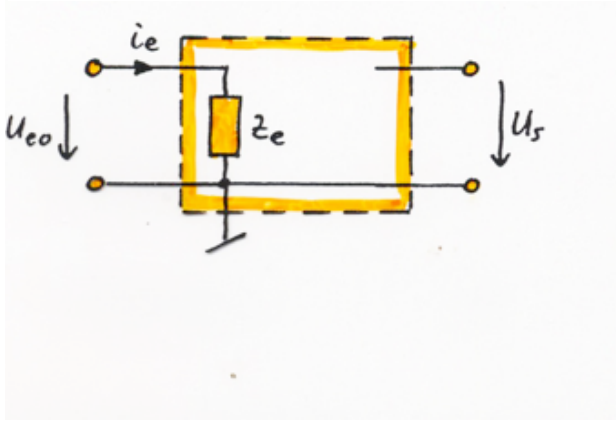
$$i_s \cong i_e$$

$$u_{eo} - u_s = Ri_s = Ri_e$$

$$\Rightarrow \quad u_{e1} = 0$$

$$u_s = G(u_{e1} - u_{e0}) = -G(u_s + Ri_e)$$

$$G >> 1 \quad \Rightarrow \quad \boxed{u_s = \frac{-GRi_e}{1+G} \cong -Ri_e}$$



Impédance d’entrée vue par la source :

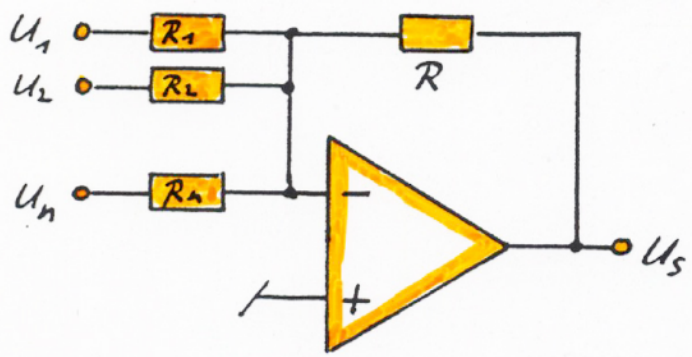
$$z_e = \frac{u_{eo}}{i_e} = \frac{u_s + Ri_e}{i_e} = \left(1 - \frac{G}{1+G}\right)R$$

$$\boxed{z_e = \frac{1}{1+G}R}$$

Comme G est très grand, z_e est petit ($z_e << R$)

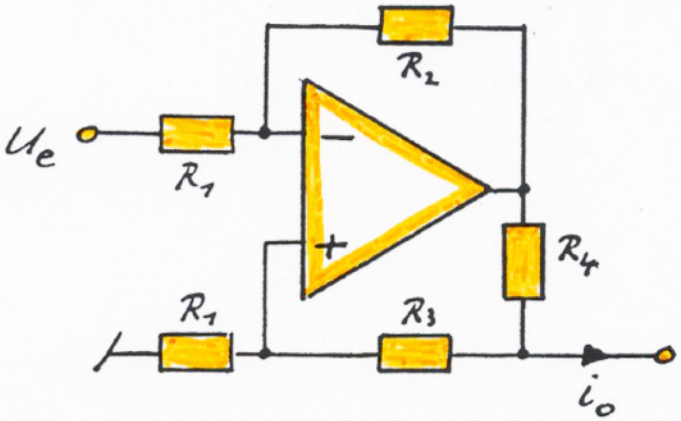
Circuits linéaires

Amplificateur sommateur



$$u_s = -R\sum_{i=1}^{n}\frac{u_i}{R_i}$$

Source de courant pilotée en tension

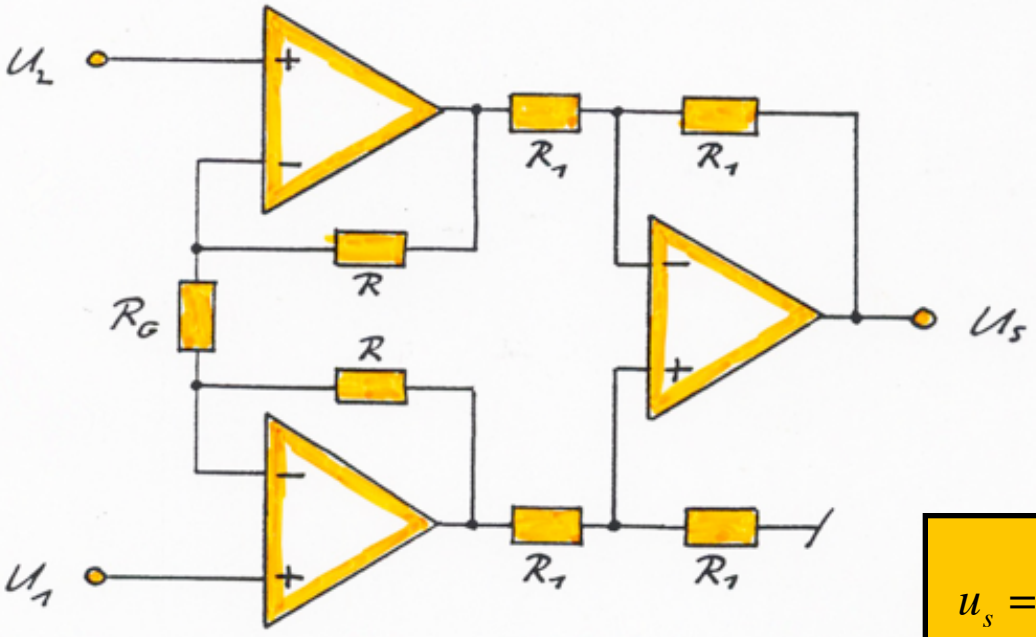


si $\begin{cases} R_2 = R_3 + R_4 \\ R_4 >> R_3 \end{cases}$

$$i_0 = \frac{R_2}{R_1 R_4}u_e$$

Circuits linéaires

Amplificateur différentiel d'instrumentation



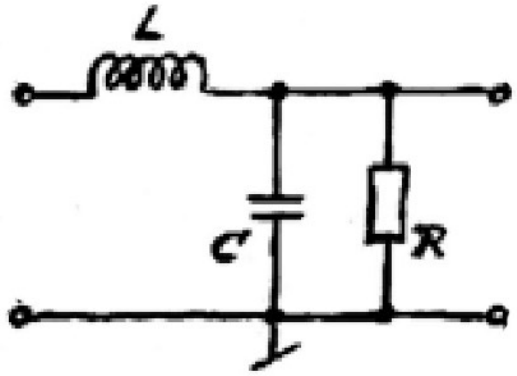
$$u_s = \left(1 + \frac{R_2}{R_1 R_4}\right)(u_1 - u_2)$$

