I.U.T. « A » Bordeaux **Département : G.E.I.I.**

Capacité de transition et de diffusion de la jonction PN.

Schéma équivalent du transistor bipolaire en H.F.

Réponse en fréquences du gain en courant du transistor bipolaire

Schéma équivalent et courbe de réponse des montages fondamentaux du transistor bipolaire NPN en hautes fréquences :

- Emetteur commun
- Base commune
- Collecteur commun

Schéma équivalent du transistor JFET et MOSFET en H.F.

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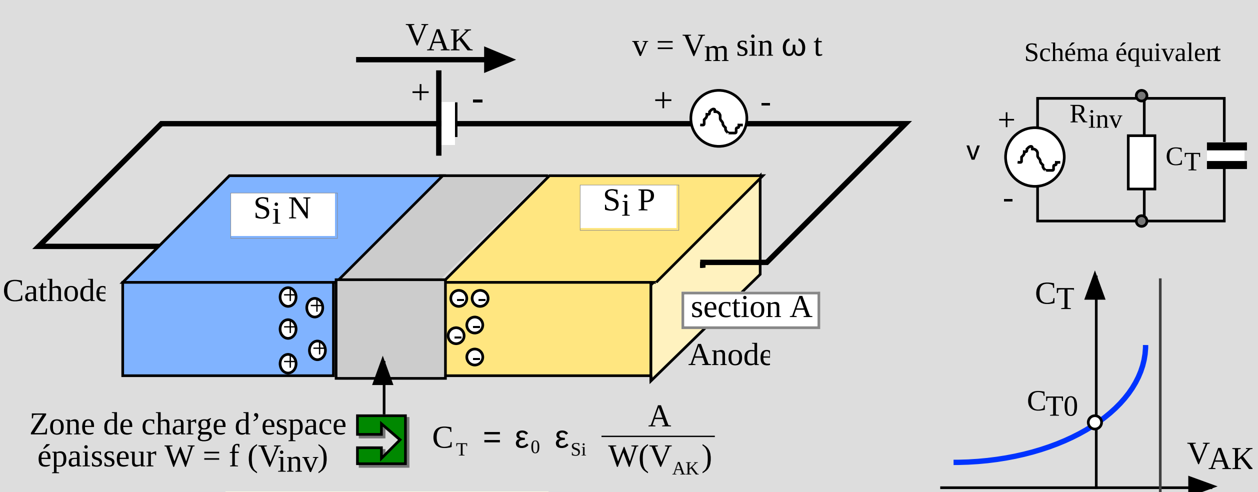
JONCTION POLARISEE EN INVERSE : CAPACITÉ DE TRANSITION

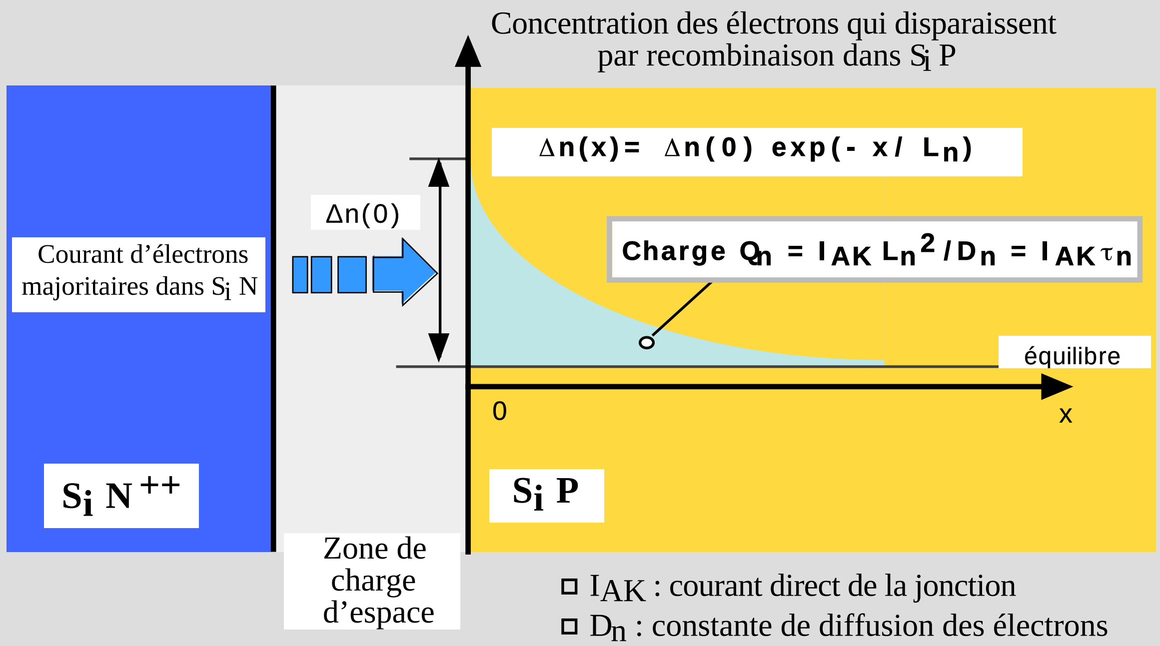


$$C_T = \varepsilon_0 \, \varepsilon_{Si} \frac{A}{W(V_{AK})}$$

$$C_T = \frac{C_{T0}}{\sqrt[2\text{ à }3]{1 - \frac{V_{AK}}{V_\varphi}}}$$

$$V_\varphi = U_T \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

JONCTION POLARISEE EN DIRECT : CAPACITE DE DIFFUSION



- I_{AK} : courant direct de la jonction
- D_n : constante de diffusion des électrons
- L_n : longueur de diffusion des électrons
- τ_n : durée de vie des électrons dans Si P

$$C_d = \frac{dQ_n}{dV_{AK}} = \tau_n \frac{dI_{AK}}{dV_{AK}} = \tau_n \frac{I_{A\ repos}}{U_T}$$

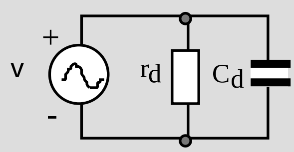
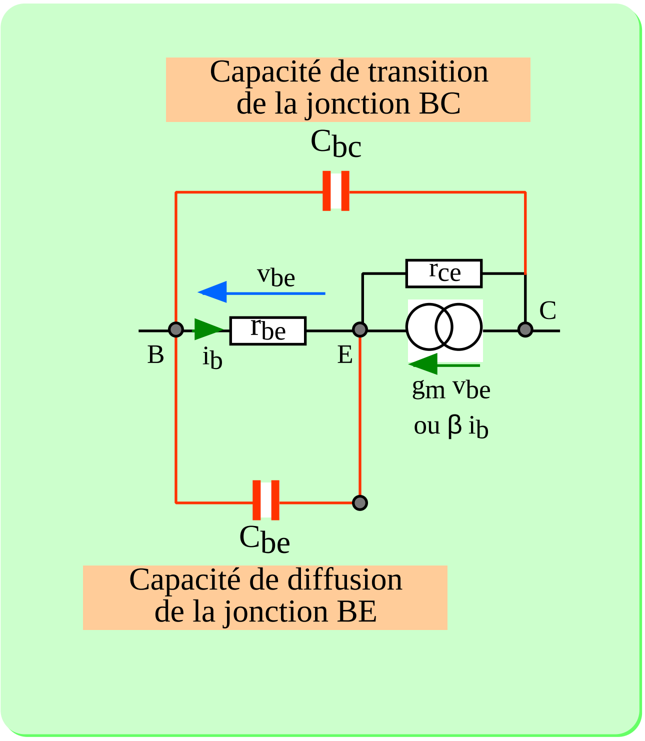
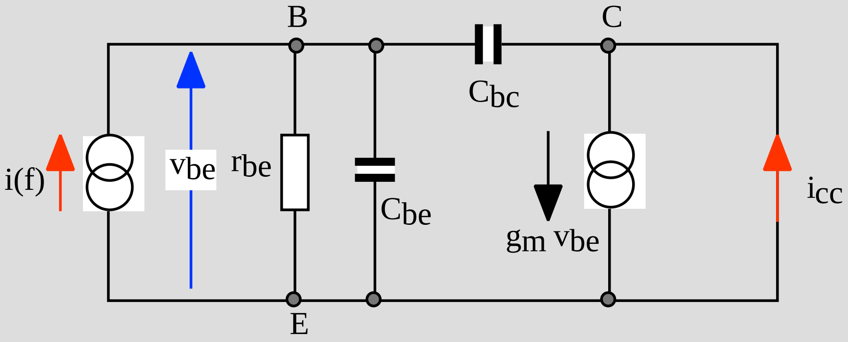


