Aplicada I — 2018

## BJT

- Tipos, Configuración, corrientes en el Tx
- Juntura de entrada
- Juntura de salida
- Ganancia de I en CC y CA
- Polarización → Emisor común
- Capacitores de acople y desacople
- Máxima excursión simétrica (MES) → Recta de carga

- Análisis de potencia → Disp lineal
  - → suministrada por la fuente
  - → " en la carga
  - → " en el colector
- Rendimiento y factor de mérito

- Estabilidad de la polarización:
  - Efecto de la T en el pto Q
  - Factores de estabilidad
  - Compensación de ΔT mediante polarización por diodo → caso ideal
    - → caso real
  - Polarización balanceada → Espejo de corriente
    - → " " con 2 Rb

- Amplificador de potencia
  - Acoplamiento por bobina
  - " por trafo

- Parámetros híbridos → Emisor común
  - → base "
  - → colector " → falta
  - → Relación entre parámetros del EC y BC

## FET

JFET → Relación entre Ipo y la temp
- → Polarización
- → Análisis y diseño
- → Circ equivalente

Mosfet → Polarización
- → Etapa amplificadora → Surtidor común
  - → Gate "
  - → Drenador "

**Circuito con transistores** → Circ inversor de fase → FeT
- → BJT
- → Darlington → salida por colector
  - → " por emisor
- → Cascode → como amplificador
  - → como desplazador de nivel → falta

NOTA

Diseño: hallar valores cruzando el dato

# Resumen

HOJA N°

FECHA

$I_{BQ} = \frac{I_{CQ}}{\beta}$ $h_{ie} = \frac{25mV\,\beta}{I_{CQ}}$ $h_{ib} = \frac{h_{ie}}{h_{fe}}$ $\hat{I}_L = \frac{I_{CQ}}{2}$

$R_b = \frac{\beta R_E}{10}$ $R_2 = \frac{V_{cc} R_b}{V_{bb}}$ $R_1 = \frac{R_b}{1 - V_{bb}/V_{cc}}$

## Análisis de potencia

$P_{cc} = V_{cc} I_{CQ} = P_C + P_L$

máx → $P_{cc_{max}} = \frac{V_{cc}^2}{2(R_L + R_E)}$

$P_L = (\hat{I}_c^2\, R_L)/2$

máx → $P_{L_{max}} = \frac{V_{cc}^2\, R_L}{8(R_L+R_E)^2} = \frac{I_{CQ}^2 R_L}{2}$

$P_{C_{max}}\Big|_{\substack{i_c = 0 \\ \text{sin señal}}} = \frac{V_{cc}^2}{4R_L} = V_{CE} \cdot I_{CQ}$

$P_{C_{min}}\Big|_{\substack{\hat{I}_c = I_{CQ} \\ \text{con máx señal}}} = \frac{V_{cc}^2}{8R_L}$

- Rendimiento y Fm

$\eta = \frac{P_{L_{max}}}{P_{cc_{max}}}$ 0,25

$Fm = \frac{P_{C_{max}}}{P_{L_{max}}} = 2$

## Ganancias

$A_I = A_V \frac{Z_I}{R_L}$ $A_P = A_I^2 \frac{R_L}{Z_I}$

JFET $\left\{ \begin{array}{l} I_D = I_{P0}\left[1 + \frac{3 V_{GS}}{V_{P0}} + 2\left(-\frac{V_{GS}}{V_{P0}}\right)^{3/2}\right] \\ I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS\,off}}\right)^2 \end{array}\right.$

MOSFET → $I_D = I_{P0}\left(1 + \frac{V_{GS}}{V_{P0}}\right)^2$

## Parámetros internos

$Z_i$ $r_{gs} = \frac{\Delta V_{GS}}{\Delta I_G}$

$A_v$ $\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$

$Z_o$ $r_{ds} = \frac{\Delta V_{DS}}{\Delta I_D}$

Trans $g_m = \frac{\Delta I_D}{\Delta V_{GS}}$

$\mu = g_m\, r_{ds}$

## Espejo corriente ($A_I$)

$R_{d} = R_E$ $\beta_1 = \beta_2$

$I_{CQ_1} = I_{CQ_2}$ $I_{BQ_1} = I_{BQ_2}$

$\Delta I_{CQ} = \frac{K\,\Delta T}{R_b + R_E}$ → $K = 2{,}5\frac{mV}{C}$

$\Delta I_{CQ} = \frac{K}{R_E}$ → con $R_b$ en las bases

## Darlington ($A_I$)

$h_{ib_2} = h_{ib_1}/h_{fe}$ $I_{CQ_1} = I_{CQ_2}/\beta$

$I_{CQ_2} = \beta^2 I_{b_1}$ → si $T_1 = T_2$

$R_b = \frac{\beta^2 R_E}{10}$ $h_{ie_2} = \frac{h_{ie_1}}{h_{fe}}$

## Acopl. por trafo

$R_{cc} = 0$ $R_{CA} = R'_L$ $R'_L = N^2 R_L$

$N = \sqrt{\frac{R'_L}{R_L}} = \frac{P_L}{P_{cc}}$

$I_{CQ} = \frac{V_{cc}}{R'_L}\left(1 - \frac{R_E}{R_L}\right)$ $V_{CEQ} = V_{cc}\left(1 - \frac{R_E}{R_L}\right)$