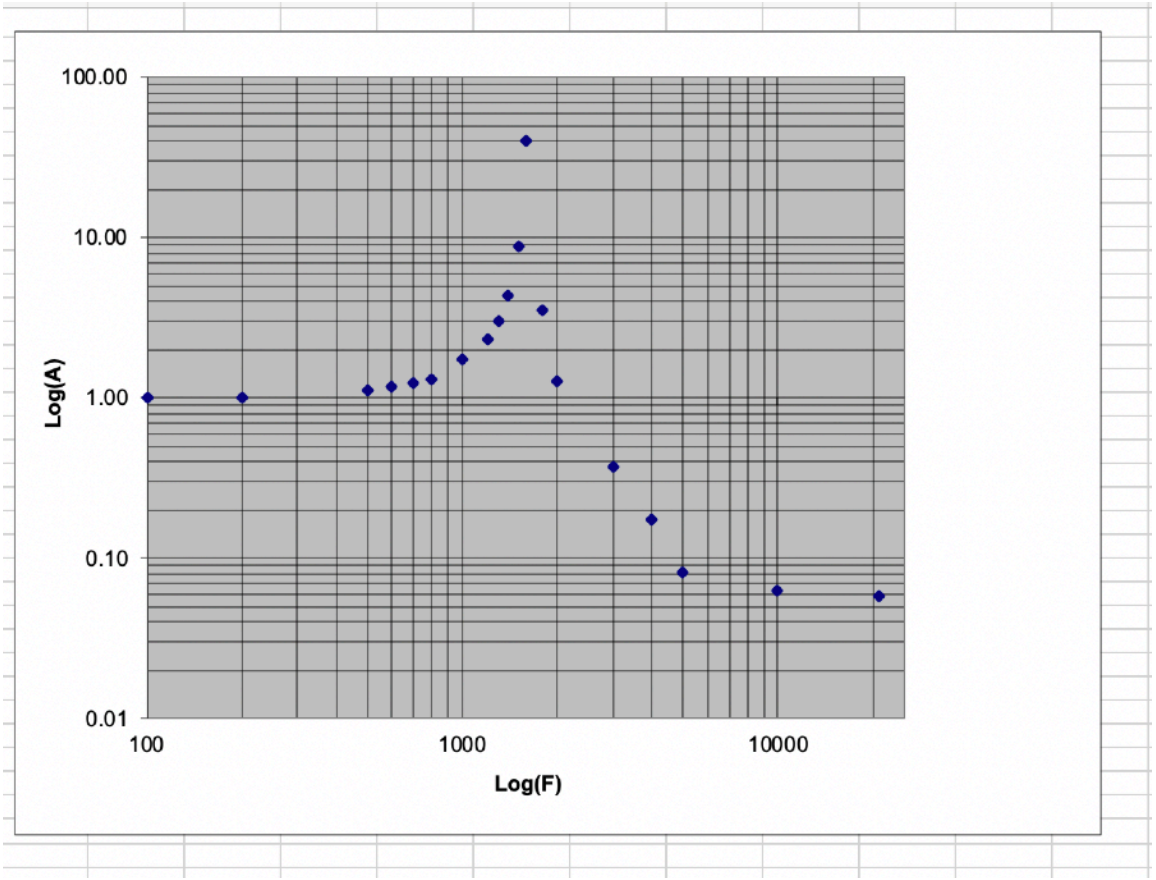
L'impédance d'entrée z_i peut être très grande

($z_i \cong 1 \times 10^{12}\,\Omega$ pour des transistors FET)

Le gain peut aller de 1 ($R_G \to \infty$) à des milliers.

FILTRAGE





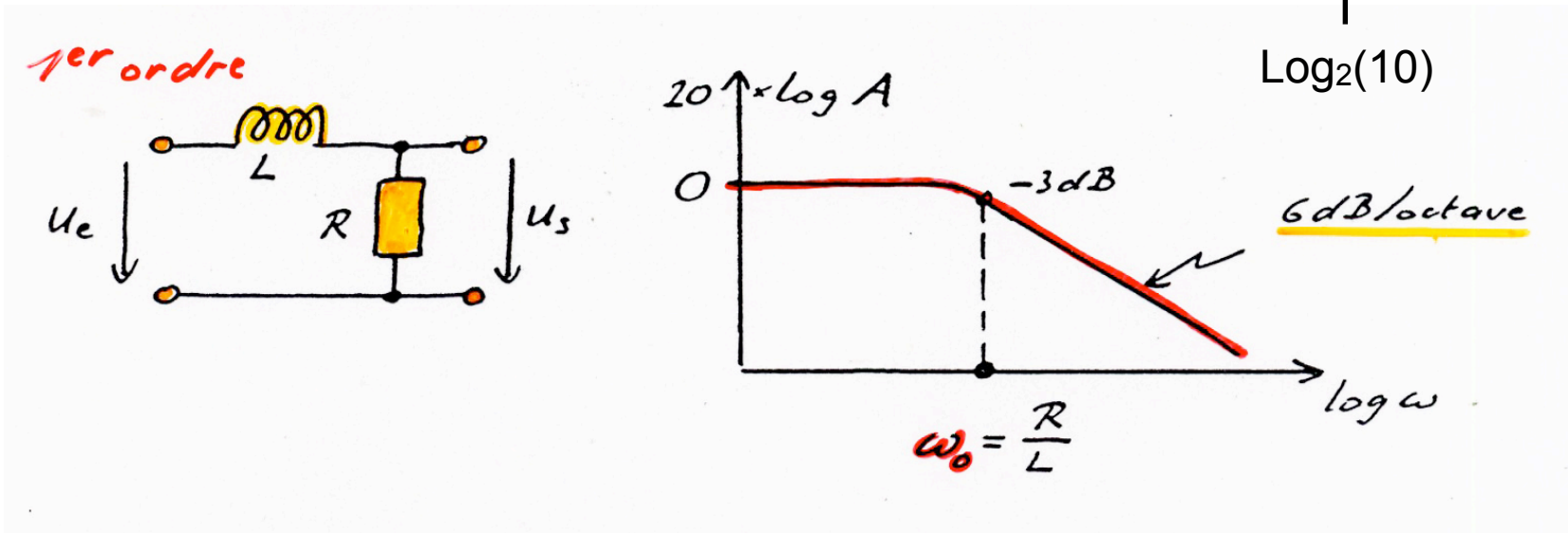
Les filtres passifs

Note: 6 dB/octave=20dB/décade
Ou dB/décade=3.32dB/octave

$\uparrow$

$Log_2(10)$

Filtres passe-bas



Les filtres passifs

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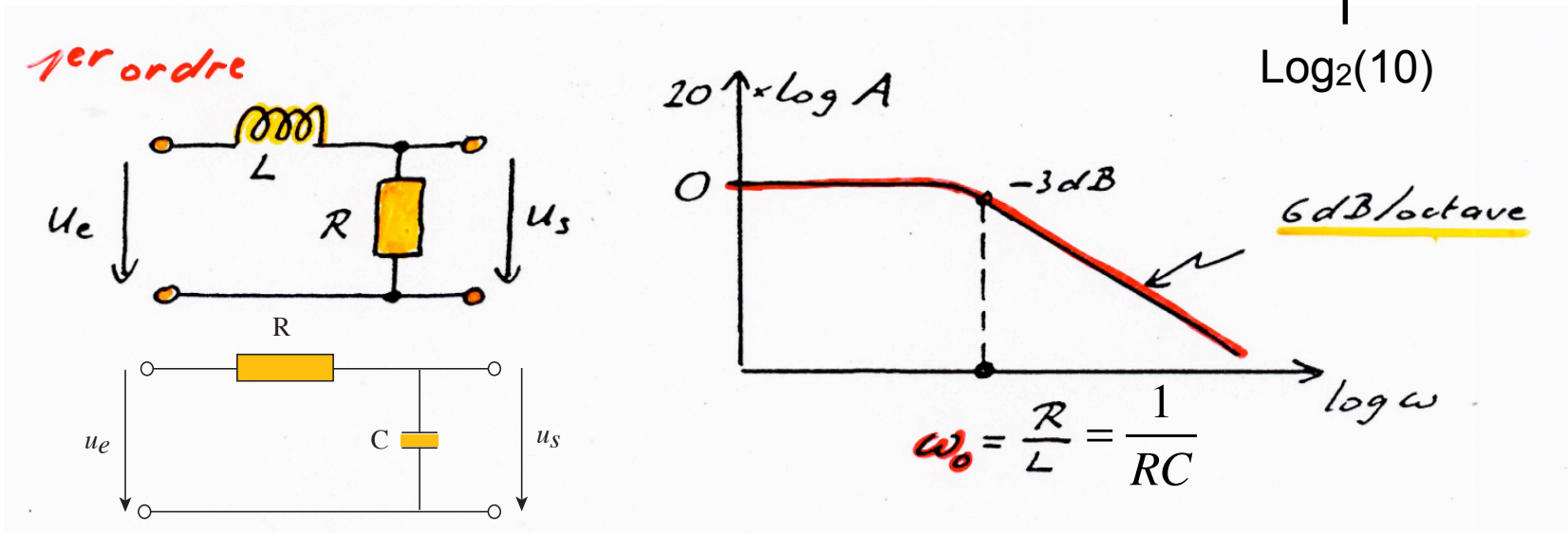
$\uparrow$