Schéma équivalent

SCHÉMA EQUIVALENT AUX PETITES VARIATIONS HAUTES FREQUENCES DU TRANSISTOR BIPOLAIRE NPN OU PNP

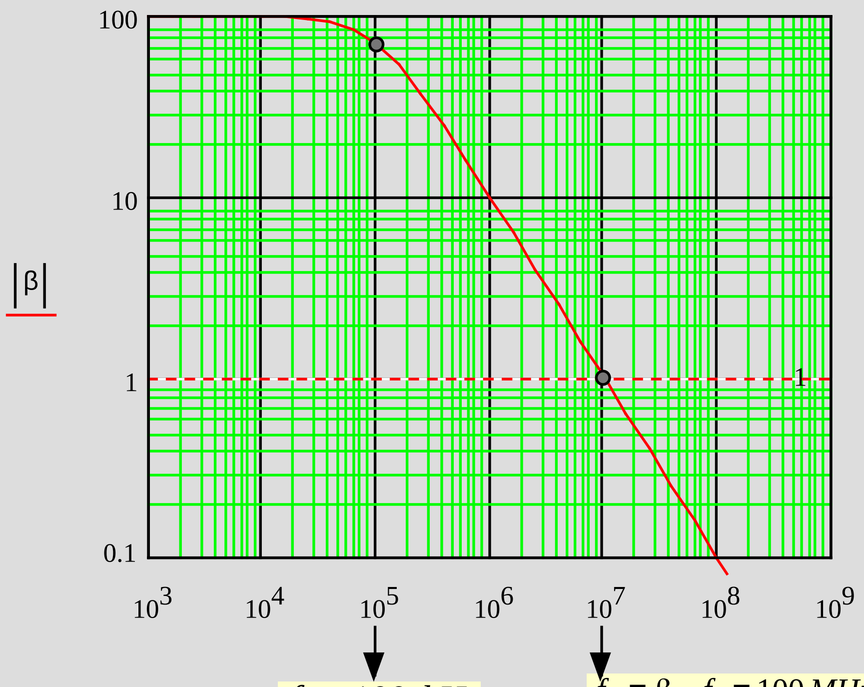


REPONSE EN FREQUENCE DU GAIN EN COURANT DU TRANSISTOR BIPOLAIRE



$$\beta(f) = \frac{i_{cc}}{i} = \frac{g_m r_{be}}{1 + j\omega\ r_{be}(C_{be} + C_{bc})}$$

$$\beta(f) = \frac{\beta_0}{1 + j\dfrac{f}{f_\beta}}$$

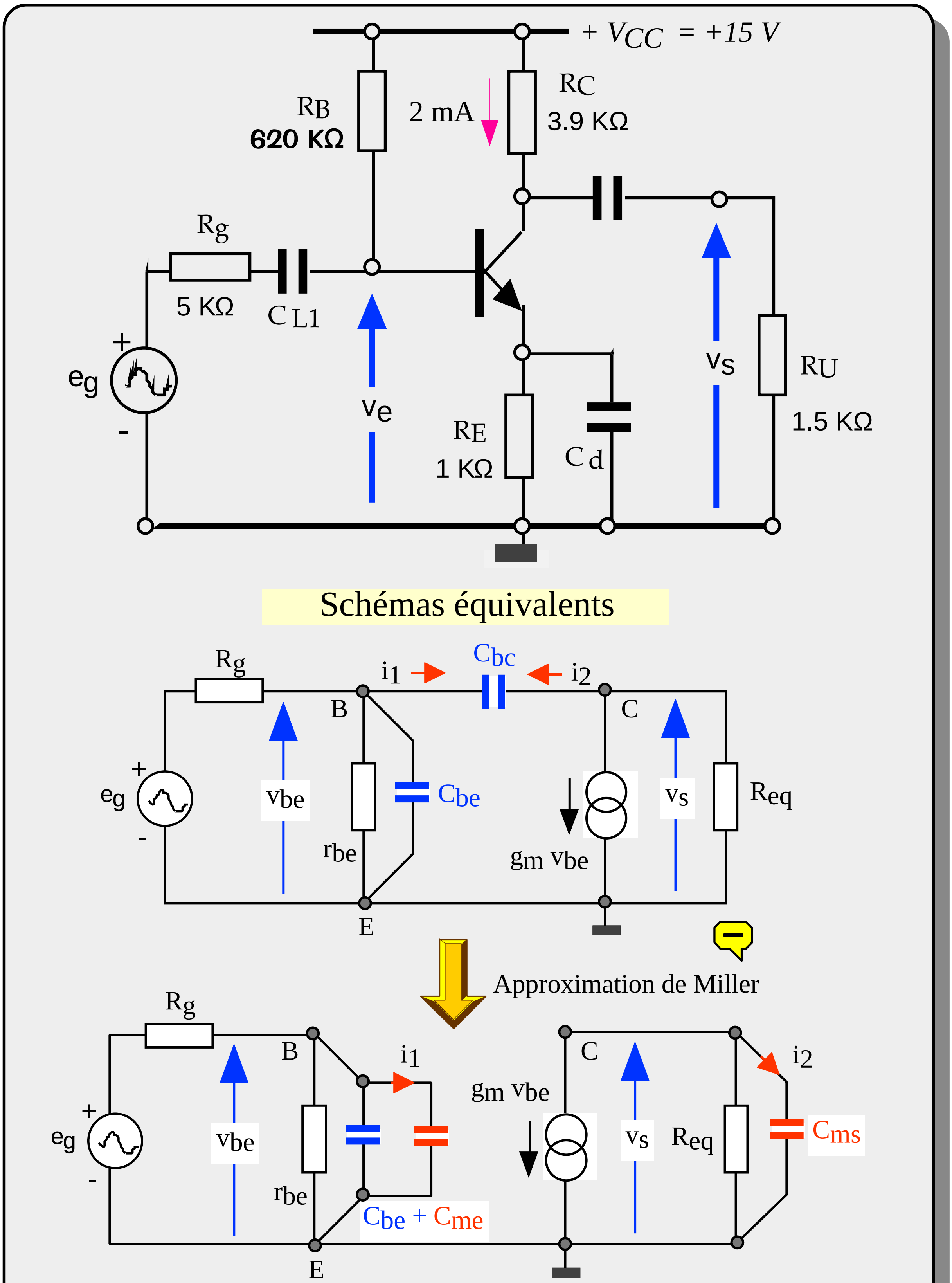


$f_\beta = 100\ kHz$

$f_T = \beta_0\ f_\beta = 100\, MHz$

Fréquence de transition : $f_t = \dfrac{g_m}{2\pi(C_{be} + C_{bc})}$

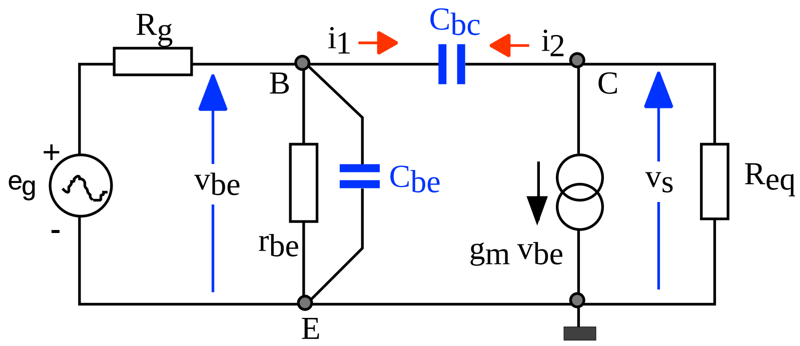
MONTAGE EMETTEUR COMMUN EN HAUTES FREQUENCES (T= 25 °C)



