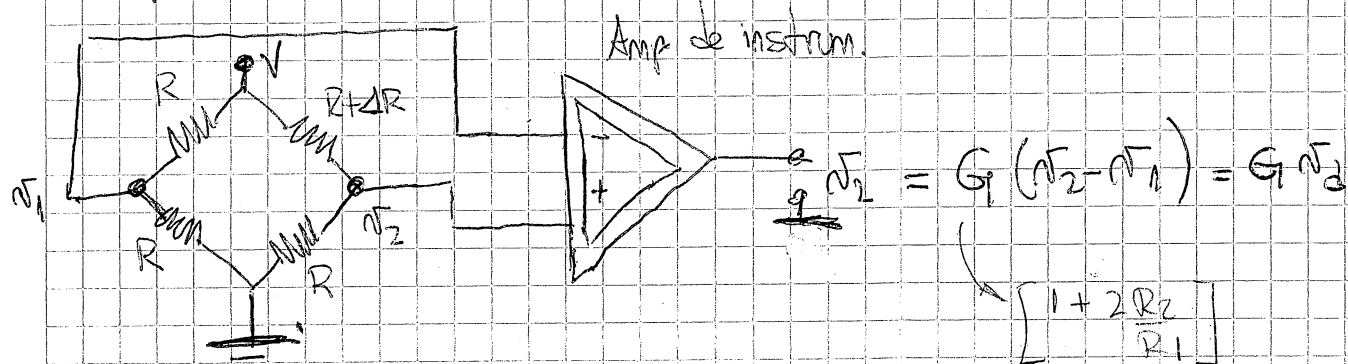


# Amplificador de instrumentación con un puente de Wheatstone



$$V_1 = \frac{V}{R+R} \cdot R = \frac{V}{2R} \cdot R = \frac{V}{2}$$

$$V_2 = \frac{V}{R+R+\Delta R} \cdot R = \frac{V \cdot R}{2R+\Delta R} = \frac{V}{\frac{2R}{R} + \frac{\Delta R}{R}} = \frac{V}{2 + \frac{\Delta R}{R}}$$

haciendo  $\frac{\Delta R}{R} = \delta$

$$\therefore V_2 = \frac{V}{2 + \delta}$$

$$V_2 = G(V_2 - V_1) \Rightarrow V_2 - V_1 = \frac{V}{2 + \delta} - \frac{V}{2} = \frac{2V - V(2 + \delta)}{2(2 + \delta)} =$$

$$\Delta V = V_2 - V_1 = \frac{2V - 2V - V\delta}{2(2 + \delta)} = \frac{-V\delta}{4 + \delta \cdot 2} = \frac{-V\delta}{4(1 + \frac{\delta}{2})} = -\frac{V}{4} \cdot \frac{\delta}{1 + \frac{\delta}{2}}$$

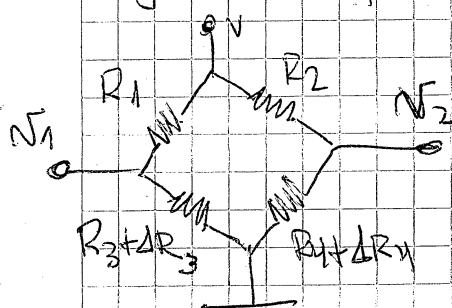
$$\therefore V_2 = -G \cdot \frac{V}{4} \cdot \frac{\delta}{1 + \frac{\delta}{2}} \quad \text{si } \frac{\delta}{2} \ll 1 \quad \therefore \boxed{V_2 = -G \frac{V \delta}{4}}$$

$V_2$  es lineal para pequeñas variaciones.

Ajustes de equilibrio en el puente: Temperatura:

$$R_1 = R_2 = R_3 = R \quad (\text{puente ideal})$$

$\Delta R_3$  y  $\Delta R_4$  Variación que sufre  $R_3$  y  $R_4$  debido a la temperatura.



$$V_2 - V_1 = \frac{V \cdot R + \Delta R_4}{2R + \Delta R_4} - \frac{R + \Delta R_3}{2R + \Delta R_3} \cdot V$$

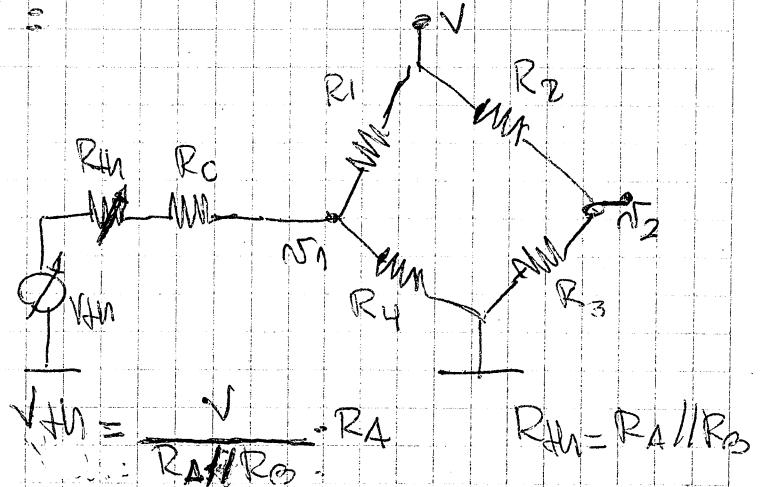
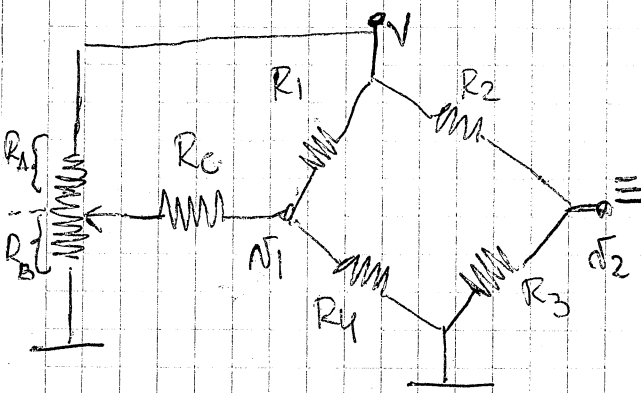
$$V_2 - V_1 = \frac{V \cdot (2R + \Delta R_3)(R + \Delta R_4) - (2R + \Delta R_4)(R + \Delta R_3) \cdot V}{(2R + \Delta R_4)(2R + \Delta R_3)}$$

$$V_2 - V_1 = V \frac{2R^2 + 2R\Delta R_4 + R\Delta R_3 + \Delta R_3\Delta R_4 - 2R^2 - 2R\Delta R_3 - \Delta R_4R - \Delta R_4\Delta R_3}{(2R + \Delta R_4)(2R + \Delta R_3)}$$

$$\Delta_2 = \frac{(R \Delta R_3 - R \Delta R_4) V}{(2R + \Delta R_3)(2R + \Delta R_4)} = \frac{R(\Delta R_3 - \Delta R_4) V}{(2R + \Delta R_3)(2R + \Delta R_4)} = \frac{V \cdot R}{(2R + \Delta R_3)(2R + \Delta R_4)} (\Delta R_3 - \Delta R_4)$$

$\therefore \Delta_2 = 0 \Rightarrow \Delta R_3 - \Delta R_4 = 0 \therefore \Delta R_3 = \Delta R_4$  Esto se logra haciendo  $R_4$  sea un sensor termico con las mismas caracteristicas termicas que  $R_3$ .

- tolerancia de las resistencias :



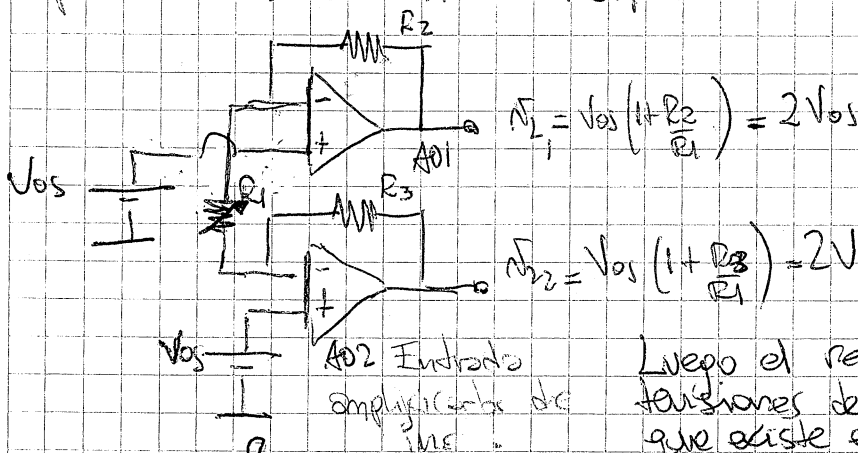
si  $R_c \gg R_{th}$

si  $R_c \gg R_4$

si  $R_c \gg R_A + R_B$

El conjunto  $R_{th}$  y  $V_{th}$  actúan como una fuente de corriente constante y de alta impedancia  $R_c$  no afecta al puente. Con  $V_{th}$  podemos variar la corriente que circula por  $R_4$  y ajustar  $N_1$  para  $\Delta_2 = 0$ .