$Log_2(10)$

Filtres passe-bas



Les filtres passifs

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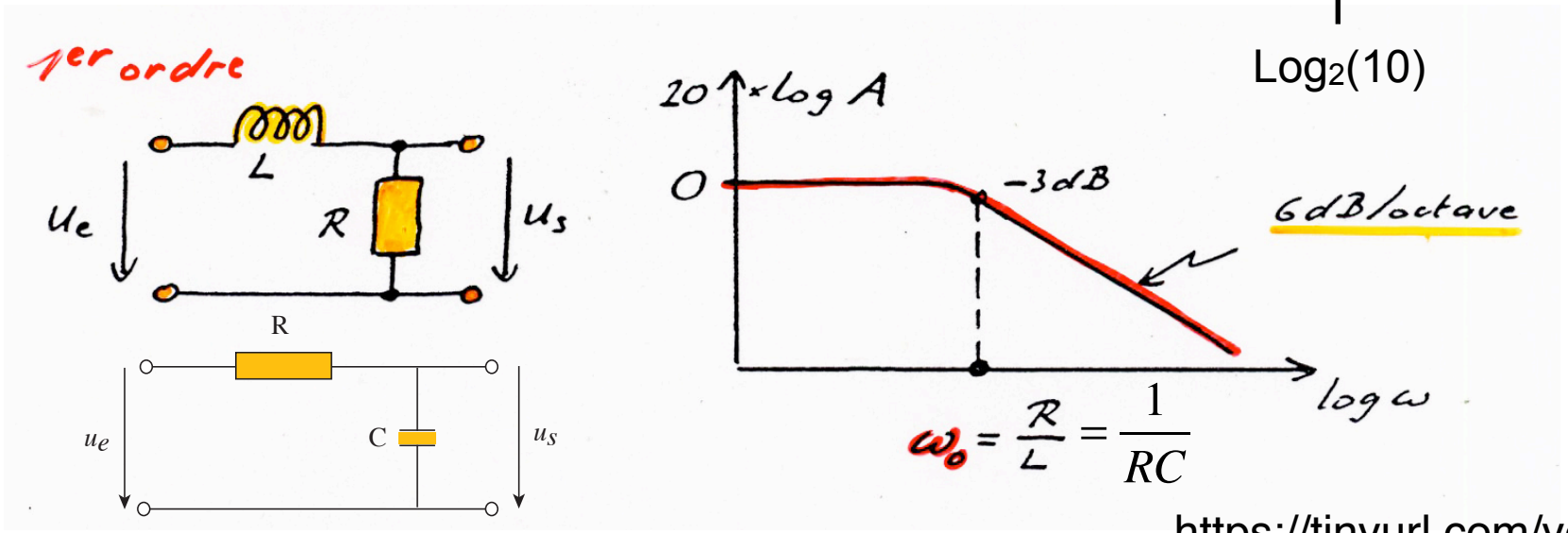
$\uparrow$