β =100 g_m = 80 mS r_{be} = 1250 Ω C_{be} = 20 pF Cbc = 5.5 pF

C_{me} = 445 pF C_{ms} = 5.5 pF

EMETTEUR COMMUN EN HAUTES FREQUENCES



Equations aux noeuds C et B (on pose p = j ω)

```
> restart:
```

> $noeud\_B := (eg - ve)\,Gg - ve\,Gbe - ve\,p\,Cbe + (vs - ve)\,p\,Cbc = 0$

> $noeud\_C := (ve - vs)\,p\,Cbc - gm\,ve - vs\,Gequi = 0$

> $systéme := \{noeud\_B, noeud\_C\}$

> $var := \{eg, vs\}$

Résolution du systéme d'équations

```
> sol:=solve(systéme,var):assign(sol):
```

Expression du gain en tension du montage complet

```
> gain1:=(vs/eg):
> D1:=collect(denom(gain1),[p,Gequi,Cbc]):gain2:=numer(gain1)/D
1;
```

$$gain2 := \frac{(p\,Cbc - gm)\,Gg}{p^2\,Cbe\,Cbc + ((Cbe + Cbc)\,Gequi + (Gg + Gbe + gm)\,Cbc)\,p + (Gg + Gbe)\,Gequi}$$

Application numérique

> $AN := Gg = \frac{1}{5000},\ gm = .080,\ Gbe = \frac{1}{1250},\ Cbe = .20\ 10^{-10},\ Cbc = .55\ 10^{-11},\ Gequi = \frac{1}{990}$

```
> gain3:=subs(AN,gain2):
> p:=I*2*Pi*f;gain4:=abs(gain3);
```

$$p := 2\,I\,\pi\,f$$

$$gain4 := \frac{1}{5000}\left|\frac{.110\ 10^{-10}\,I\,\pi\,f - .080}{-.4400\ 10^{-21}\,\pi^2\,f^2 + .9425151516\ 10^{-12}\,I\,\pi\,f + \frac{1}{990000}}\right|$$

Courbe de réponse

Gain max à f = 1 Hz

```
> gain_max:=evalf(subs(f=1,gain4));
```

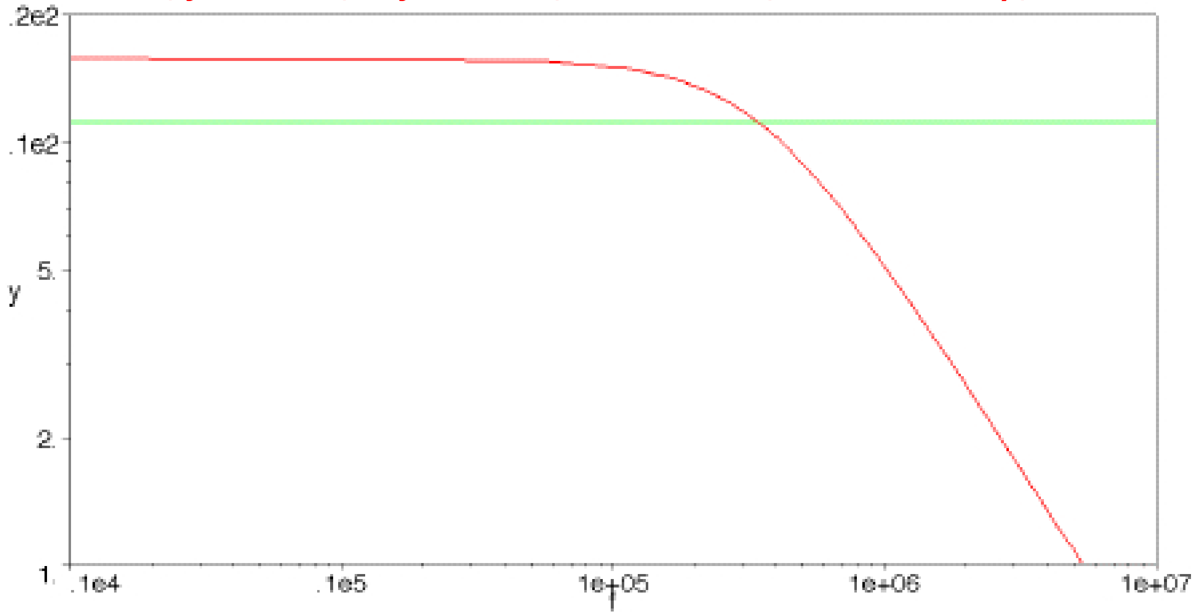
$gain\_max := 15.84000000$

Fréquence de coupure haute à - 3 dB

```
> eq1:=gain4=gain_max/sqrt(2):f_coupure:=fsolve(eq1,f=1e5..1e6)
;
```

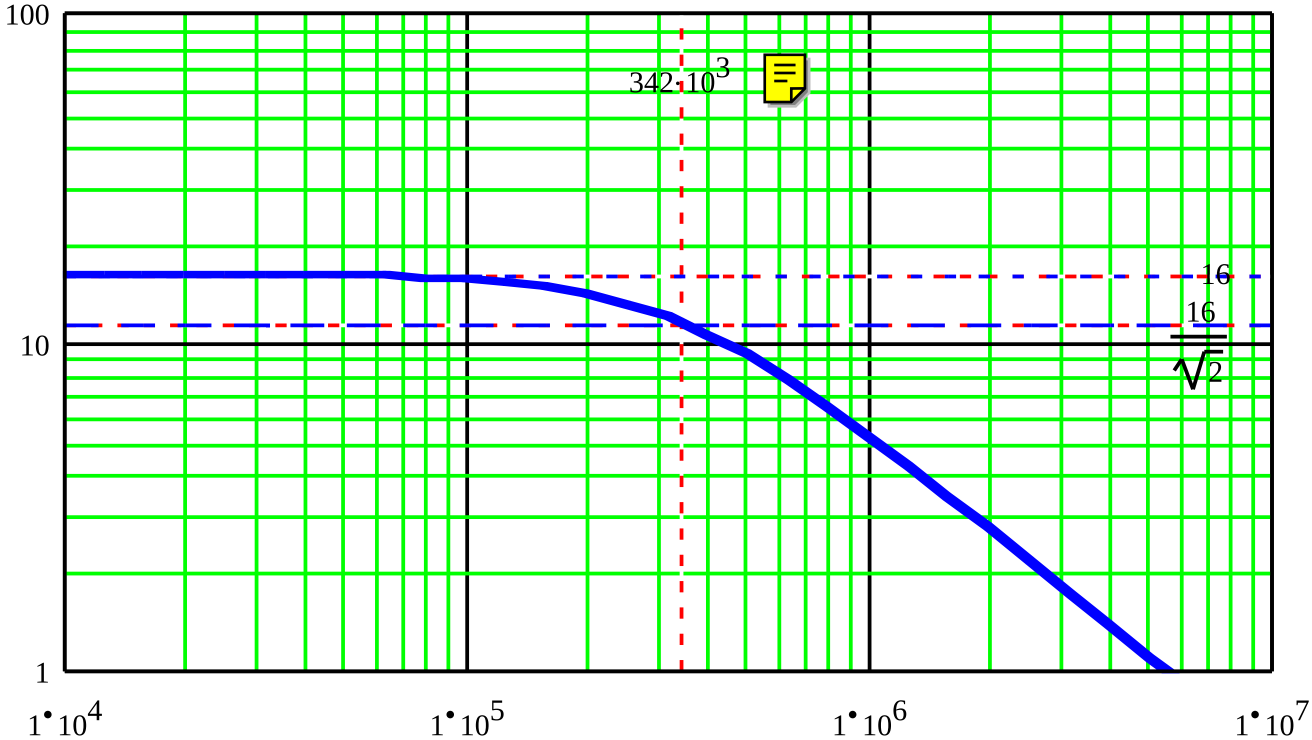
$f\_coupure := 341306.0122$

```
> with(plots):loglogplot([evalf(gain4),gain_max/(sqrt(2))],f=1e
3..10e6,y=1...20,style=line,axes=boxed,thickness=2);
```