Se pueden minimizar los efectos de  $I_{os}$  si se usan amplificadores operacionales con entrada FET, en la entrada del amp. de instrumentación



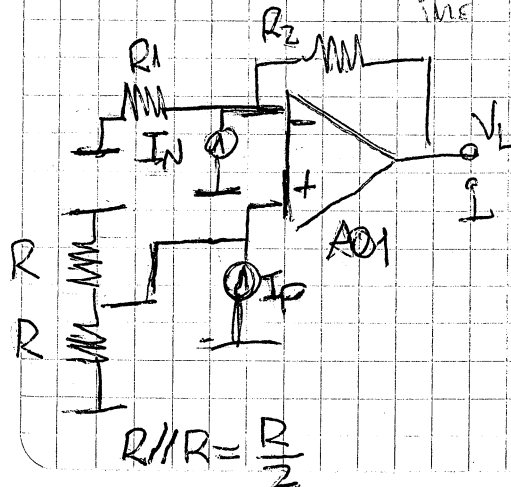
$$N_1 = V_{os} \left(1 + \frac{R_2}{R_1}\right) = 2V_{os}$$

$$N_2 = V_{os} \left(1 + \frac{R_3}{R_1}\right) = 2V_{os}$$

$$R_2 = R_3 \wedge R_1 = R_2$$

alta RRMC

Luego el restador diferencial suma estas tensiones de error. Solo la diferencia que existe entre ambas.



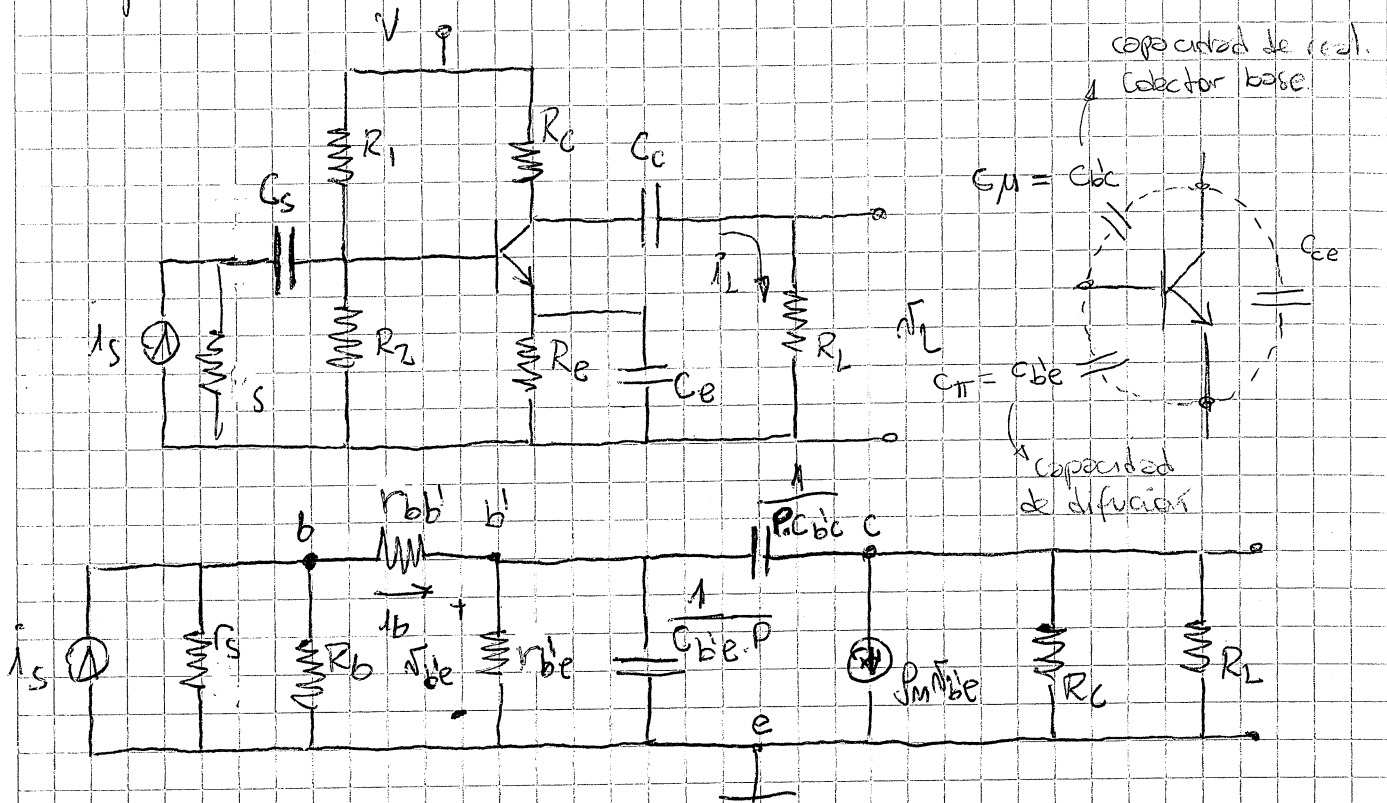
$$V_L = \frac{R}{2} I_p \left(1 + \frac{R_2}{R_1}\right) - R_1 I_n \frac{R_2}{R_1}$$

$$\begin{matrix} R_2 = R_2 \\ R_2 = R_3 \end{matrix}$$

$$V_L = R \cdot I_p - I_n R_2$$

El analisis para AO2 es similar. Si  $R_2 = R_3$  el amp. restador debería sumar esta tension de error.

Respuesta en esta frecuencia. Configuración IC.



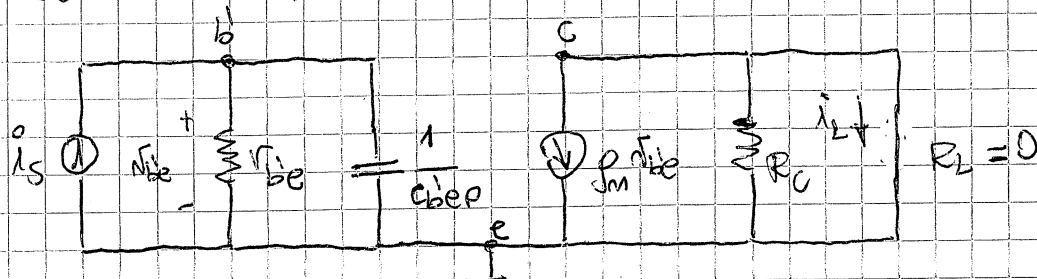
frecuencia de corte  $f_p$ .

definimos primero la ganancia de corriente cuando  $r_{ce} = 0$  ( $R_L = 0$ ).

$r_S \gg R_B$  entonces podemos despreciar  $r_S$

$r_{bb'} \approx 0$   
 $R_B \gg r_{bb'}$  } podemos despreciarlos

$C_{be} \gg C_{bc}$  podemos despreciar  $C_{bc}$



$$A_{i, f_0} \Big|_{r_{ce}=0} = \frac{i_L}{i_S} = \frac{i_L}{i_S} \cdot \frac{\beta I_B}{i_S}$$

$$\frac{i_L}{\beta I_B} = -g_m$$

$$\frac{r_{be}}{i_S} = r_{be} \parallel \frac{1}{C_{be} \cdot P} = \frac{r_{be}}{r_{be} + \frac{1}{C_{be} \cdot P}} = \frac{r_{be}}{1 + r_{be} C_{be} P} = \frac{r_{be}}{\frac{P}{1} + 1}$$

$$\frac{r_{be}}{1s} = \frac{r_{be}}{\frac{p}{p} + 1}$$

$$\therefore A_{i\beta} = -\beta_m \cdot \frac{r_{be}}{\frac{p}{p} + 1} \Rightarrow \boxed{A_{i\beta} = A_{ifm} \cdot \frac{1}{\frac{p}{p} + 1}}$$

$$p_p = 2\pi f_p = \frac{1}{r_{be} C_{be}} \Rightarrow \boxed{f_p = \frac{1}{2\pi r_{be} C_{be}}}$$

- producto Ganancia por ancho de banda:

Como  $f_p \gg f_n$  el ancho de banda suele ser igual  $f_p$ .

$$G(BW) = A_{ifm} \cdot f_p = -\beta_m r_{be} \cdot \frac{1}{2\pi r_{be} C_{be}}$$

$$\therefore \boxed{G(BW) = \frac{-\beta_m}{2\pi C_{be}}}$$

- frecuencia de transición  $f_T$ :

Es la frecuencia en donde la ganancia de corriente decae a la unidad

$$\left| A_{i\beta}(j\omega) \right|_{N_{ce}=0} = 1 \Rightarrow \left| A_{ifm} \cdot \frac{1}{\frac{j\omega_T + 1}{\omega_p}} \right| = |1|$$

$$\left| A_{ifm} \right| \cdot \frac{|1|}{\left| \frac{j\omega_T + 1}{\omega_p} \right|} = 1 \Rightarrow A_{ifm} \cdot \frac{1}{\sqrt{\left(\frac{\omega_T}{\omega_p}\right)^2 + 1}} = 1$$

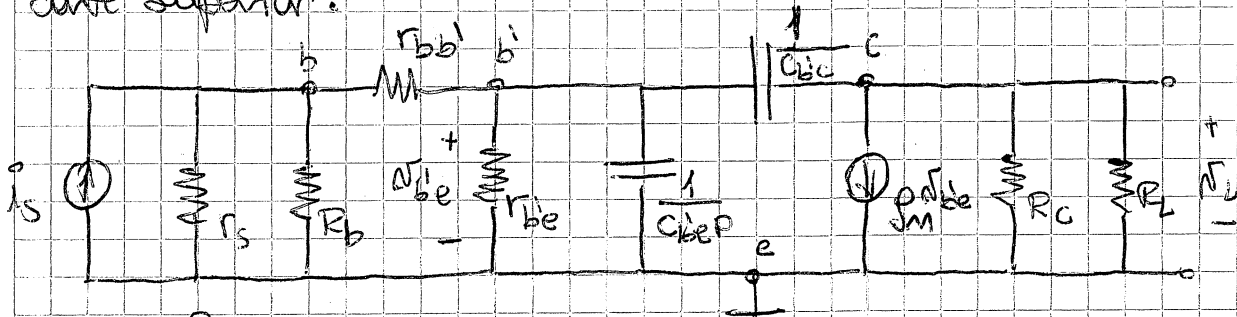
$$\sqrt{\left(\frac{\omega_T}{\omega_p}\right)^2 + 1} = A_{ifm} \Rightarrow \omega_T = \omega_p A_{ifm} \Rightarrow 2\pi f_T = 2\pi f_p A_{ifm}$$

$$\therefore f_T = f_p A_{ifm} = \frac{1}{2\pi r_{be} C_{be}} \cdot -\beta_m r_{be}$$

$$\therefore \boxed{f_T = \frac{-\beta_m}{2\pi C_{be}}}$$

# Capacitad de Miller:

La capacidad de realimentación  $C_{bc}$  influye sobre la frecuencia de corte superior.