$Log_2(10)$

Filtres passe-bas



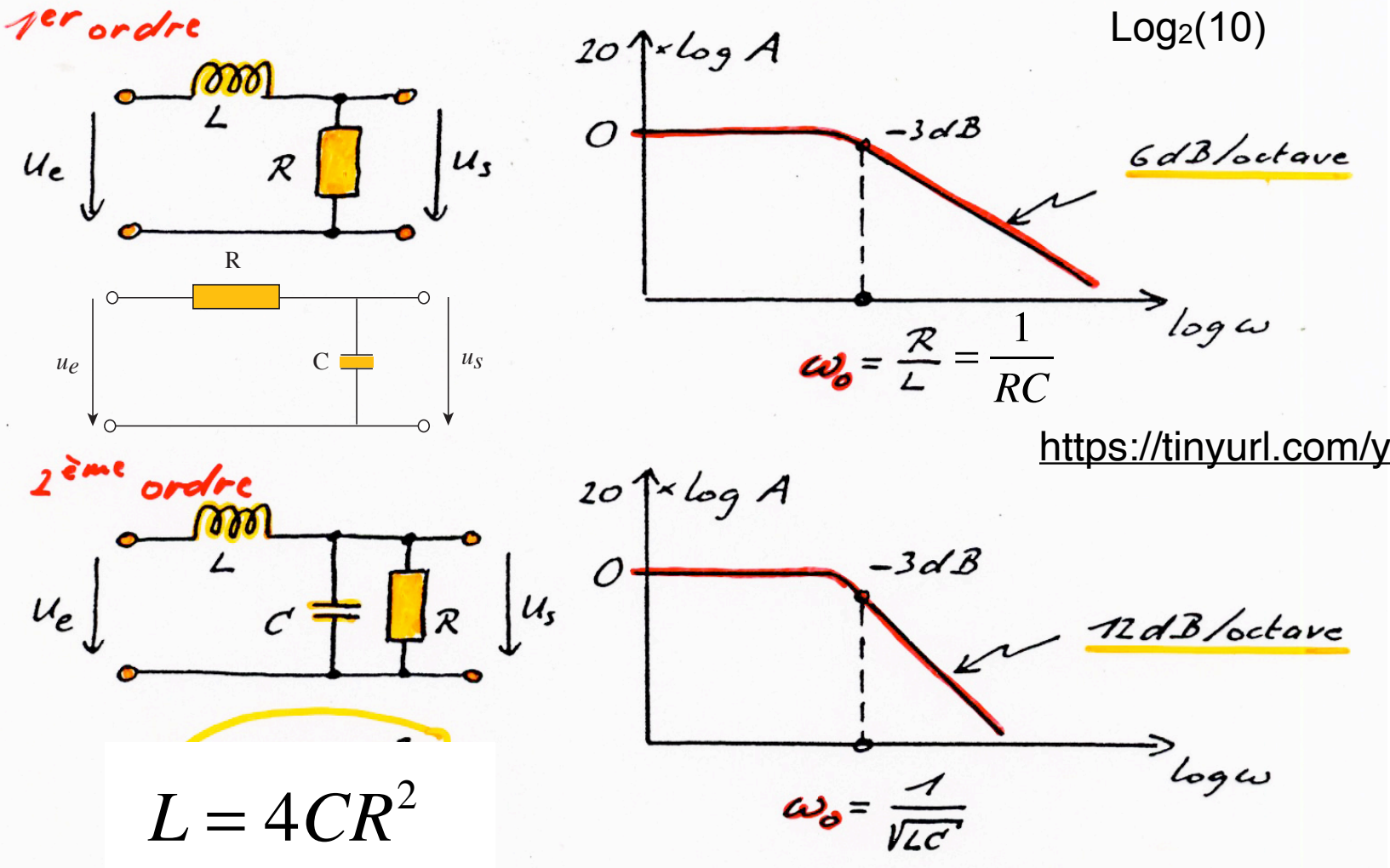
https://tinyurl.com/yerd6sd7

Les filtres passifs

Note: 6 dB/octave=20dB/décade
Ou dB/décade=3.32dB/octave

$\text{Log}_2(10)$

Filtres passe-bas



https://tinyurl.com/yerd6sd7

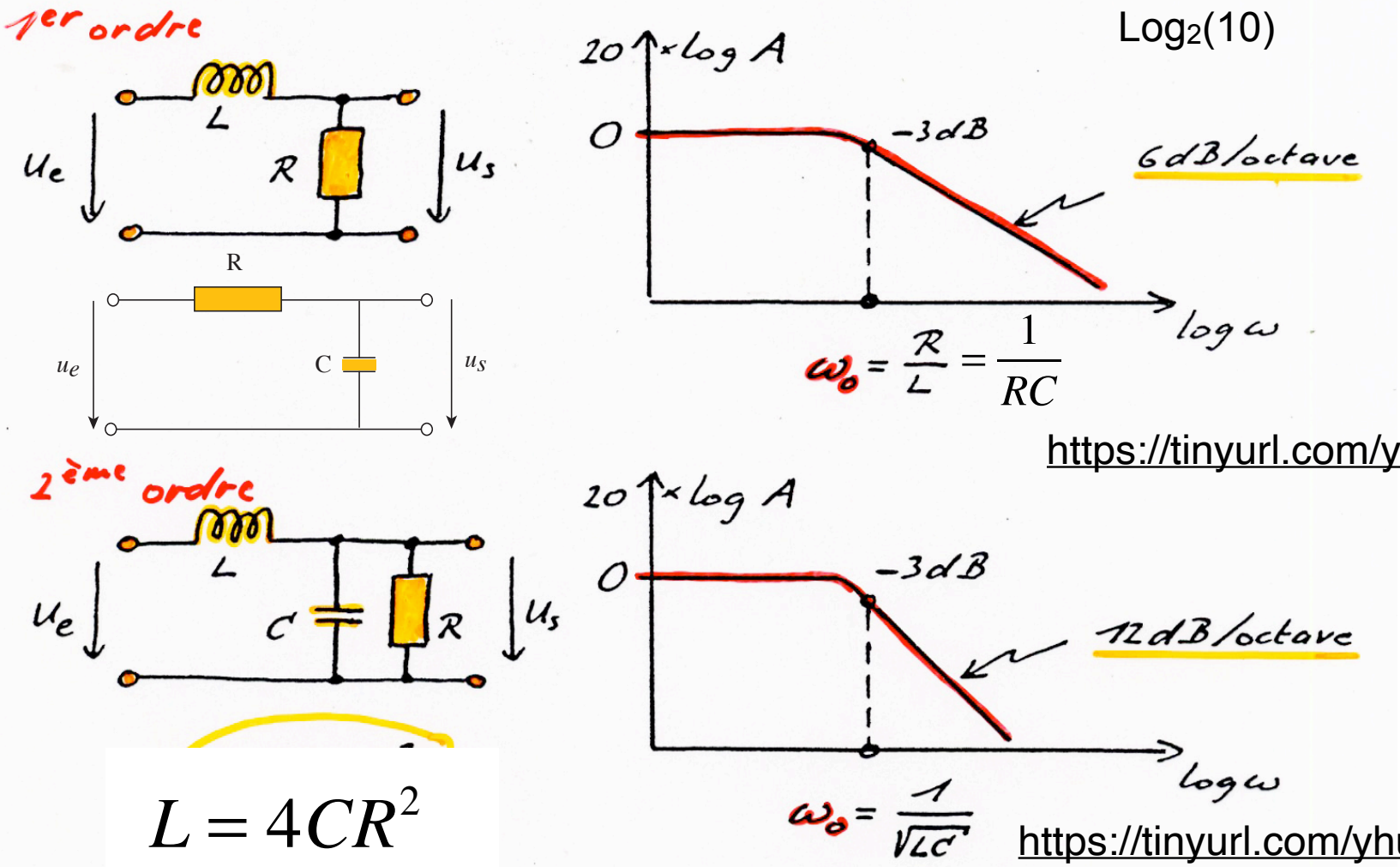
$$L = 4CR^2$$

Les filtres passifs

Note: 6 dB/octave=20dB/décade
Ou dB/décade=3.32dB/octave

$\text{Log}_2(10)$

Filtres passe-bas



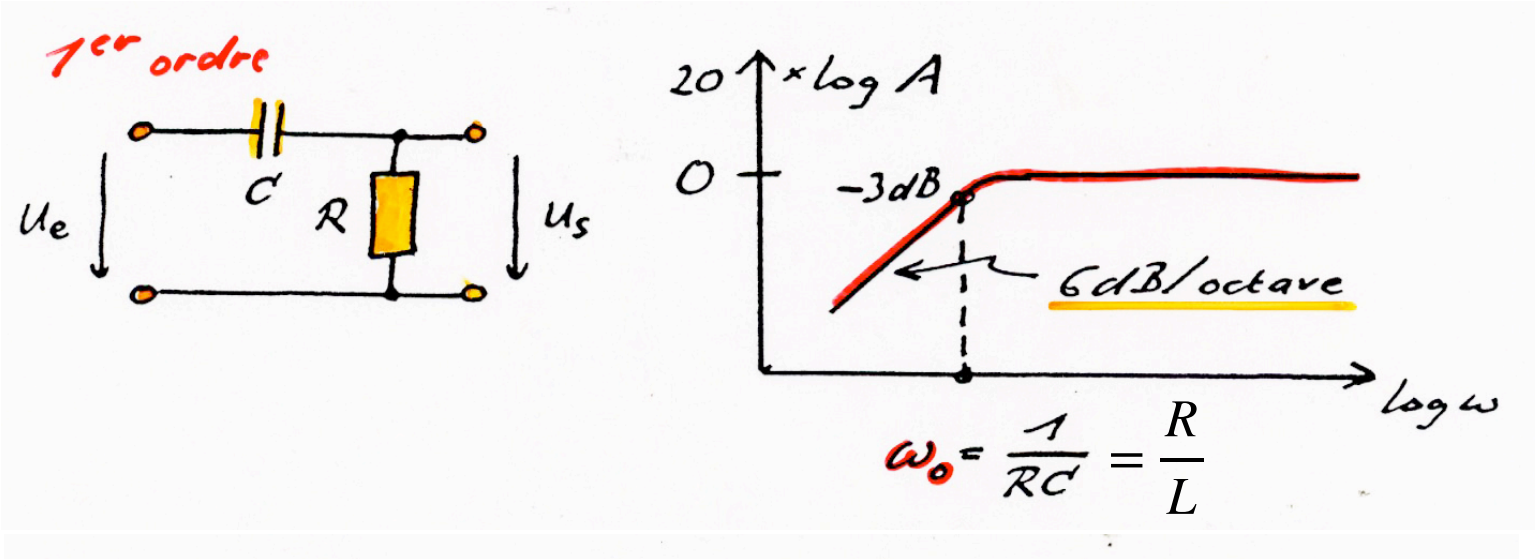
https://tinyurl.com/yerd6sd7

https://tinyurl.com/yhuvwz93

$$L = 4CR^2$$

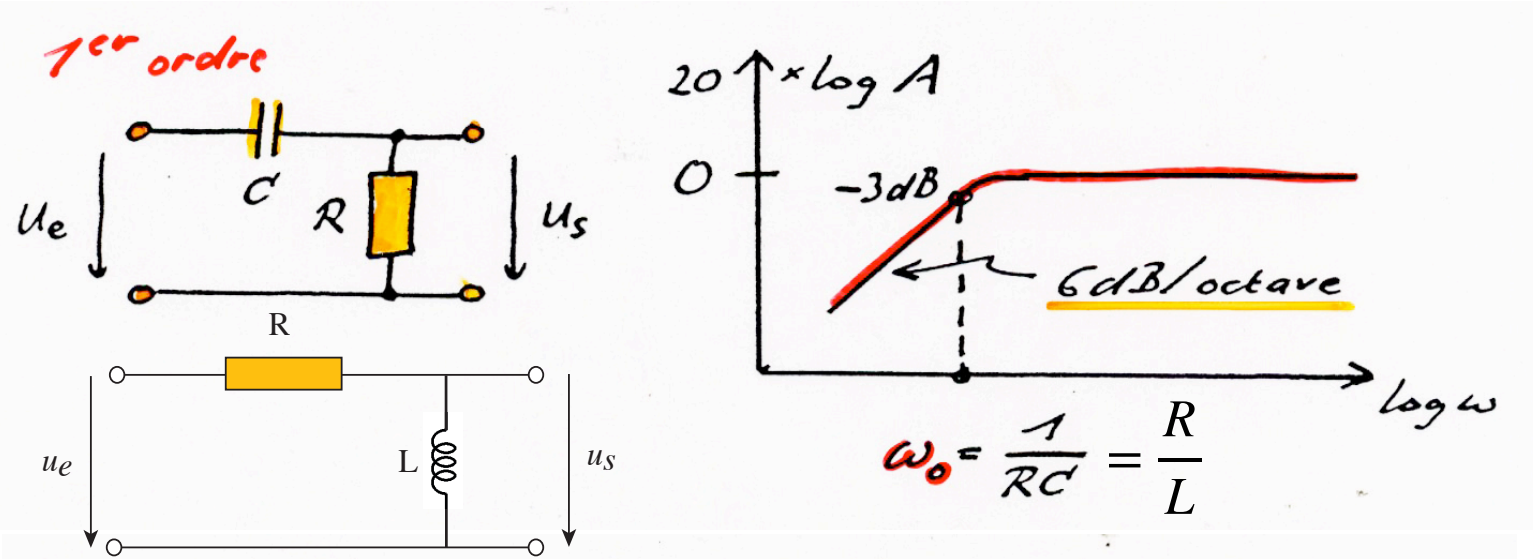
Les filtres passifs

Filtres passe-haut



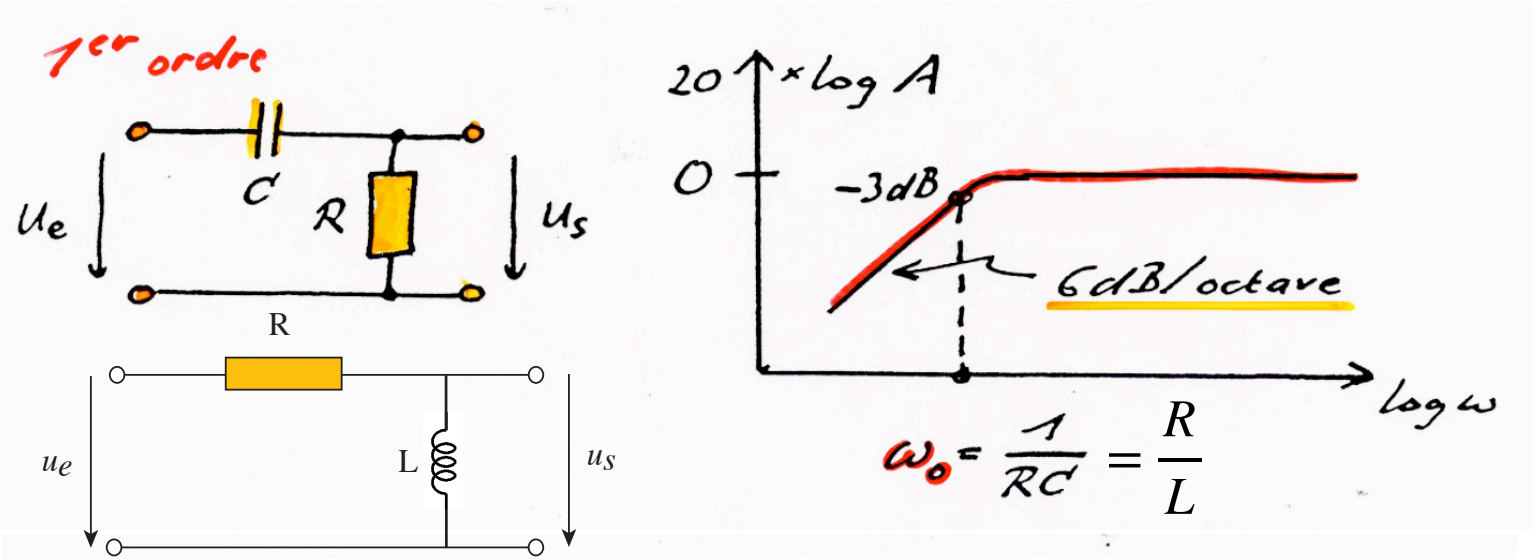
Les filtres passifs

Filtres passe-haut



Les filtres passifs

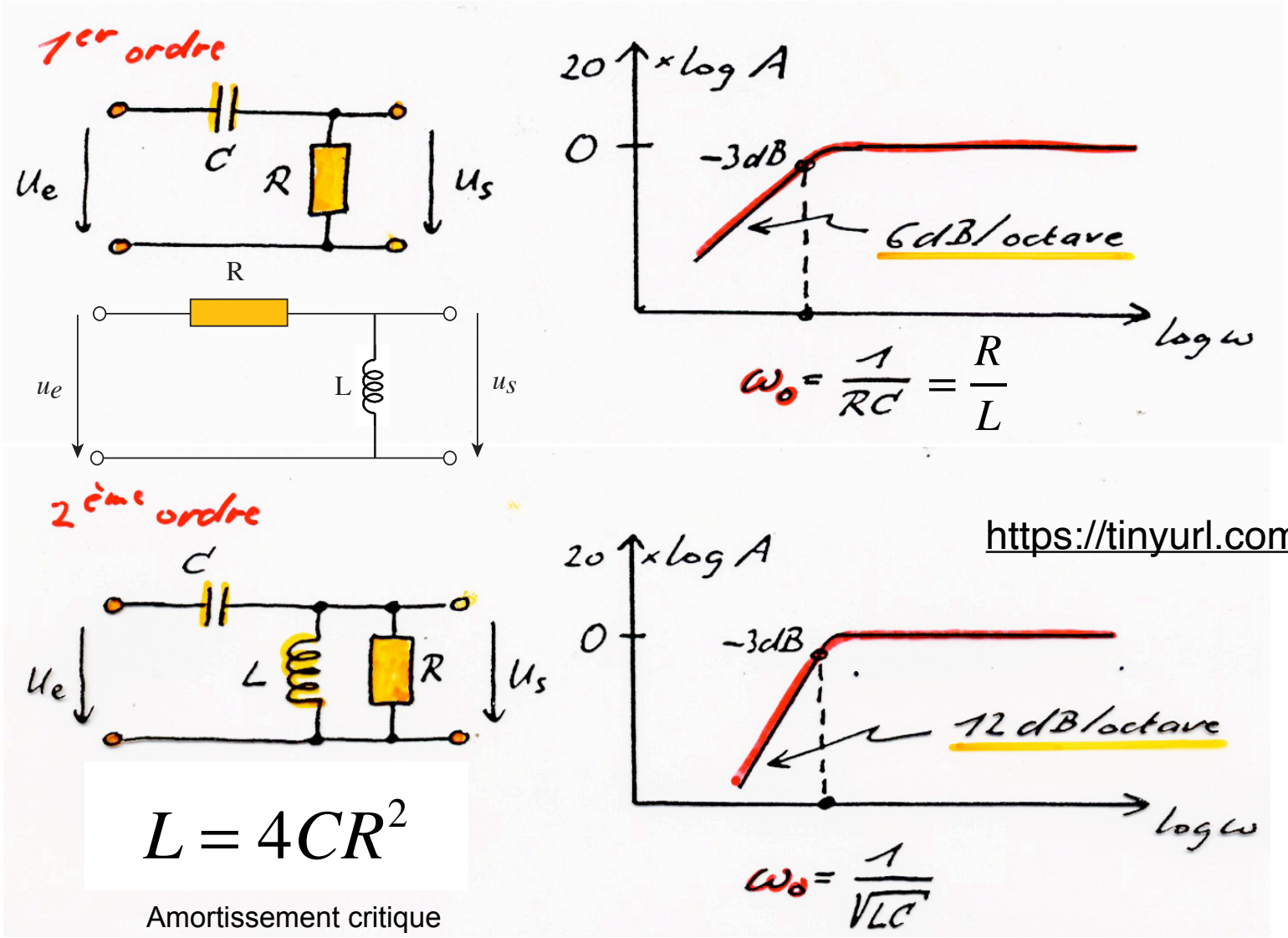
Filtres passe-haut



https://tinyurl.com/yzmmwbt6

Les filtres passifs