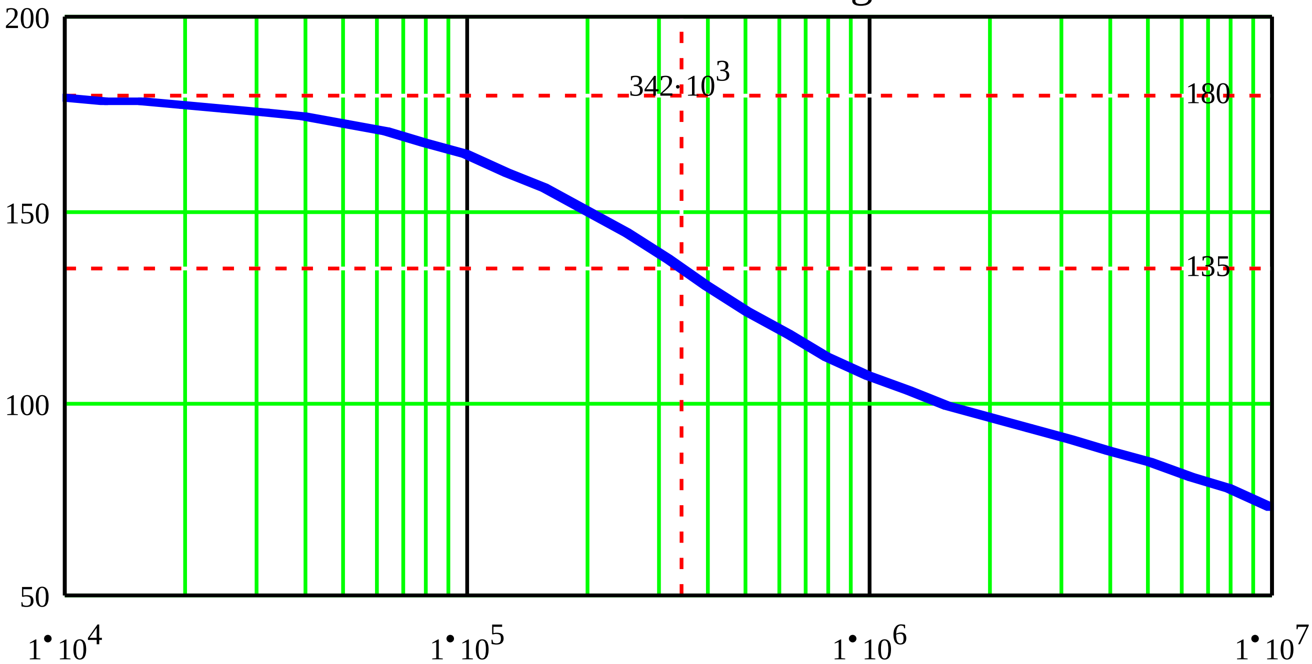



```
>
```

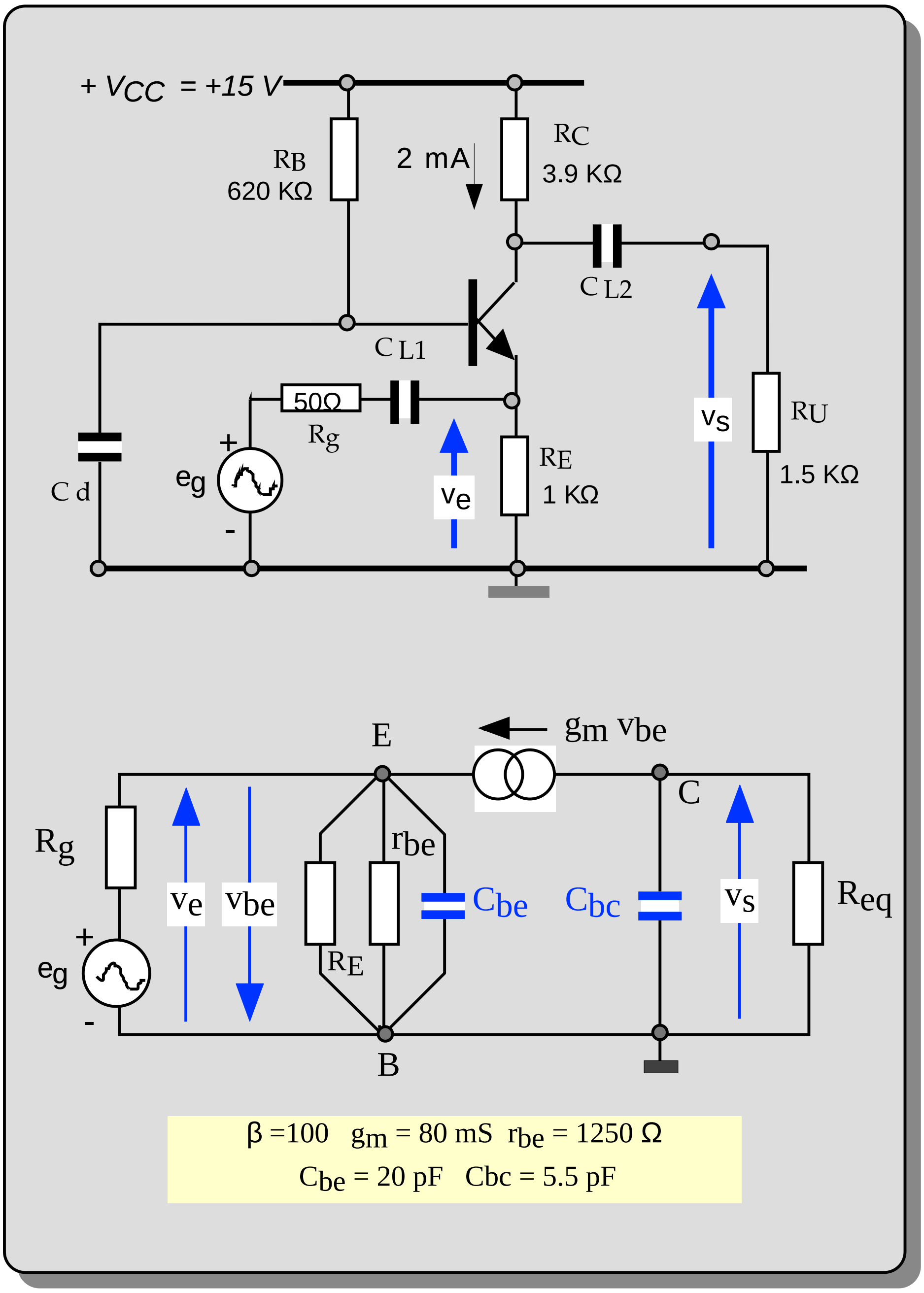
Module du gain en tension $[v_S/e_g]$ en fonction de la fréquence



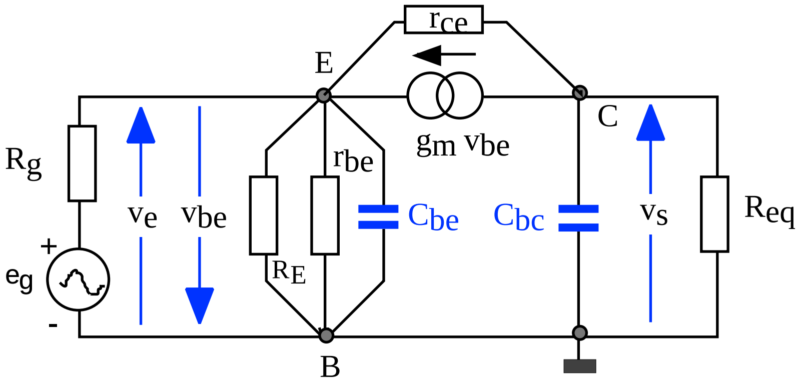
Argument en degrés du gain en tension $[v_S/e_g]$ en fonction de la fréquence