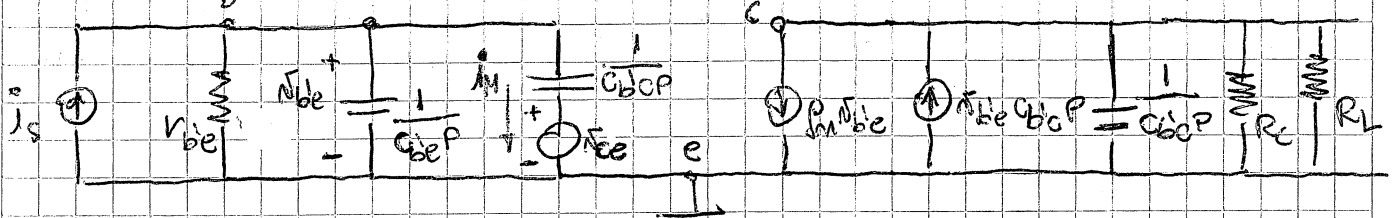
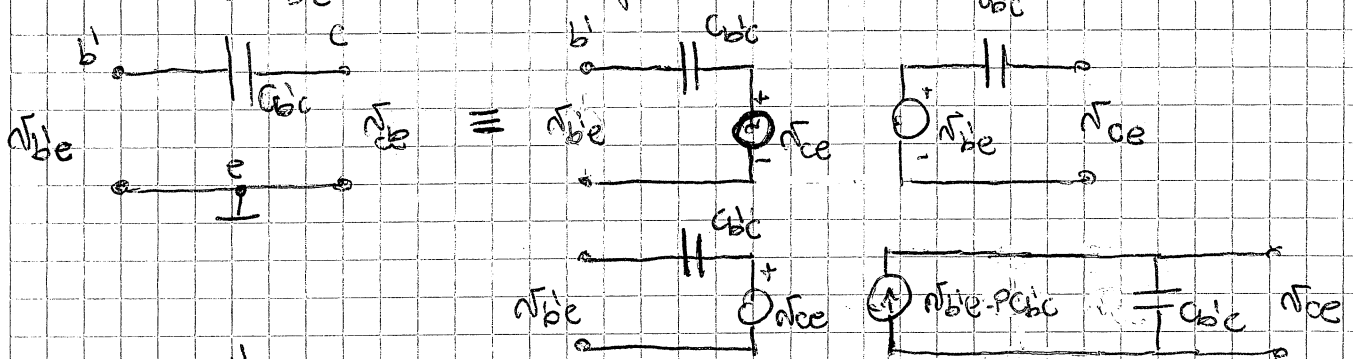
$$r_s \gg R_b$$

$$r_{b'b} \approx 0$$

$$R_b \gg r_{bb'}$$

podemos despreciar  $r_s, R_b$  y  $r_{bb'}$

Convertimos  $C_{bc}$  en un cuadripolo:

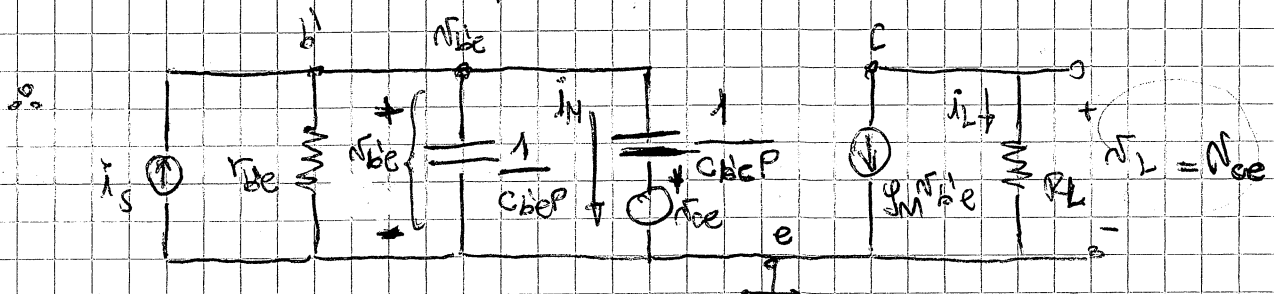


$$R_C \gg R_L$$

$$\frac{1}{C_{bcP}} \gg R_L$$

despreciamos  $R_C$  y  $C_{bc}$

$| \beta i_{be} | \gg | i_{be} C_{bcP} |$  despreciamos esta última fuente de corriente



$$i_M = \frac{(\beta i_{be} - i_{ce})}{\frac{1}{C_{bcP}}} = C_{bcP} (\beta i_{be} - i_{ce}) \quad (1)$$

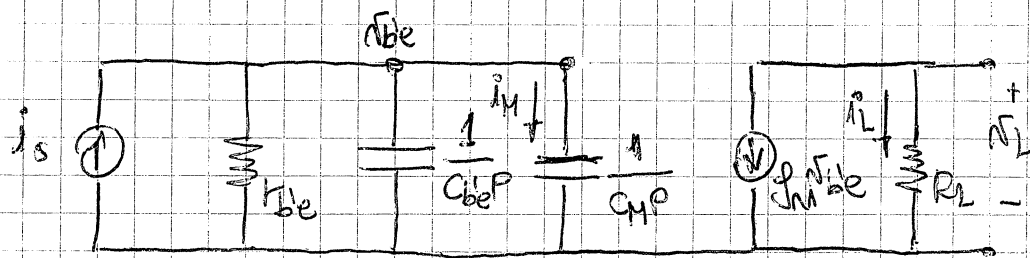
$$V_L = V_{ce} = -g_m V_{be} R_L \quad (2)$$

∴ Sustituyendo (2) en (1):

$$i_M = C_{be} P (V_{be} + g_m V_{be} R_L) = C_{be} P V_{be} (1 + g_m R_L)$$

$$\therefore Z_M = \frac{V_{be}}{i_M} = \frac{1}{C_{be} P} \Rightarrow \frac{V_{be}}{C_{be} P V_{be} (1 + g_m R_L)} = \frac{1}{C_{be} P}$$

$$\therefore \boxed{C_M = C_{be} (1 + g_m R_L)}$$



$$A_{if} = \frac{i_L}{i_s} = \frac{i_L}{V_{be}} \cdot \frac{V_{be}}{i_s}$$

$$\frac{i_L}{V_{be}} = -g_m$$

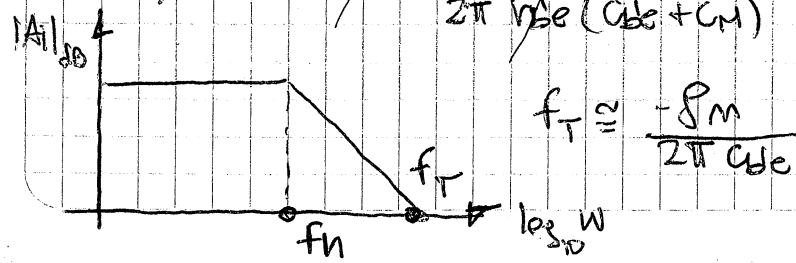
$$\frac{V_{be}}{i_s} = r_{be} // \left[ \frac{1}{j\omega(C_{be} + C_M)} \right] = r_{be} // \frac{1}{j\omega C_P} = \frac{\frac{r_{be}}{j\omega C_P}}{r_{be} + \frac{1}{j\omega C_P}} = \frac{r_{be}}{1 + r_{be} j\omega C_P}$$

$$\frac{V_{be}}{i_s} = \frac{r_{be}}{1 + \frac{P}{1}} = \frac{r_{be}}{1 + \frac{P}{P_h}}$$

$$\therefore A_{if} = -g_m \cdot \frac{r_{be}}{1 + \frac{P}{P_h}} \Rightarrow \boxed{A_{if} = A_{ifm} \cdot \frac{1}{1 + \frac{P}{P_h}}}$$

$$-P_h = 2\pi f_h = \frac{1}{r_{be}(C_{be} + C_M)} \Rightarrow \boxed{f_h = \frac{1}{2\pi r_{be}(C_{be} + C_M)}}$$

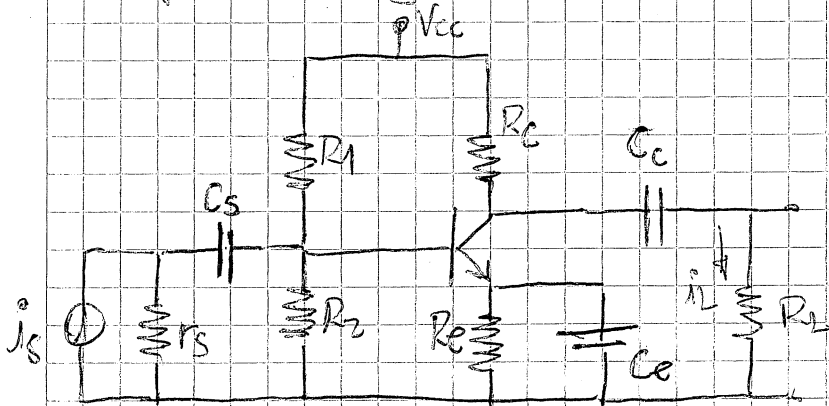
$$-G(BW) = -g_m r_{be} \cdot \frac{1}{2\pi r_{be}(C_{be} + C_M)} \Rightarrow G(BW) = \frac{-g_m}{2\pi (C_{be} + C_M)}$$