Filtres passe-haut



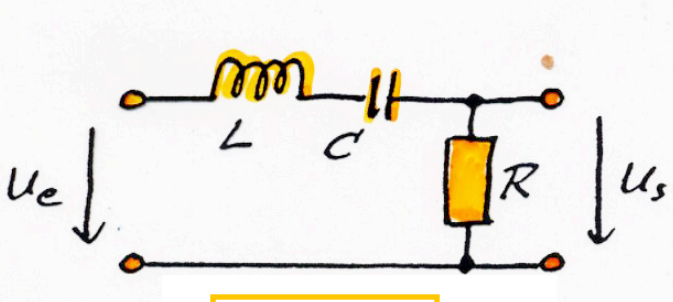
$$L = 4CR^2$$

Amortissement critique

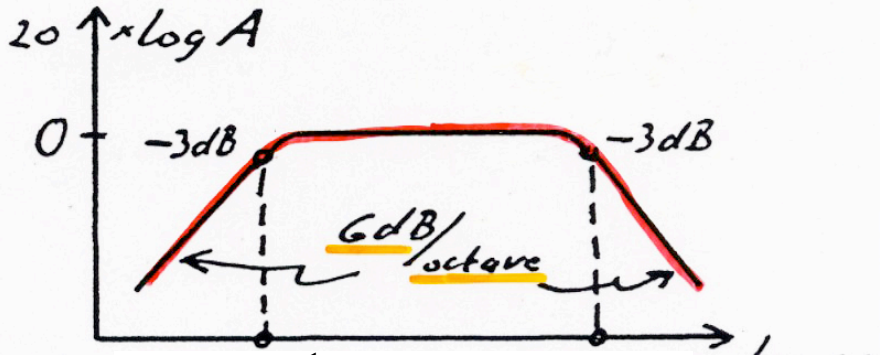
https://tinyurl.com/yzmmwbt6

Les filtres passifs

Filtre passe-bande

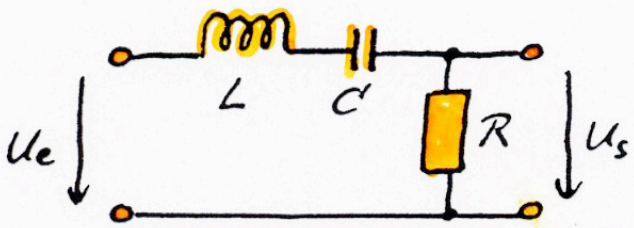


$$R > 2\sqrt{\frac{L}{C}}$$

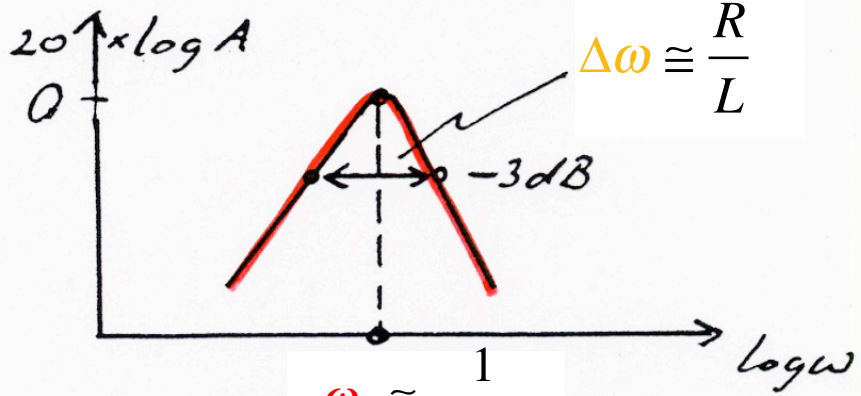


$$\omega_1 \cong \frac{1}{RC} \qquad \omega_2 \cong \frac{R}{L}$$

Filtre résonnant



$$R < 2\sqrt{\frac{L}{C}}$$

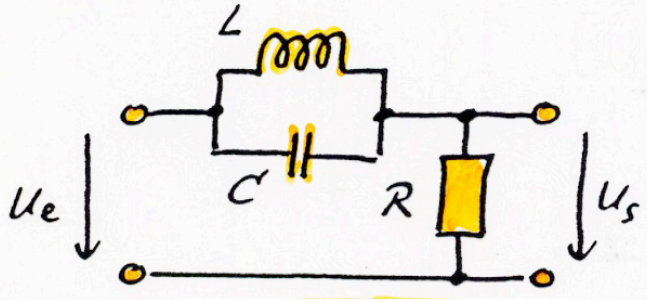


$$\Delta\omega \cong \frac{R}{L}$$

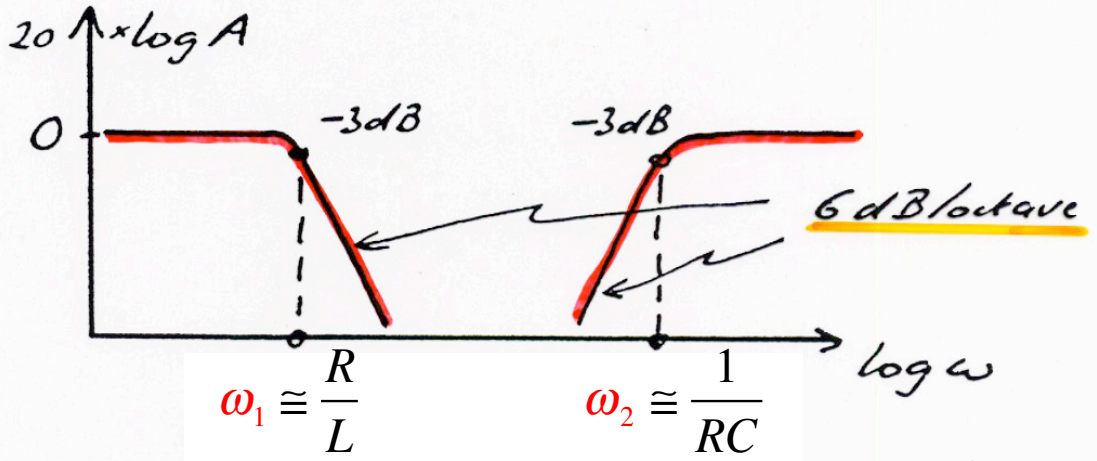
$$\omega_0 \cong \frac{1}{\sqrt{LC}}$$

Filtres passifs

Filtre coupe-bande

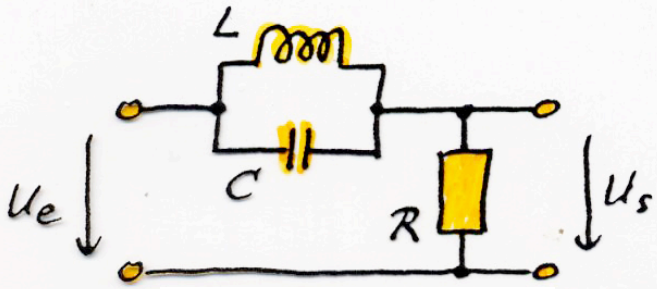


$$R < \frac{1}{2}\sqrt{\frac{L}{C}}$$

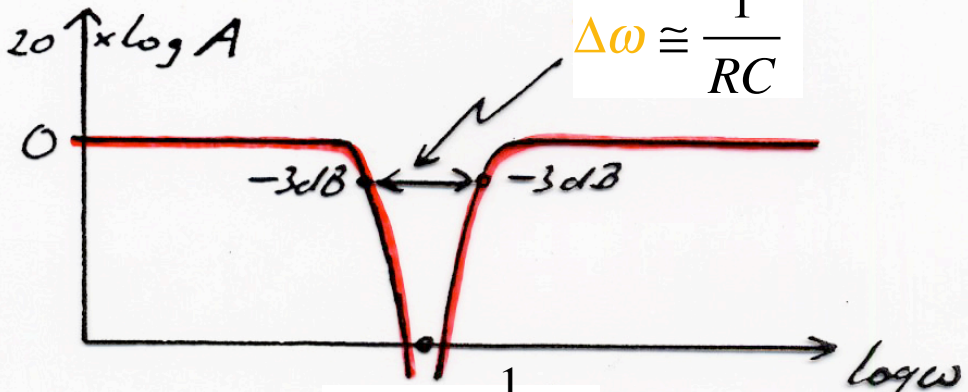


$$\omega_1 \cong \frac{R}{L} \qquad \omega_2 \cong \frac{1}{RC}$$