MONTAGE BASE COMMUNE
EN HAUTES FREQUENCES (T= 25 °C)



BASE COMMUNE EN HAUTES FREQUENCES



Equations aux noeuds E et C -> système

```
> restart:
```

> $noeud\_E := (eg - ve)\,Gg - ve\,(GE + Gbe + p\,Cbe) - gm\,ve + (ve - vs)\,Gce = 0$

> $noeud\_C := gm\,ve - vs\,(Gequi + p\,Cbc) + (ve - vs)\,Gce = 0$

> $systeme := \{noeud\_E, noeud\_C\}$

> $var := \{vs, eg\}$

Résolution et expression du gain du montage vs/eg

```
> sol:=solve(systeme,var):assign(sol);
> gain:=simplify(vs/eg);
```

$$gain := ((gm + Gce)\,Gg) / (Gg\,Gequi + Gg\,p\,Cbc + Gg\,Gce + GE\,Gequi + GE\,p\,Cbc + GE\,Gce + Gbe\,Gequi + Gbe\,p\,Cbc + Gbe\,Gce + p\,Cbe\,Gequi + p^2\,Cbe\,Cbc + p\,Cbe\,Gce + gm\,Gequi + gm\,p\,Cbc + 2\,gm\,Gce - Gce\,Gequi - Gce\,p\,Cbc)$$

Application numérique

> $AN := Gg = \frac{1}{50}, GE = \frac{1}{1000}, gm = .080, Gbe = \frac{1}{1250}, Cbe = .20\ 10^{-10}, Cbc = .55\ 10^{-11}, Gequi = \frac{1}{3900} + \frac{1}{1500}, Gce = \frac{1}{30000}$

```
> gain1:=subs(AN,gain):
> p:=I*2*Pi*f;gain1;
```

$$p := 2\,I\,\pi\,f$$

$$.001600666667\,\frac{1}{.00009999846154 + .1157689744\ 10^{-11}\,I\,\pi\,f - .4400\ 10^{-21}\,\pi^2\,f^2}$$

```
> gain2:=abs(gain1);
```

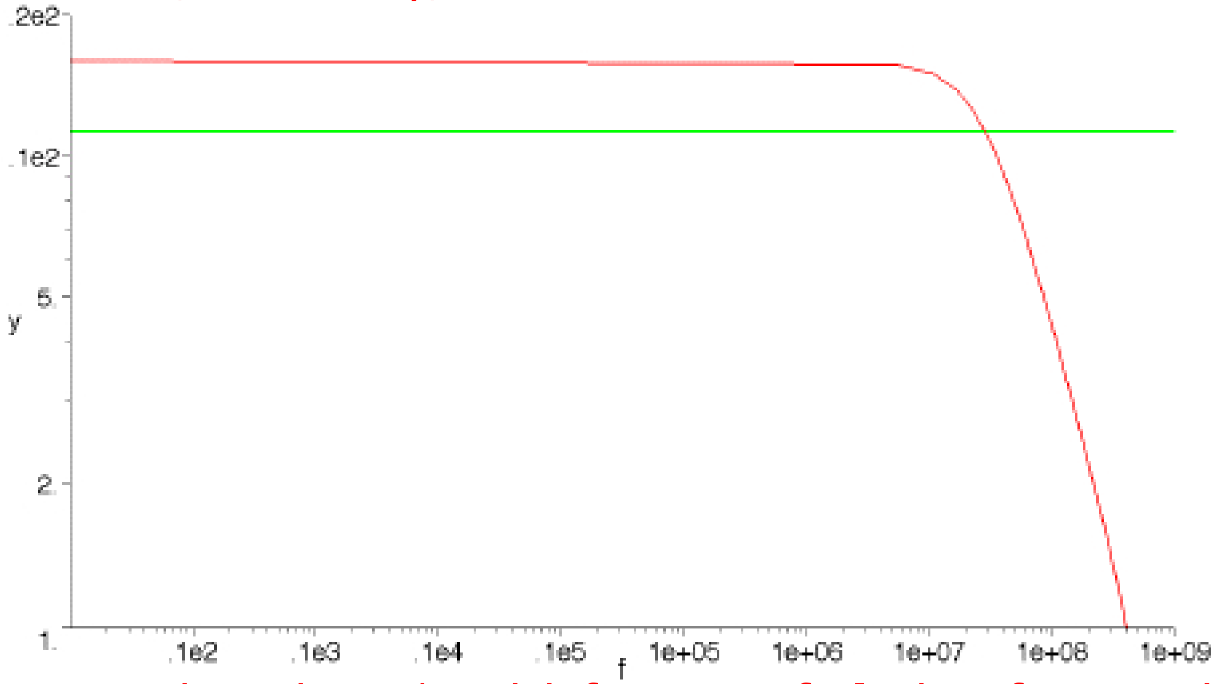
$$gain2 := .001600666667 \frac{1}{\left| .00009999846154 + .1157689744\ 10^{-11}\ I\ \pi f - .4400\ 10^{-21}\ \pi^2 f^2 \right|}$$

Courbe de réponse

```
> gain_max:=evalf(subs(f=1,gain2));
```

$$gain\_max := 16.00691293$$

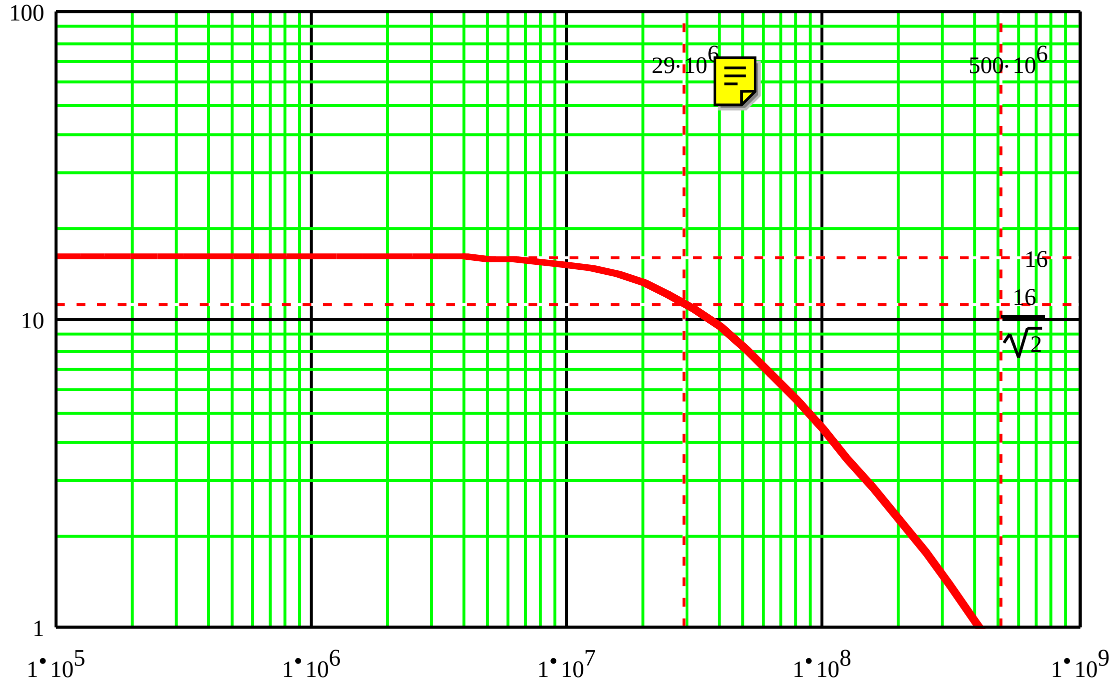
```
> with(plots):
> loglogplot([evalf(abs(gain2)),gain_max/(sqrt(2))],f=1..10e8,y
=1...20,thickness=2);
```