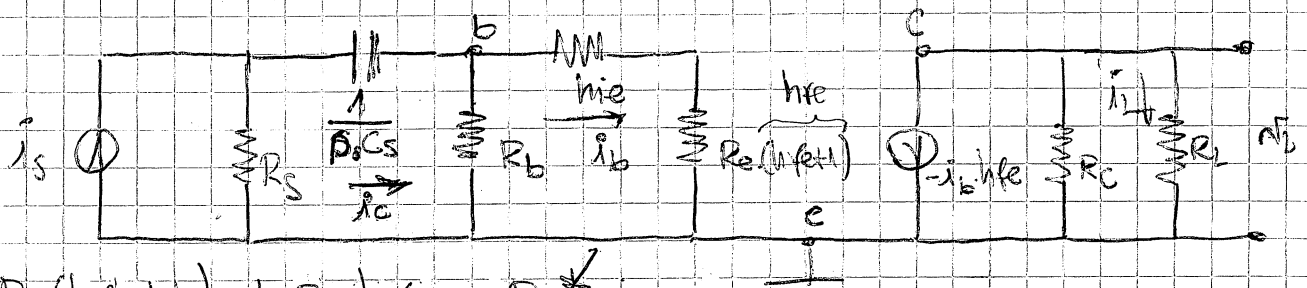
$$f_T \approx \frac{-g_m}{2\pi C_{be}}$$



Respuesta en baja frecuencia. Configuración EC



Considerando el capacitor de acoplamiento de entrada  $C_s$ :



$$R_e(hfe+1) \approx R_e hfe = R_e^*$$

$$A_{i_{fb}} = \frac{i_L}{i_s} = \frac{i_L}{i_b} \cdot \frac{i_b}{i_c} \cdot \frac{i_c}{i_s}$$

$$\frac{i_L}{i_b} = -hfe \cdot \frac{R_c}{R_c + R_L}$$

$$\frac{i_b}{i_c} = \frac{R_b}{R_b + hie + R_e hfe} = \frac{R_b}{R_b + hie + R_e^*}$$

$$\frac{i_c}{i_s} = \frac{R_b}{R_s + \frac{1}{j\omega C_s} + \left[ R_b \parallel (hie + R_e^*) \right]} = \frac{R_s}{\frac{1}{j\omega C_s} + R_{Ts}} = \frac{R_s}{1 + R_{Ts} j\omega C_s}$$

$$\frac{i_c}{i_s} = \frac{R_s j\omega C_s}{1 + j\omega R_{Ts} C_s} = \frac{j\omega R_s C_s}{R_{Ts} C_s \left( \frac{1}{C_s R_{Ts}} + j\omega \right)} = \frac{R_s}{R_{Ts}} \cdot \frac{j\omega R_{Ts} C_s}{1 + j\omega R_{Ts} C_s}$$

$$\therefore A_{i_{fb}} = -hfe \cdot \frac{R_c}{R_c + R_L} \cdot \frac{R_b}{R_b + hie + R_e^*} \cdot \frac{R_s}{R_{Ts}} \cdot \frac{j\omega R_{Ts} C_s}{1 + j\omega R_{Ts} C_s}$$

$$A_{i_{fb}} = -A_{i_{fm}} \cdot \frac{P}{P + P_s}$$

Frecuencia de Corte Inferior:

$$|A_{ifb}|(\omega) = \frac{|A_{ifm}|}{\sqrt{2}} \Rightarrow \left| A_{ifm} \cdot \frac{j\omega L}{j\omega L + \omega_s} \right| = \frac{|A_{ifm}|}{\sqrt{2}}$$

$$\frac{|A_{ifm}|}{|A_{ifm}|} \cdot \frac{|j\omega L|}{|j\omega L + \omega_s|} = \frac{|A_{ifm}|}{\sqrt{2}} \Rightarrow \frac{\omega L}{\sqrt{\omega_L^2 + \omega_s^2}} = \frac{1}{\sqrt{2}} \Rightarrow \frac{\omega L \sqrt{2}}{\sqrt{\omega_L^2 + \omega_s^2}} = 1$$

$$\frac{\sqrt{2} \omega L^2}{\sqrt{\omega_L^2 + \omega_s^2}} = 1 \Rightarrow \frac{2 \omega_L^2}{\omega_L^2 + \omega_s^2} = 1 \Rightarrow 2 \omega_L^2 = \omega_L^2 + \omega_s^2$$

$$\omega_L = \omega_s = \frac{1}{C_s R_{Ts}} = \frac{1}{C_s [R_s + R_o // (\omega_i e + R^*)]}$$

$$f_L = \frac{1}{2\pi C_s [R_s + R_o // (\omega_i e + R^*)]}$$

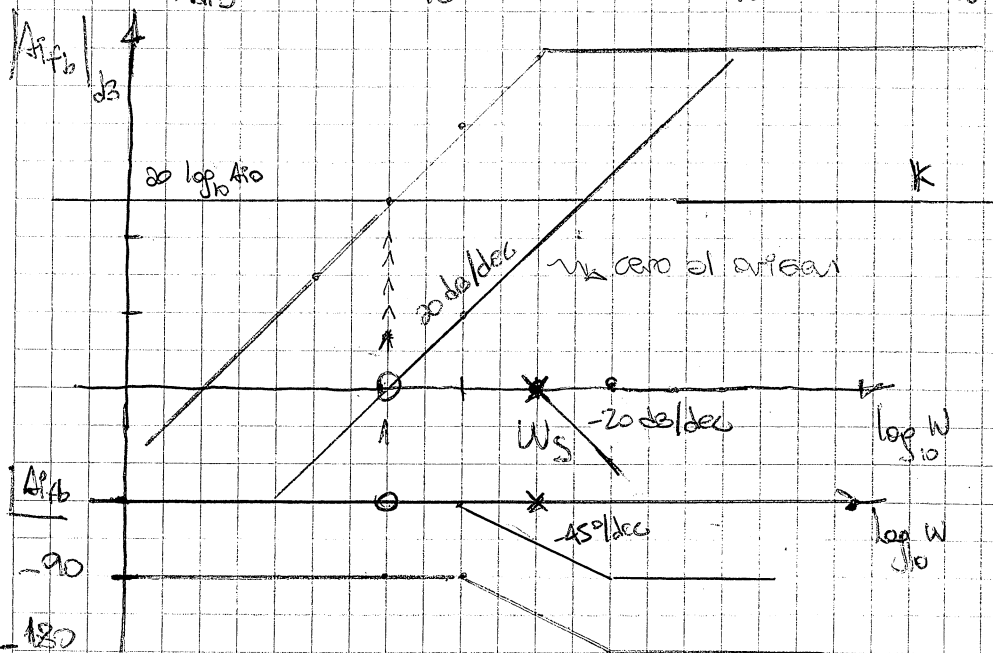
Diagrama de bode

$$A_{ifb}(j\omega) = -A_{ifm} \cdot \frac{j\omega}{j\omega + \omega_s} = \frac{-A_{ifm}}{\omega_s} \cdot \frac{j\omega}{\frac{j\omega}{\omega_s} + 1}$$

$$|A_{ifb}(j\omega)| = |A_{io}| \cdot \frac{|j\omega|}{\left| \frac{j\omega}{\omega_s} + 1 \right|} = A_{io} \cdot \frac{\omega}{\sqrt{\left(\frac{\omega}{\omega_s}\right)^2 + 1}}$$

$$|A_{ifb}(j\omega)|_{dB} = 20 \log_{10} \left( A_{io} \cdot \frac{\omega}{\sqrt{\left(\frac{\omega}{\omega_s}\right)^2 + 1}} \right)$$

$$|A_{ifb}|_{dB} = 20 \log_{10} A_{io} + 20 \log_{10} \omega - 20 \log_{10} \sqrt{\left(\frac{\omega}{\omega_s}\right)^2 + 1}$$



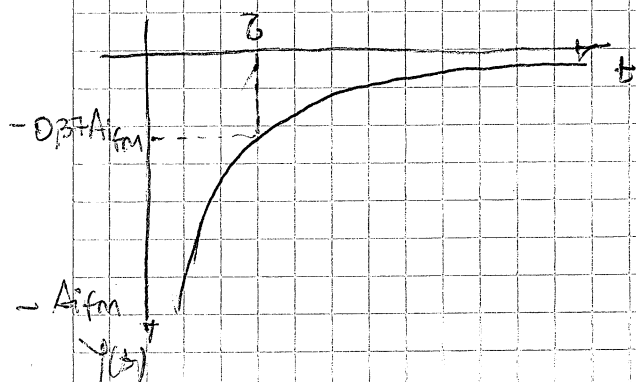
$$|A_{ifb}(j\omega)| = -180^\circ + 0^\circ + 90^\circ + \frac{1}{2} \frac{\omega}{\omega_s} = -90^\circ + \frac{1}{2} \frac{\omega}{\omega_s}$$