Filtre bouchon



$$R > \frac{1}{2}\sqrt{\frac{L}{C}}$$

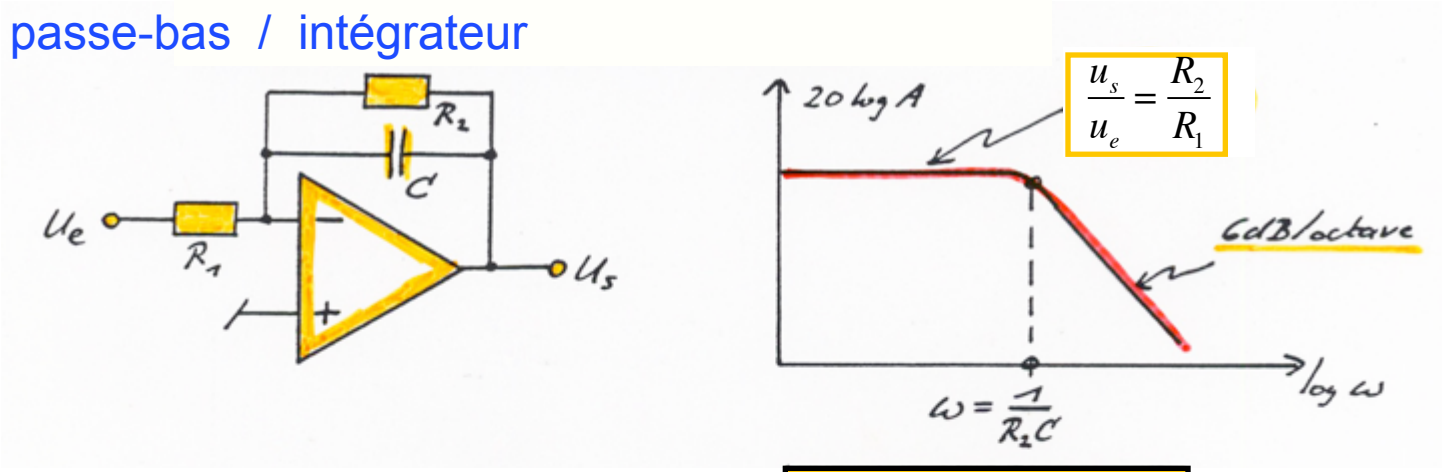


$$\Delta\omega \cong \frac{1}{RC}$$

$$\omega_0 \cong \frac{1}{\sqrt{LC}}$$

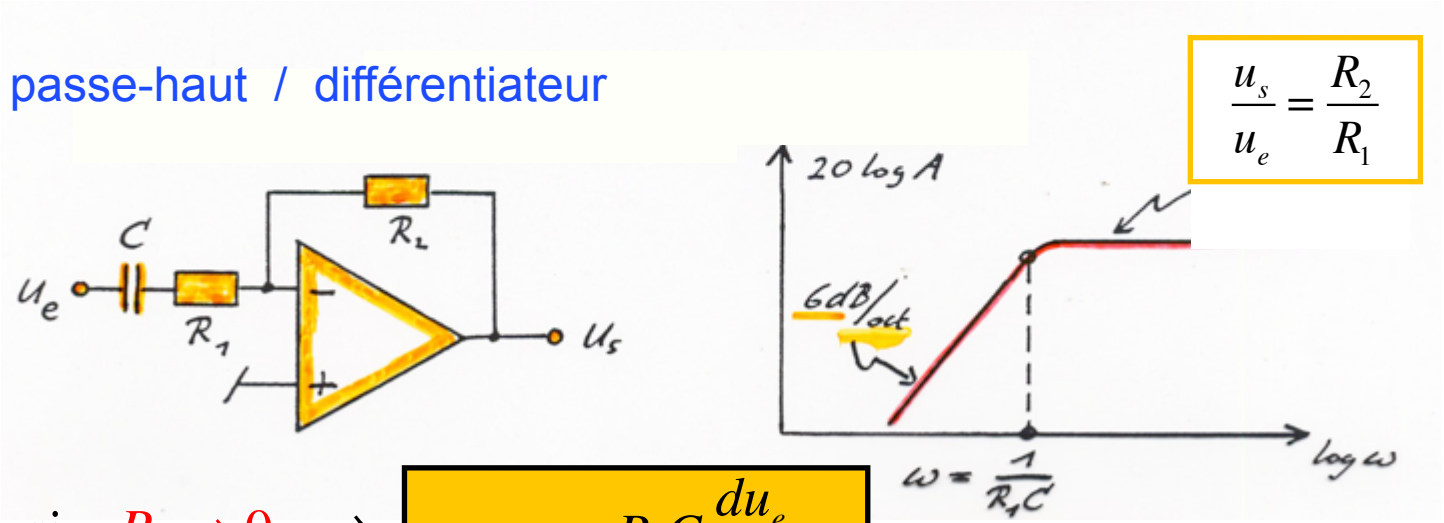
Circuits linéaires

Filtre passe-bas / intégrateur



$$si \quad R_2 \to \infty \quad \Rightarrow \quad u_s = -\frac{1}{R_1 C}\int u_e \, dt$$

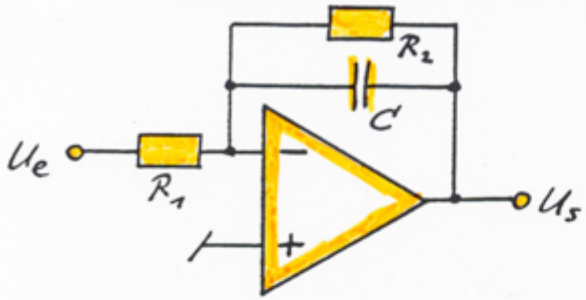
Filtre passe-haut / différentiateur

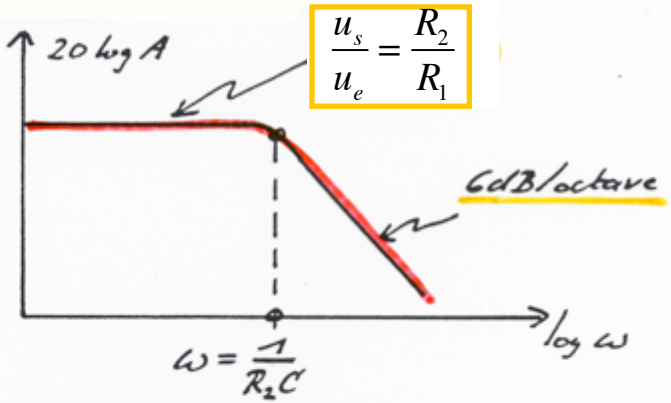


$$si \quad R_1 \to 0 \quad \Rightarrow \quad u_s = -R_2 C \frac{du_e}{dt}$$

Circuits linéaires

Filtre passe-bas / intégrateur



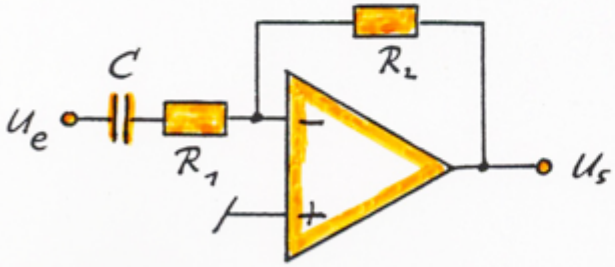


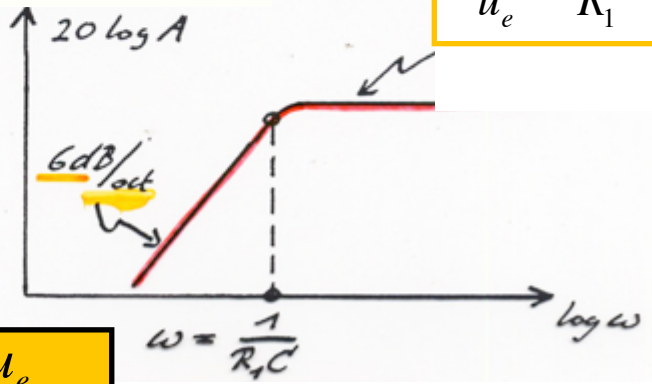
https://tinyurl.com/yzngnrbm

$$si \quad R_2 \to \infty \quad \Rightarrow \quad u_s = -\frac{1}{R_1 C}\int u_e \, dt$$

Filtre passe-haut / différentiateur