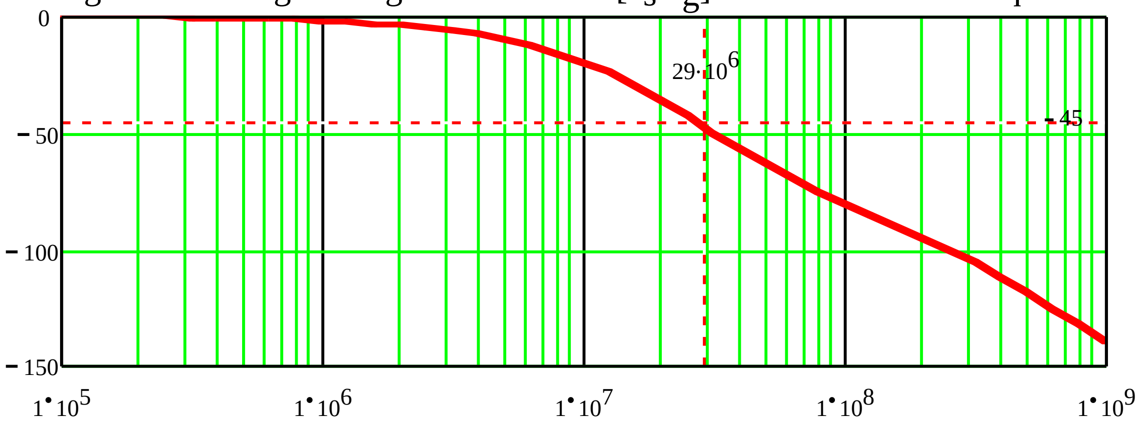

```
> eq1:=gain2=gain_max/sqrt(2):f_coupure:=fsolve(eq1,f=1e7..1e8)
;
```

$$f\_coupure := .2842699005\ 10^8$$

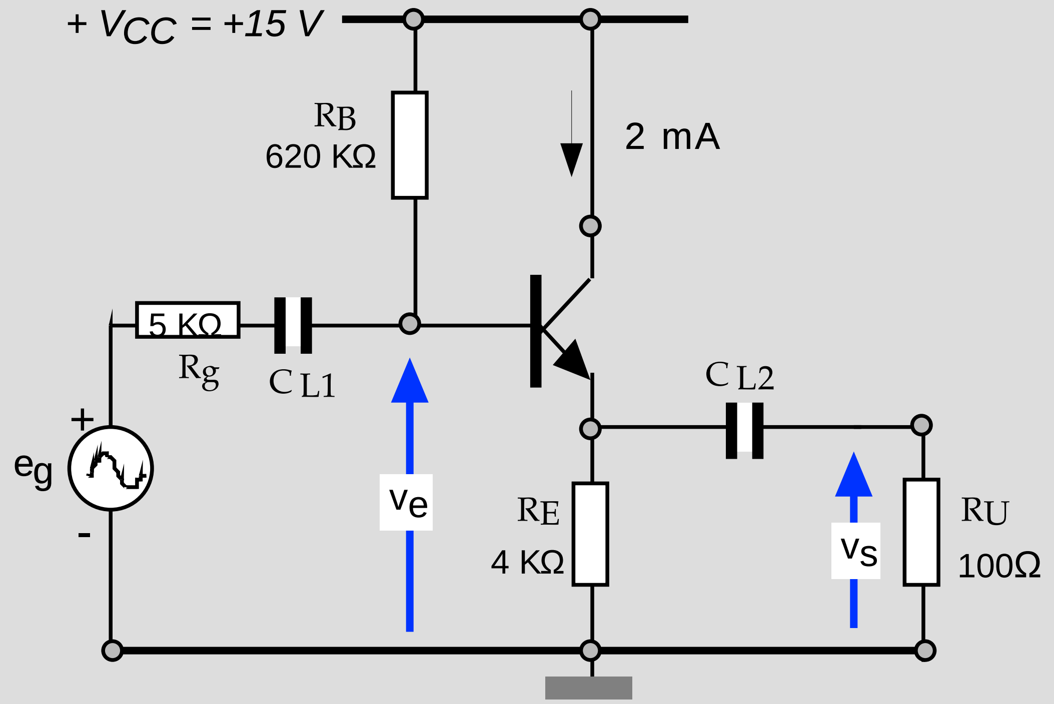
Module du gain en tension $[v_S/e_g]$ en fonction de la fréquence

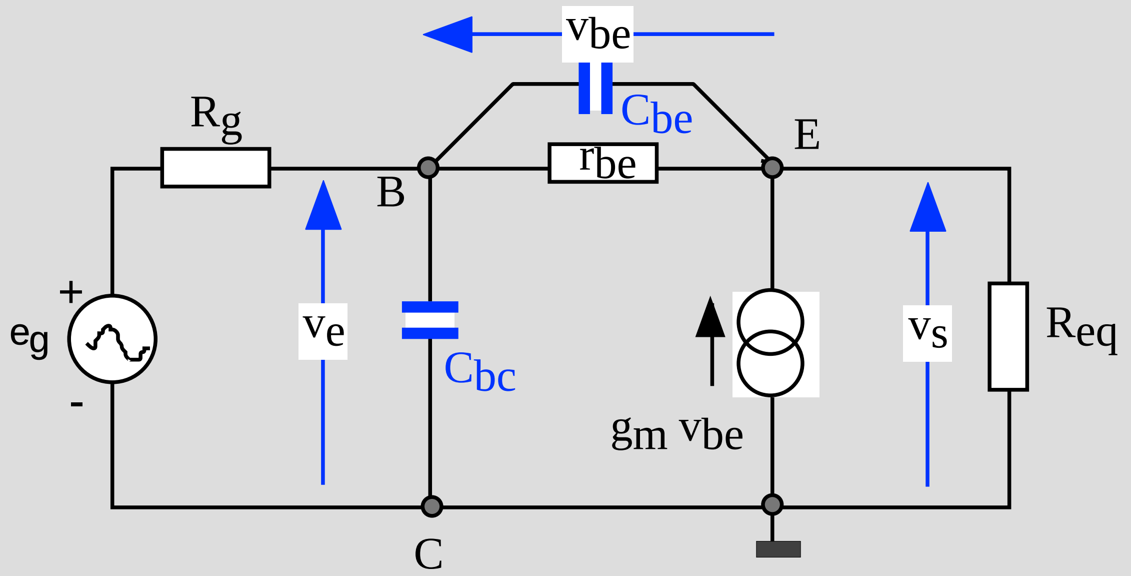


Argument en degrés du gain en tension $[v_S/e_g]$ en fonction de la fréquence



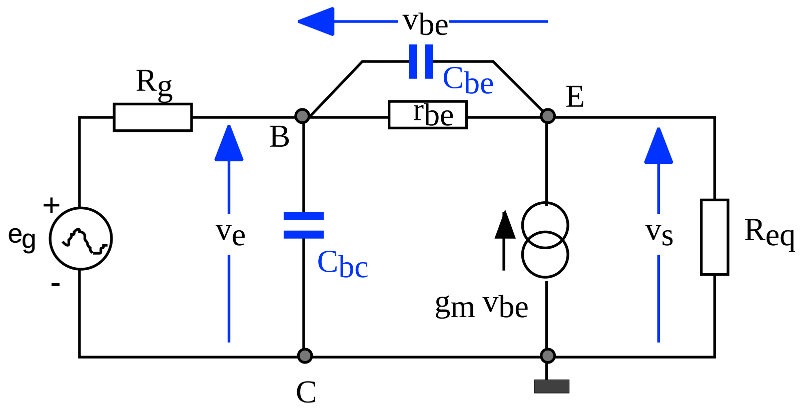
MONTAGE COLLECTEUR COMMUN
EN HAUTES FREQUENCES (T= 25 °C)