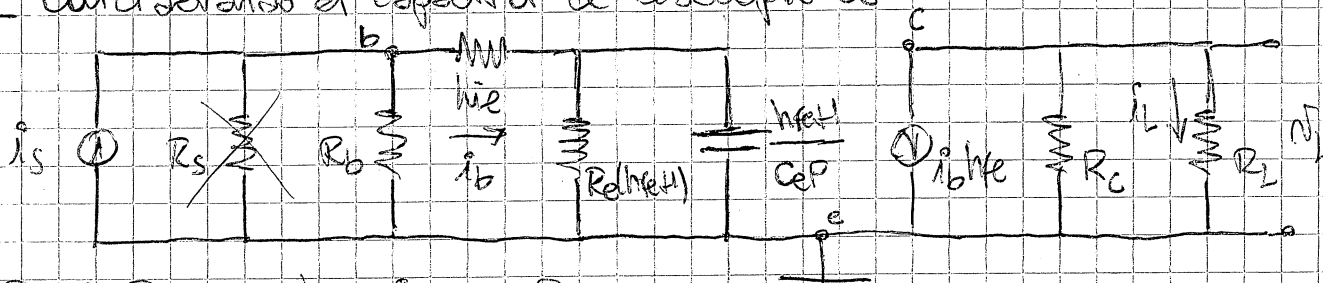
- respuesta al escalón:

$$Y(P) = F(P) \cdot \frac{1}{P} = -A_{ifm} \cdot \frac{1}{P + P_s} \cdot \frac{1}{P} = \frac{-A_{ifm}}{P + P_s}$$

$$\therefore y(t) = -A_{ifm} e^{-tP_s} = -A_{ifm} e^{-t/\tau_s} \quad P_s = \frac{1}{\tau_s} = C_s \cdot R_{\tau s}$$



Considerando el capacitor de desacoplo \$C\_e\$



\$R\_s \gg R\_b \therefore\$ despreciamos \$R\_s\$

$$A_{vfb} = \frac{i_L}{i_s} = \frac{i_L}{i_b} \cdot \frac{i_b}{i_s}$$

$$R_e^* = R_e(h_{fe} + 1) \quad \wedge \quad h_{fe} + 1 \approx h_{fe}$$

$$\frac{i_L}{i_b} = \frac{-h_{fe} R_c}{R_c + R_L}$$

$$\frac{i_b}{i_s} = \frac{R_b}{R_b + h_{ie} + \underbrace{R_e^* // h_{fe} / C_e P}_{\text{parallel combination}}}$$

$$R_e^* // h_{fe} / C_e P = \frac{R_e h_{fe} \cdot \frac{h_{fe}}{C_e P}}{R_e h_{fe} + \frac{h_{fe}}{C_e P}} = \frac{\frac{R_e h_{fe}}{C_e P}}{1 + \frac{R_e C_e P}{h_{fe}}} = \frac{R_e^*}{1 + R_e C_e P}$$

$$\frac{i_b}{i_s} = \frac{R_b}{R_b + h_{ie} + \frac{R_e^*}{1 + R_e C_e P}} = \frac{R_b}{(R_b + h_{ie})(1 + R_e C_e P) + R_e^*}$$

$$\frac{i_b}{i_s} = \frac{R_b(1 + R_e C_e P)}{R_b + R_b C_e R_e P + h_{ie} + h_{ie} C_e R_e P + R_e^*} = \frac{R_b(1 + R_e C_e P)}{R_e C_e P (R_b + h_{ie}) + R_b + h_{ie} + R_e^*}$$

$$\frac{i_b}{i_s} = \frac{R_b}{R_b + h_{ie}} \cdot \frac{P + \frac{1}{C_e R_e}}{P + \frac{R_b + h_{ie} + R_e^*}{(R_b + h_{ie}) R_e}} = \frac{R_b}{R_b + h_{ie}} \cdot \frac{P + Z_e}{P + P_e}$$

$$A_{ifb} = \frac{-i\omega R_c}{R_c + R_b} - \frac{R_b}{i\omega R_b} \frac{P + Z_e}{P + P_e}$$

\* El cero se tiene q' encontrar mucho mas abajo que el polo

$$\infty \left| A_{ifb} = -A_{ifm} \frac{P + Z_e}{P + P_e} \right|$$

- frecuencias de corte inferior:

$$|A_{ifb}|_{\omega} = \frac{A_{ifm}}{\sqrt{2}} \Rightarrow \left| \frac{A_{ifm}}{\sqrt{2}} \right| = |A_{ifm}| \left| \frac{j\omega L + \omega Z_e}{j\omega L + \omega P_e} \right|$$

$$\frac{|A_{ifm}|}{\sqrt{2}} = |A_{ifm}| \frac{\sqrt{\omega L^2 + \omega Z_e^2}}{\sqrt{\omega L^2 + \omega P_e^2}} = \frac{1}{\sqrt{2}} \quad \text{Como } \omega P_e \gg \omega Z_e$$

$$\frac{\sqrt{\omega L^2}}{\sqrt{\omega L^2 + \omega P_e^2}} = \frac{1}{\sqrt{2}} \Rightarrow \omega L = \omega P_e = \frac{R_b + i\omega L + R_e^*}{R_e G_e (i\omega L + R_b)}$$

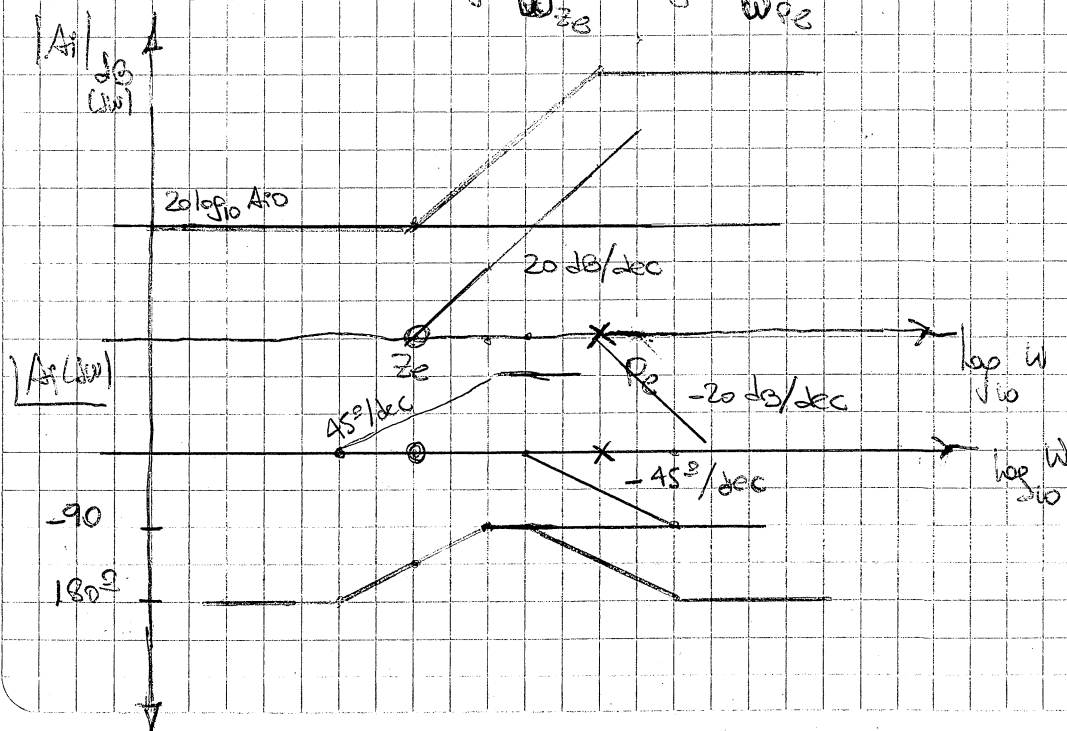
$$\infty \left| f_1 = \frac{R_b + i\omega L + R_e^*}{2\pi G_e R_e (i\omega L + R_b)} \right|$$

- Diagrama de bode

$$A_{ifb}(j\omega) = -A_{ifm} \frac{j\omega + \omega Z_e}{j\omega + \omega P_e} = A_{ifm} \frac{\omega Z_e}{\omega P_e} \frac{\frac{j\omega}{\omega Z_e} + 1}{\frac{j\omega}{\omega P_e} + 1}$$

$$|A_{ifb}(j\omega)| = |A_{if0}| \frac{\sqrt{\left(\frac{\omega}{\omega Z_e}\right)^2 + 1}}{\sqrt{\left(\frac{\omega}{\omega P_e}\right)^2 + 1}} \Rightarrow |A_{ifb}(j\omega)| = 20 \log A_{if0} + 20 \log \sqrt{\left(\frac{\omega}{\omega Z_e}\right)^2 + 1} - 20 \log \sqrt{\left(\frac{\omega}{\omega P_e}\right)^2 + 1}$$

$$\angle A_{ifb}(j\omega) = -180^\circ + \tan^{-1} \frac{\omega}{\omega Z_e} + \tan^{-1} \frac{\omega}{\omega P_e}$$



Respuesta al escalón:

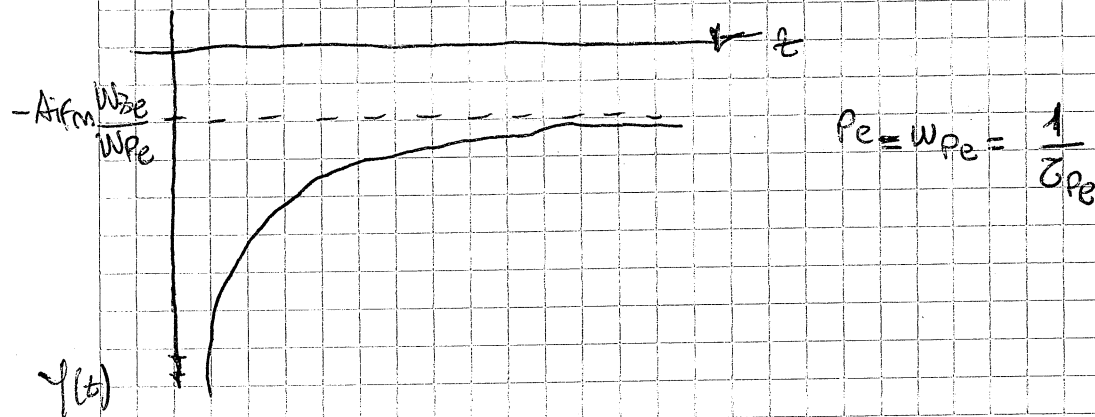
$$Y(p) = F(p) \frac{1}{p} = -A_{ifm} \frac{1}{p} \frac{p + z_e}{p + p_e} = \frac{A}{p} + \frac{B}{p + p_e}$$

$$A = \lim_{p \rightarrow 0} p \cdot (-A_{ifm}) \frac{1}{p} \frac{p + z_e}{p + p_e} = -A_{ifm} \frac{w_{ze}}{w_{pe}}$$

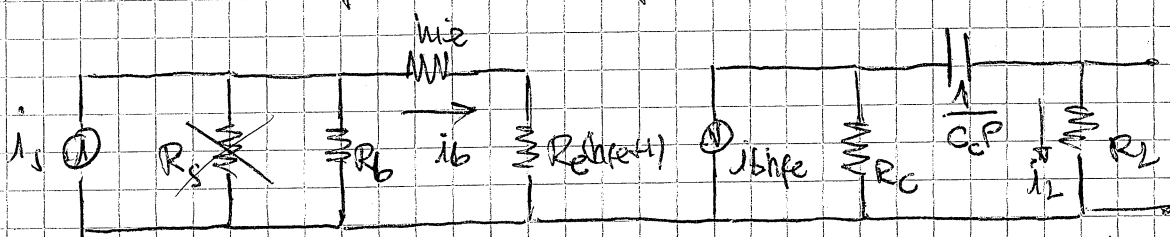
$$B = \lim_{p \rightarrow -p_e} (p + p_e) \frac{1}{p} (-A_{ifm}) \frac{p + z_e}{p + p_e} = \frac{1}{-w_{pe}} (-A_{ifm}) (w_{pe} + w_{ze})$$

$$B = \frac{1}{w_{pe}} \cdot A_{ifm} [w_{ze} - w_{pe}] = -\frac{A_{ifm}}{w_{pe}} [w_{pe} - w_{ze}]$$

$$\therefore y(t) = -A_{ifm} \frac{w_{ze}}{w_{pe}} - \frac{A_{ifm}}{w_{pe}} [w_{pe} - w_{ze}] e^{-t/\tau_{pe}}$$



Calculando el capacitor de acoplamiento  $C_c$ :



$R_s \gg R_b$  : despreciamos  $R_s$   $\wedge$   $R_e^* = R_c(h_{fe}+1) \wedge h_{fe}+1 \approx h_{fe}$

$$A_{ifm} = \frac{i_L}{i_b} = \frac{i_b}{i_s}$$

$$\frac{i_L}{i_b} = \frac{-h_{fe} R_c}{R_c + \frac{1}{C_c p} + R_L}$$

$$R_c + \frac{1}{C_c p} + R_L = \frac{R_c C_c p + 1 + R_L C_c p}{C_c p} = \frac{p C_c (R_c + R_L) + 1}{C_c p}$$

$$\frac{i_L}{i_b} = \frac{-h_{fe} R_c C_c p}{p C_c (R_c + R_L) + 1} = \frac{-h_{fe} R_c C_c \cdot p}{C_c (R_c + R_L) \left[ p + \frac{1}{C_c (R_c + R_L)} \right]}$$

$$\frac{i_L}{i_b} = \frac{-h_{fe} R_c}{R_c + R_L} \cdot \frac{p}{p + p_e}$$

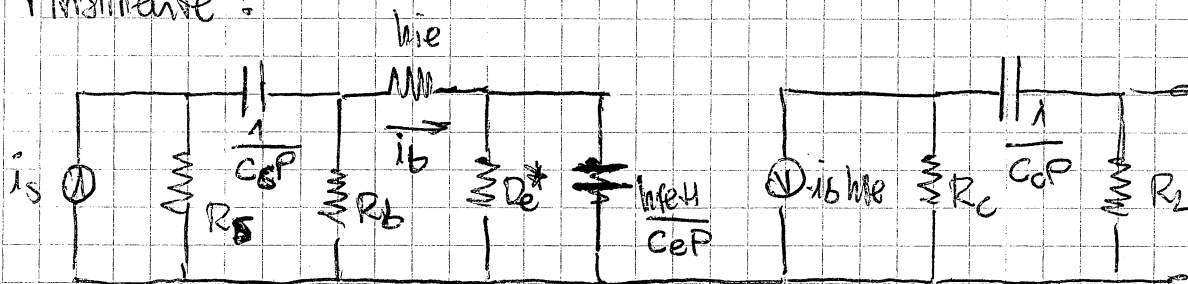
$$\frac{i_b}{i_s} = \frac{R_b}{R_b + h_{ie} + R_{e^*}}$$

$$A_{ifb} = \frac{-R_b}{R_b + h_{ie} + R_{e^*}} \cdot \frac{h_{fe} R_c}{R_c + R_L} \cdot \frac{P}{P + P_c} \Rightarrow \boxed{A_{ifb} = A_{ifm} \cdot \frac{P}{P + P_c}}$$

- El cálculo de la frecuencia de corte inferior, el diagrama de bode y la respuesta al escalón es muy similar a la del capacitor  $C_s$ .

$$f_L = 1/2\pi C_c (R_c + R_L)$$

finalmente:



$$\therefore A_{ibf} = -A_{ifm} \cdot \frac{P}{P + P_s} \cdot \frac{P + R_e}{P + P_e} \cdot \frac{P}{P + P_c}$$

El proyecto se diseña de manera q' el capacitor  $C_e$  determine la frecuencia de corte inferior  $f_L$ . Si tenemos  $f_L$

$$C_e = \frac{1}{2\pi f_L [R_{ehfe} // (R_b + h_{ie})]}$$

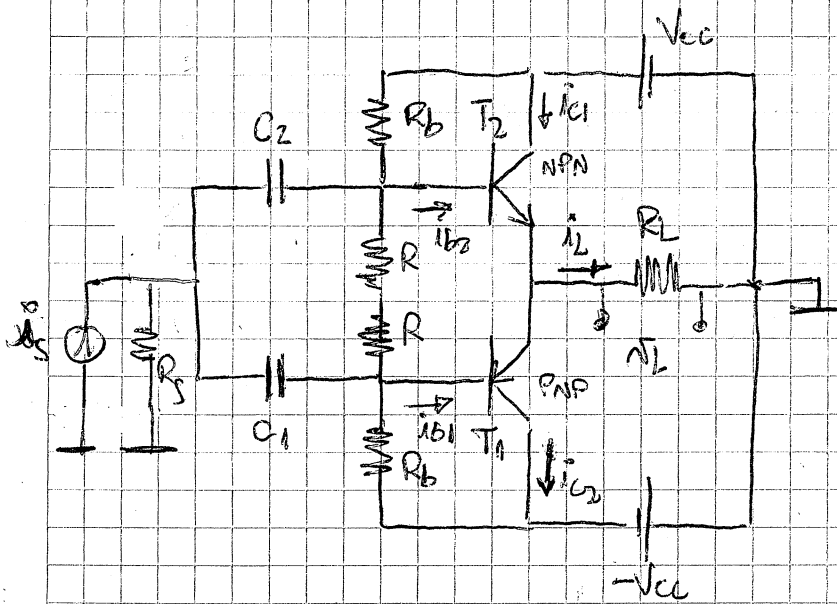
los capacitores  $C_c$  y  $C_s$  deben elegirse de manera q' sus polos se encuentren muy por debajo del polo de  $C_e$ .

$$f_0 = \frac{f_L}{10}$$

$$C_s = \frac{1}{2\pi f_0 [R_b + h_{ie} + h_{fe} R_e]}$$

$$C_c = \frac{1}{2\pi f_0 (R_c + R_L)}$$

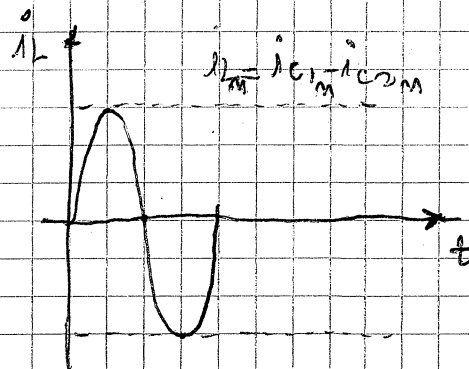
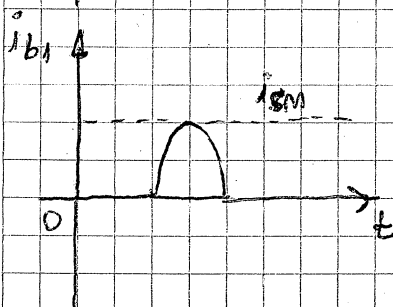
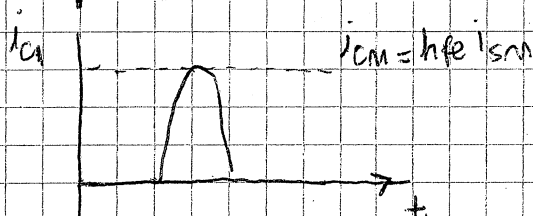
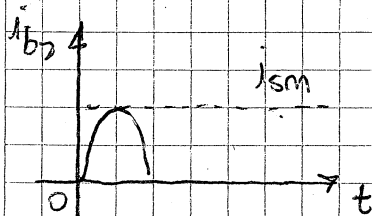
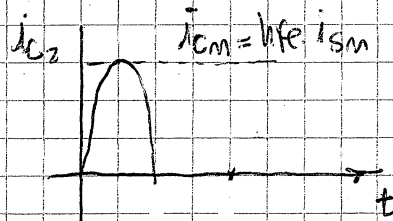
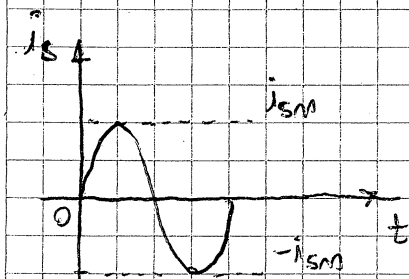
# Amplificador de potencia simétrico con complementario clase AB