$$\frac{u_s}{u_e} = \frac{R_2}{R_1}$$

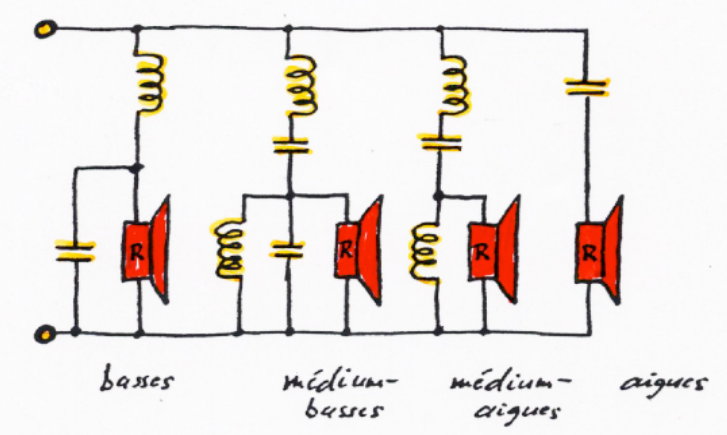




$$si \quad R_1 \to 0 \quad \Rightarrow \quad u_s = -R_2 C \frac{du_e}{dt}$$

Circuits - II
Dipôles et quadripôles

D. Mari



Le décibel (dB): niveau de pression ou de puissance acoustique

En acoustique, la force d'un son se mesure en décibels (dB). C'est une unité qui utilise le logarithme soit de la puissance du son, elle-mème exprimée en Watts par mètre carré W/m^{-2} ou bien de la différence de pression produite dans le milieu, exprimée en Pascals par mètre carré Pa/m^{-2}. Mais attention, la notion de puissance sonore ne donne qu'une vague idée du volume perçu par l'humain, car il faut prendre en compte la sensibilité de l'oreille, qui varie principalement selon la fréquence du son. En fait, l'oreille est moins sensible aux basses fréquences.