β =100 g_m = 80 mS r_{be} = 1250 Ω C_{be} = 20 pF C_{bc} = 5.5 pF

COLLECTEUR COMMUN EN HAUTES FREQUENCES



Mise en équations et résolution

```
> restart:
```

> $noeud\_B := (eg - ve)\,Gg - ve\,p\,Cbc + (vs - ve)\,(Gbe + p\,Cbe) = 0$

> $noeud\_E := (ve - vs)\,(Gbe + p\,Cbe) + gm\,(ve - vs) - vs\,Gequi = 0$

> $systeme := \{noeud\_B, noeud\_E\};\ var := \{eg, vs\}$

> $sol := \mathrm{solve}(systeme, var);\ \mathrm{assign}(sol)$

> $gain := \frac{vs}{eg}$

$$gain := ((Gbe + p\,Cbe + gm)\,Gg)\,/(p\,Cbe\,Gequi + Gbe\,Gequi + Gg\,p\,Cbe + p^2\,Cbc\,Cbe + p\,Cbc\,Gbe + p\,Cbc\,gm + p\,Cbc\,Gequi + Gg\,Gbe + Gg\,gm + Gg\,Gequi)$$

Application numérique, courbe de réponse

```
> AN:=Gg=1/5000,GE=1/4000,gm=80e-3,Gbe=1/1250,Cbe=20e-12,Cbc=5.
5e-12,Gequi=1/100:
> gain1:=subs(AN,gain):

> p:=I*2*Pi*f;
```

$$p := 2\,I\,\pi\,f$$

```
> gain2:=abs(gain1);
```

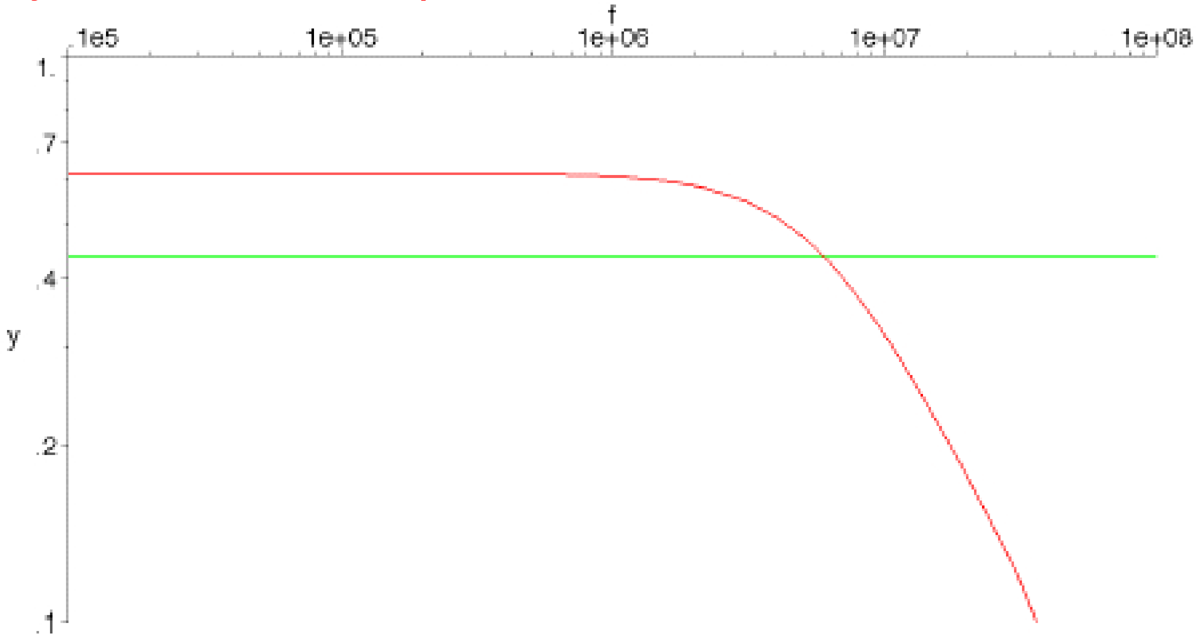
$$gain2 := \frac{1}{5000}\left|\frac{.08080000000 + .40\ 10^{-10}\,I\,\pi\,f}{.1406800000\ 10^{-11}\,I\,\pi\,f + .00002616000000 - .4400\ 10^{-21}\,\pi^2\,f^2}\right|$$

```
> gain_max:=evalf(subs(f=1,gain2));
```

$$gain\_max := .6177370030$$

```
> with(plots):
```

```
> loglogplot([evalf(abs(gain2)),gain_max/(sqrt(2))],f=1e4..1e8,
  y=0.1..1,thickness=2);
```

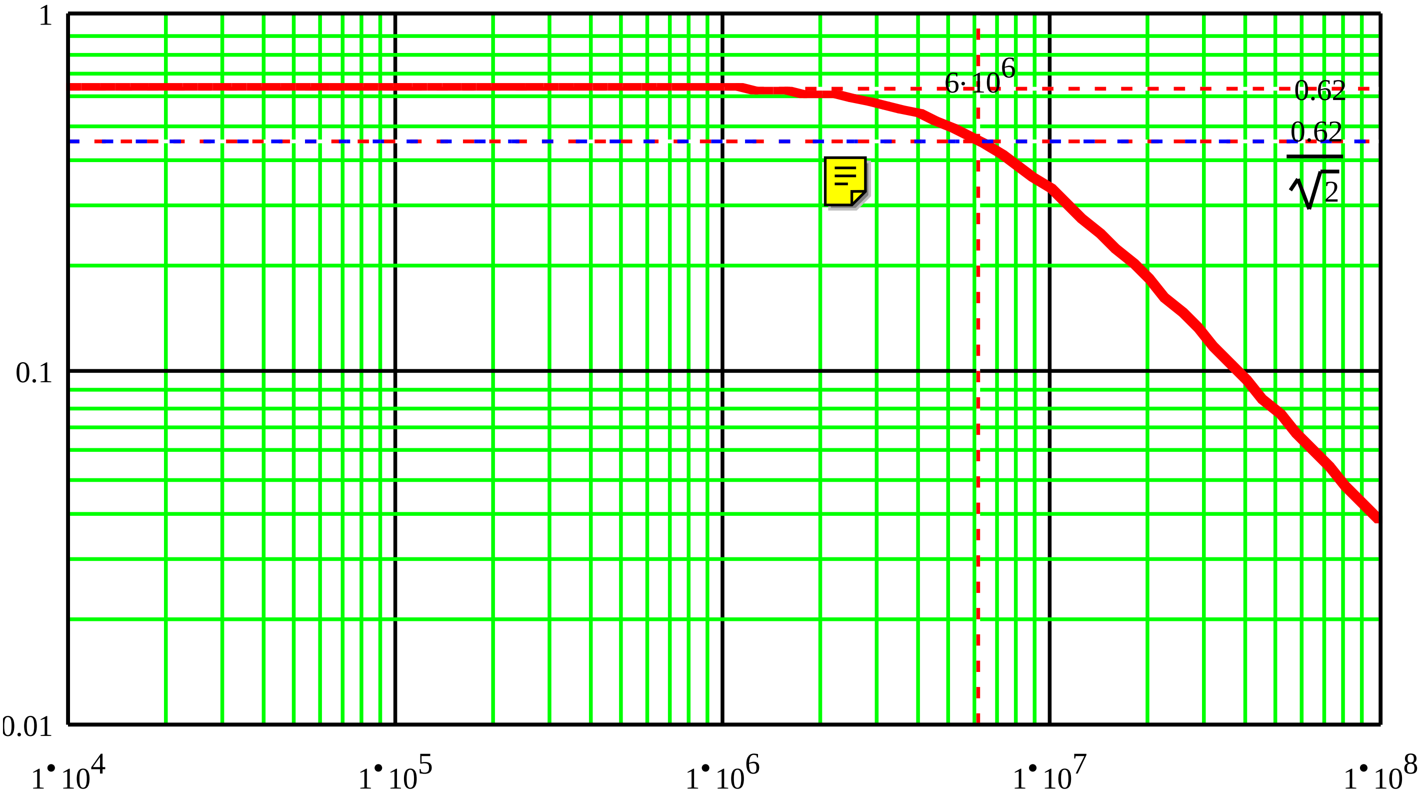



```
> eq1:=gain2=gain_max/sqrt(2):f_coupure:=fsolve(eq1,f=1e5..1e7)
  ;
```