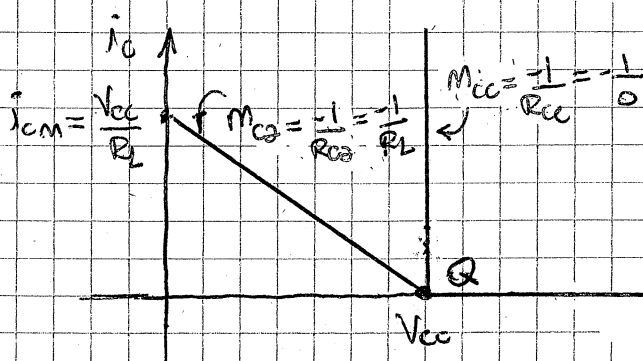
$$i_L = i_{C1} - i_{C2}$$

$$i_s(t) = i_{sm} \sin \omega t$$

$$i_c(t) = i_{cm} \sin \omega t$$



recta de carga:



$$r_{ce} = \begin{cases} V_{ce} = V_{cc} & M_{cc} = \frac{-1}{0} = \infty \end{cases}$$

$$r_{ce} = \begin{cases} i_C = \frac{1}{R_L} (V_{ce} - V_{ceQ}) & 0 < V_{ce} < V_{cc} \\ i_C = 0 & V_{cc} \leq V_{ce} \leq 2V_{cc} \\ M_{cc} = \frac{-1}{R_L} = \frac{-1}{R_L} \end{cases}$$

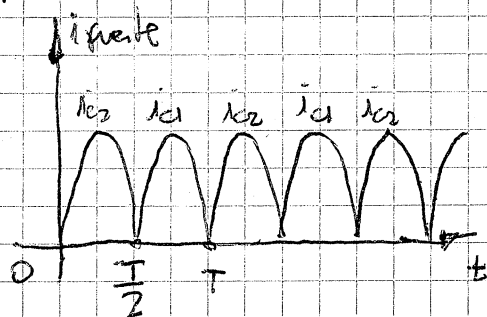
## - Cálculo de potencias

\* Potencia en la carga:

$$P_L = P_{LCA} + P_{LCC} = P_{LCA} = \left(\frac{i_L}{\sqrt{2}}\right)^2 \cdot R_L = \frac{i_{cm}^2}{2} R_L$$

$$\therefore \boxed{P_L = \frac{1}{2} i_{cm}^2 R_L} \quad \text{con } i_{cm\max} = \frac{V_{cc}}{R_L} \quad \therefore P_{L\max} = \frac{1}{2} \frac{V_{cc}^2}{R_L} = \frac{1}{2} \frac{V_{cc}^2}{R_L}$$

\* Potencia en la fuente:



$$\therefore P_{cc} = 2 \cdot \frac{1}{T} \int_0^{T/2} V_{cc} \cdot i_{cm} \sin(\omega t) dt$$

$$P_{cc} = \frac{2V_{cc}}{2\pi} \int_0^{\pi} i_{cm} \sin(\omega t) dt = \frac{2V_{cc} i_{cm}}{\pi}$$

$$\therefore \boxed{P_{cc} = \frac{2V_{cc} i_{cm}}{\pi}}$$

$$\text{con } i_{cm\max} = \frac{V_{cc}}{R_L} \quad \therefore P_{cc\max} = \frac{2V_{cc}}{\pi} \frac{V_{cc}}{R_L} = \frac{2V_{cc}^2}{\pi R_L}$$

\* Potencia en los colectores:

$$2P_c = P_{cc} - P_L = \frac{2V_{cc}}{\pi} i_{cm} - \frac{R_L}{2} i_{cm}^2$$

Como esta potencia es la diferencia entre una función lineal y otra cuadrática no podemos sacar  $2P_{c\max}$  sustituyendo por  $i_{cm\max}$

$$\frac{d[2P_c]}{di_{cm}} = \frac{2V_{cc}}{\pi} - 2 \frac{R_L}{2} i_{cm} = 0 \quad \therefore i_{cm} = \frac{2V_{cc}}{\pi R_L}$$

$$\therefore 2P_{c\max} = \frac{2V_{cc}}{\pi} \cdot \frac{2V_{cc}}{\pi R_L} - \frac{R_L}{2} \frac{2V_{cc}^2}{\pi^2 R_L^2} = \frac{4V_{cc}^2}{\pi^2 R_L} - \frac{2V_{cc}^2}{\pi^2 R_L} = \frac{2V_{cc}^2}{\pi^2 R_L}$$

\* Rendimiento

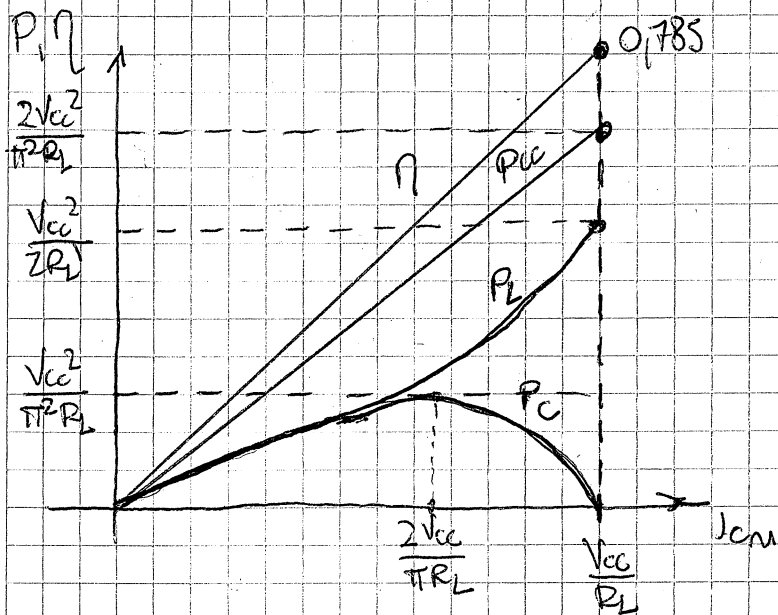
$$\eta = \frac{P_L}{P_{cc}} = \frac{\frac{1}{2} i_{cm}^2 R_L}{\frac{2V_{cc}}{\pi} i_{cm}} = \frac{\pi R_L}{4 V_{cc}} i_{cm}$$

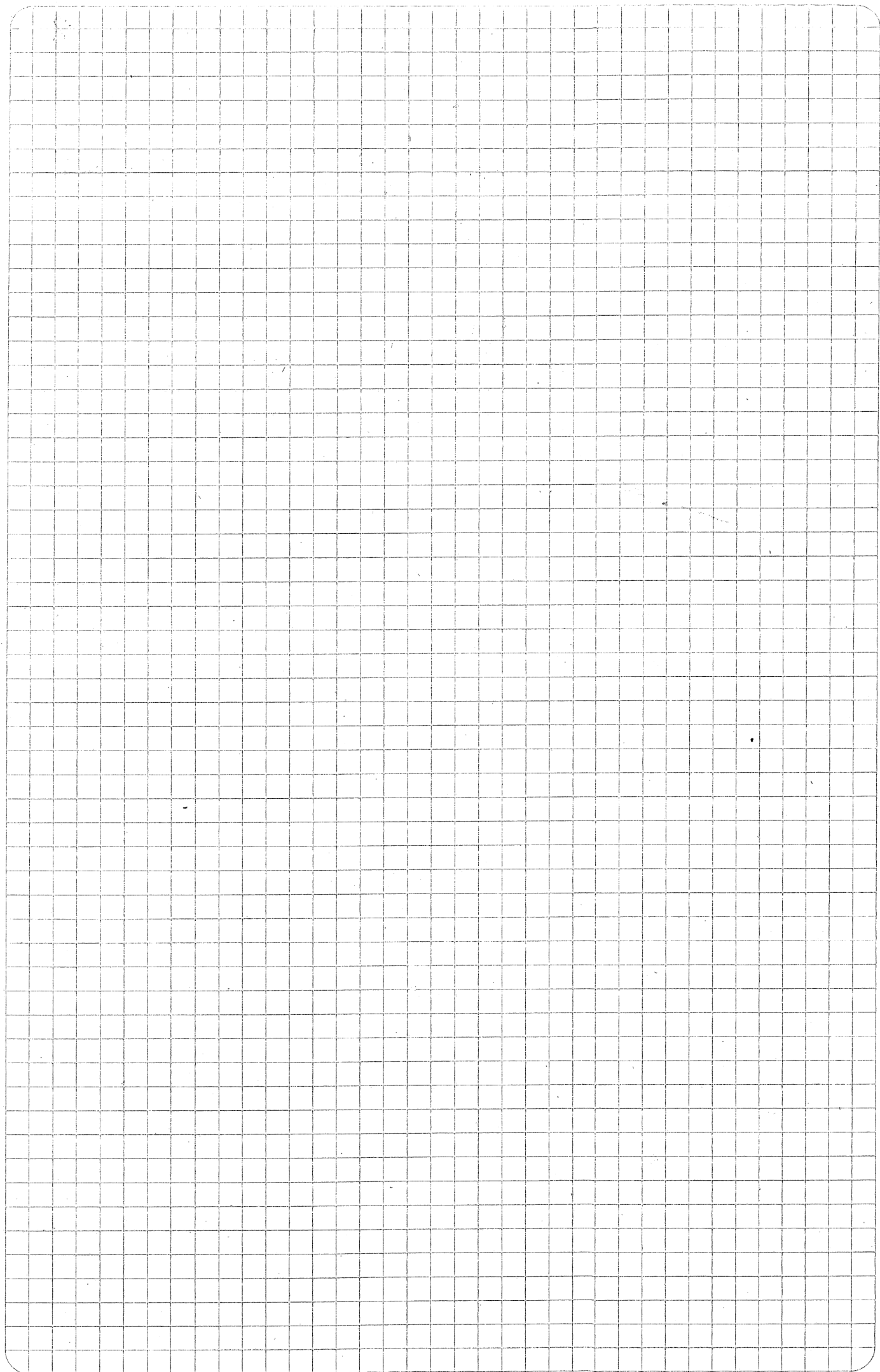
$$\text{con } i_{cm} = \frac{V_{cc}}{R_L} \quad \therefore \eta_{\max} = \frac{\pi R_L}{4 V_{cc}} \cdot \frac{V_{cc}}{R_L} = \frac{\pi}{4} \approx 0.785$$