0 dB correspond au minima que l'oreille humaine peut percevoir appelé seuil d'audibilité, et non au silence absolu. Cette valeur a été choisie par l'expérience, elle vaut 10^{-12} $W \cdot m^{-2}$ pour un son de fréquence 1000 Hz, mais la plupart des personnes ont un seuil d'audibilité supérieur a 0 dB (environ 4 dB).

Il suffit de changer la référence de puissance ou de pression (P_0 ou W_0 dans les formules ci-dessous) pour que l'échelle des volumes soit complètement changée. C'est pourquoi les décibels gradués sur le bouton de volume d'une chaine Hi-Fi ne correspondent pas du tout à des niveaux acoustiques mais à des puissances électriques de sortie de l'amplificateur, ce qui n'a quasiment rien a voir, la valeur 0 dB représentant bien souvent la puissance maximale que l'amplificateur est capable de délivrer.

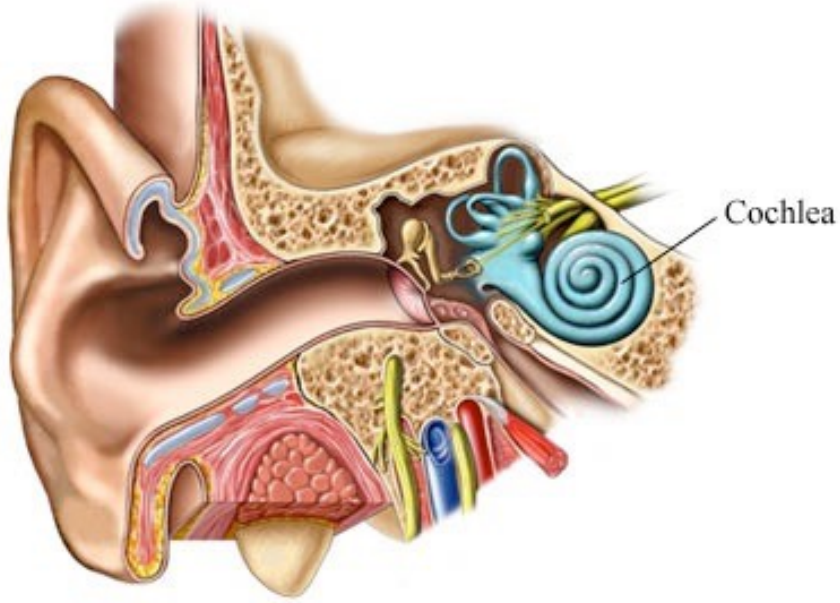
$$L_p = 10 \log_{10} \left(\frac{p}{p_0} \right)^2 = 20 \log_{10} \frac{p}{p_0}$$

$$L_W = 10 \log_{10} \frac{W}{W_0}$$

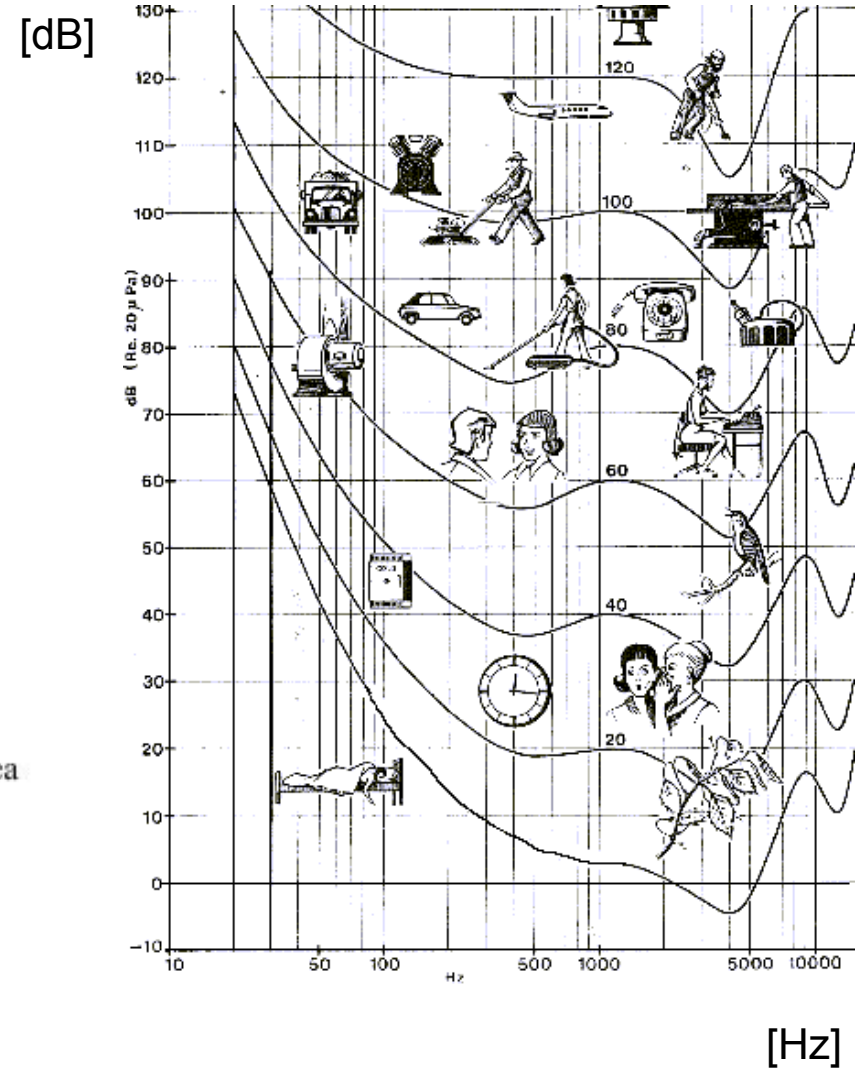
Puissance (W)	Niveau dB	Exemple	Puissance (W)
100 000 000	200	Fusée Saturn V	50 000 000
1 000 000	180		
10 000	160	Gros porteur quadriréacteurs	50 000
100	140	Grand orchestre	10
1	120	Marteau piqueur	1
0.01	100	Cri	0.001
0.000 1	80		
0.000 001	60	Conversation	$20x10^{-6}$
0.000 000 01	40		
0.000 000 000 1	20	Chuchotement	10^{-9}
0.000 000 000 001	0		

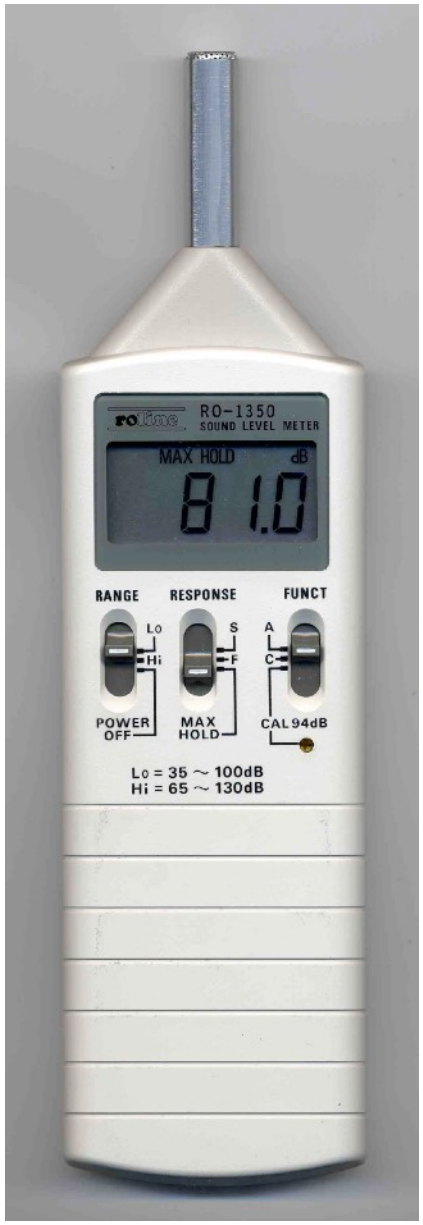
Puissances acoustiques de sources courantes de bruit

Puissances acoustiques de sources courantes de bruit



Courbes d'iso-niveaux physiologiques





Sonomètre

Courbes d'iso-niveaux physiologiques