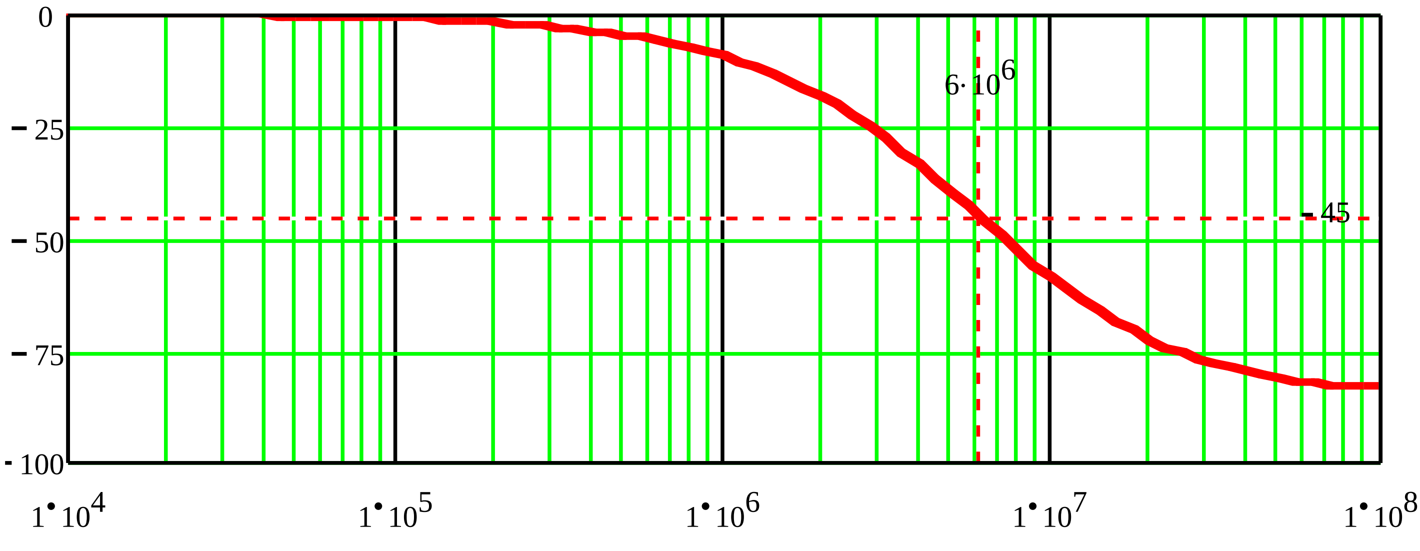
$$f\_coupure := .5954233966\ 10^{7}$$

```
>
```

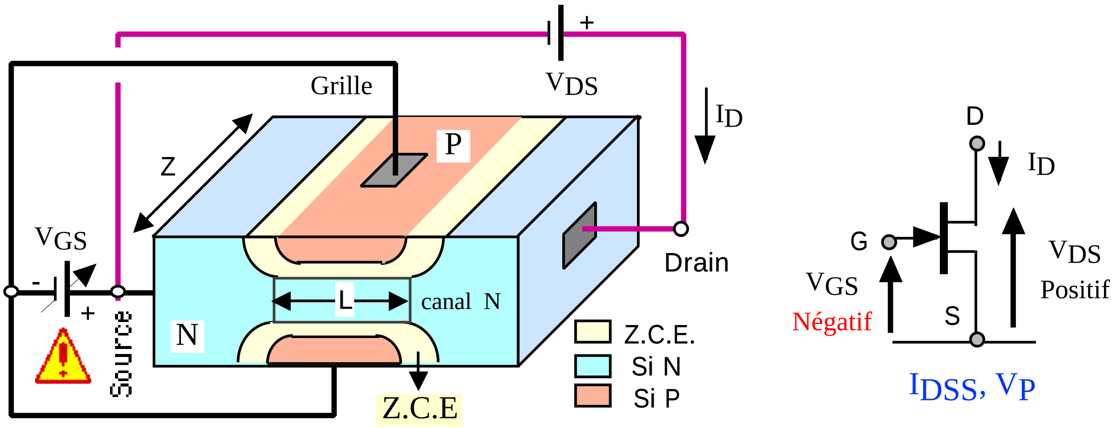
Module du gain en tension $[v_S/e_g]$ en fonction de la fréquence



Argument en degrés du gain en tension $[v_S/e_g]$ en fonction de la fréquence



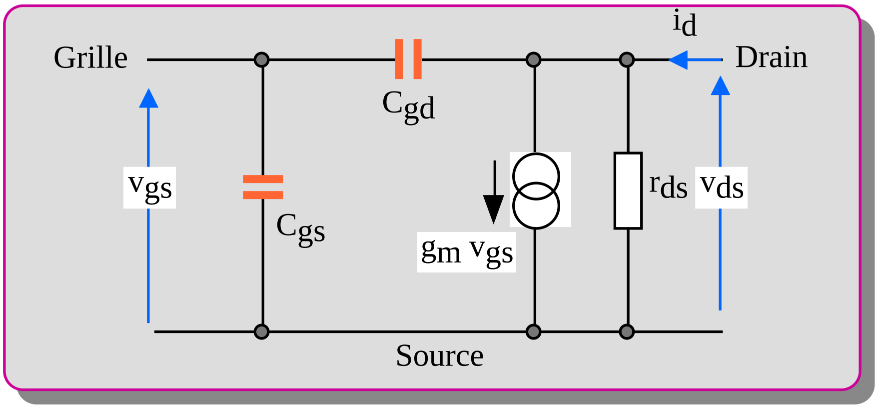
TRANSISTOR JFET



$$C_{gs} = \frac{C_{gs0}}{\sqrt[3]{1 + \frac{|V_{gs}|}{V_{\Phi}}}}$$

$$C_{gd} = \frac{C_{gd0}}{\sqrt[3]{1 + \frac{|V_{GD}|}{V_{\Phi}}}}$$

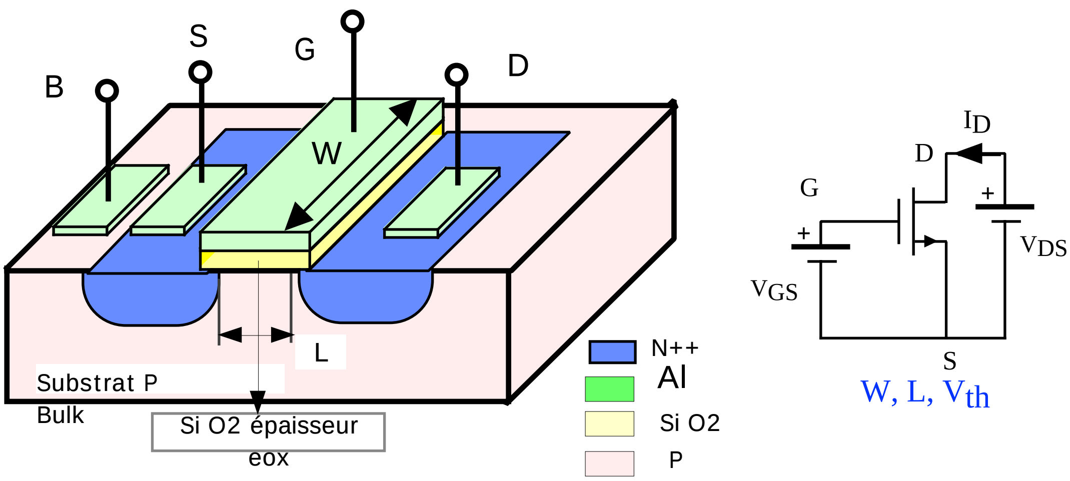
$$g_m = \frac{2}{|V_p|}\sqrt{I_{DSS}\, I_{D\ repos}}$$



$$C_{gs} = \frac{2}{3} WLC_{ox}$$

$$C_{gd} \quad \frac{1}{1000} pF$$

$$g_m = 2\sqrt{K\, I_{D\ repos}}$$



TRANSISTOR MOSFET