\* factor de merito:

$$FM = \frac{P_{Cmax}}{P_{Lmax}} = \frac{\frac{V_{cc}^2}{\pi^2 R_L}}{\frac{V_{cc}^2}{2 R_L}} = \frac{2 R_L V_{cc}^2}{V_{cc}^2 \pi^2 R_L} = \frac{2}{\pi^2} \approx 0,2$$





$$Z_0 \parallel Z_L \quad (\text{despreciando } V_{BE})$$

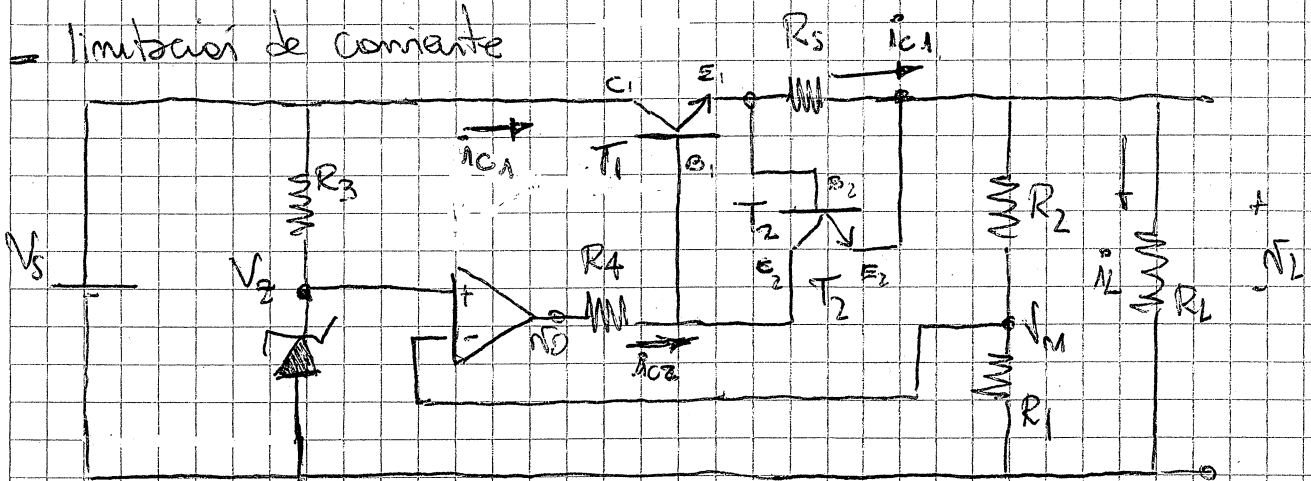
$$\sigma_0 + \beta \sigma_0 A_V = A_V V_E \Rightarrow \sigma_0 (1 + \beta A_V) = A_V V_E \Rightarrow \sigma_0 = \sigma_L = V_E \frac{A_V}{1 + \beta A_V}$$

$$\rho = \frac{R_1}{R_1 + R_2} \quad \text{Como } A_1 = 700 \quad \therefore V_1 = V_2 \frac{1}{\rho} \quad \text{reemplazando el valor de } \rho$$

$$\text{so } \sqrt{L} = V_Z \left( \frac{R_2 + R_1}{R_1} \right) \Rightarrow \boxed{\sqrt{L} = V_Z \left( 1 + \frac{R_2}{R_1} \right)}$$

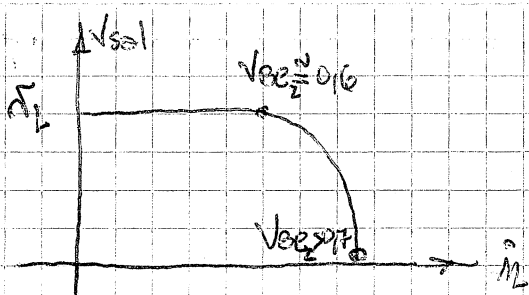
$$|P_c = i_2 (\sqrt{3} - \sqrt{2})| \Rightarrow P_c = 1.90 \text{ mW}$$

- limitación de corriente

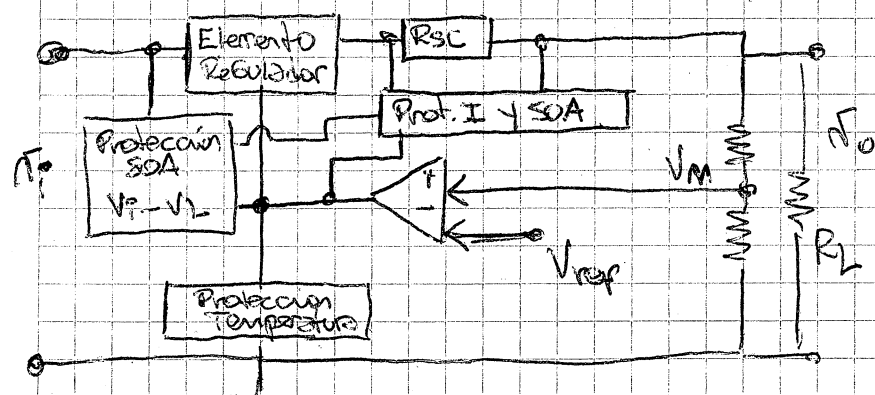


- $V_{BE2} < 0.6$   $T_2$  está an corte el regulador funciona normalmente
- $0.6 < V_{BE2} < 0.7$   $T_2$  se para a conducción,  $i_{L2}$  circula por  $R_4$  y disminuye  $V_{BE1}$  lo q' reduce  $i_{L1}$  y  $T_1$ .
- $V_{BE2} > 0.7$   $T_2$  se encuentra conduciendo fuertemente, provocando una caída de tensión  $V_{BE1} \approx 1.4 \therefore V_L = 0$  desaparece la regulación  

$i_{Lmax} = V_{BE2} / R_5$ 
 $P_{C1} \approx P_{C2} = (V_s - V_{BE2}) i_{Lmax}$

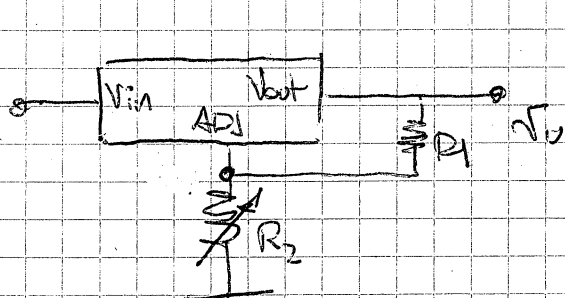


Reguladores tres terminales: 78XX, 79XX, LM317



78XX

$$V_0 = \left(1 + \frac{R_2}{R_1}\right) V_{ref}$$



LM317

$$V_0 = \left(1 + \frac{R_2}{R_1}\right) V_{ref} + I_{adj} \cdot R_2$$

$$V_0 \approx \left(1 + \frac{R_2}{R_1}\right) 1.25$$

Regulación de red ( $R_{red}$ ):

Muestra la variación de la tensión de salida  $V_L$  cuando la tensión de la red ( $V_{red}$ ) varía entre límites establecidos generalmente por norma

$$R_{red} [\%] = \frac{V_L \text{ red max} - V_L \text{ red min}}{V_L \text{ red min}} \cdot 100$$

Regulación de carga ( $R_{car}$ ):

Indica cuánto cambia  $V_L$  cuando cambia  $I_L$ :

$$[\%] R_{car} = \frac{V_L \text{ car max} - V_L \text{ car min}}{V_L \text{ car max}} \cdot 100$$

Resistencia de salida ( $R_{sal}$ ):

Equivale a la resistencia de Thevenin vista desde la carga de la fuente. Coeficiente de variación de  $V_L$  y el cambio de  $I_L$ .

$$R_{50} [\%] = \frac{V_{L\text{carmax}} - V_{L\text{carmin}}}{I_{L\text{carmax}} - I_{L\text{carmin}}}$$

- Coeficiente de temperatura (CT)

$$CT \left[ \frac{\%}{^{\circ}\text{C}} \right] = \frac{100 [V_L(T_{\text{amax}}) - V_L(T_{\text{amin}})]}{V_L(T_{\text{amin}}) (T_{\text{amax}} - T_{\text{amin}})}$$