$P_{cc} = P_{C_{max}} = \frac{V_{cc}^2}{R'_L} = V_{CEQ} \cdot I_{CQ}$

$P_{L_{max}} = P_{C_{min}} = \frac{V_{cc}^2}{2R'_L} = \frac{I_{CQ}^2 R'_L}{2}$

$V_{bb} = V_{cc}/2$ $I_L = I_{c2} \cdot N$

## Inversor de fase ($A_V$)

$R_D // R_{L_1} = R_S // R_{L_2}$

$R_C // R_{L_1} = R_E // R_{L_2}$

$Z_i = R_G$

$Z_{o_1} = R_D // [r_{ds} + (R_S // R_{L_2})\mu]$

$Z_{o_2} = R_S // \left[\frac{r_{ds} + (R_D // R_{L_1})}{\mu}\right]$

## Diferencial

$\left.\begin{array}{l} I_{CQ_1} = I_{CQ_2} \\ V_{CEQ_1} = V_{CEQ_2} \\ I_{b_1} = I_{b_2} \end{array}\right\}$ si $R_{C_1} = R_{C_2}$

$I_{E2C} = (I_c\, R_b)/(R_b/h_{fe} + h_{ib} + 2R_E)$

$I_{E2D} = (I_d\, R_b)/2(h_{ib} + R_b/h_{fe})$

$I_L = I_{E2} \cdot h_{fe}\left(\frac{R_C}{R_C + R_L}\right) = A_c I_c + A_d I_d$

$RRMC = (R_E)/(h_{ib} + R_b/h_{fe})$

NOTA

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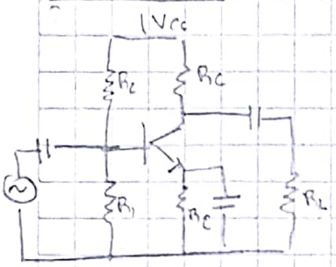
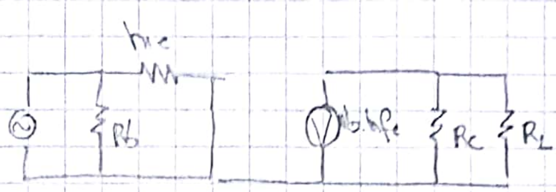
## Emisor común

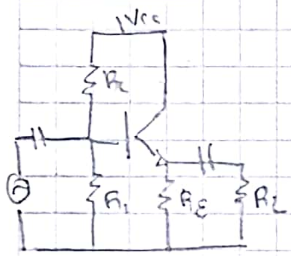


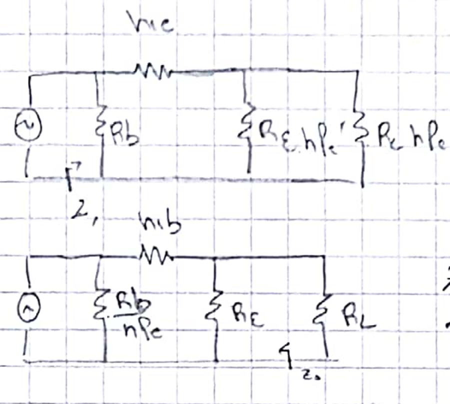




$Z_i = R_b // h_{ie}$

$Z_o = R_c$

## Colector común



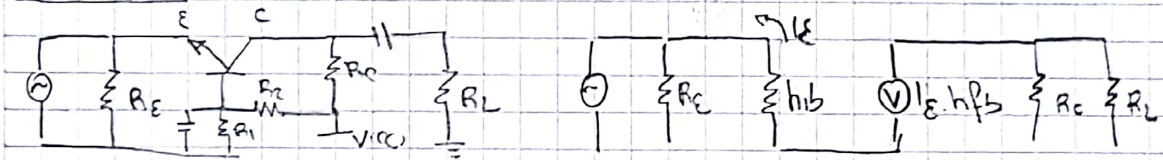




$Z_i = \{[(R_E // R_L) h_{fe}] + h_{ie}\} // R_b$

$Z_o = R_E // h_{ib}'$ sin $r_1$

$Z_o = R_E // \left[ h_{ib} + \left( \frac{r_1 // R_b}{h_{fe}} \right) \right]$ con $r_1$

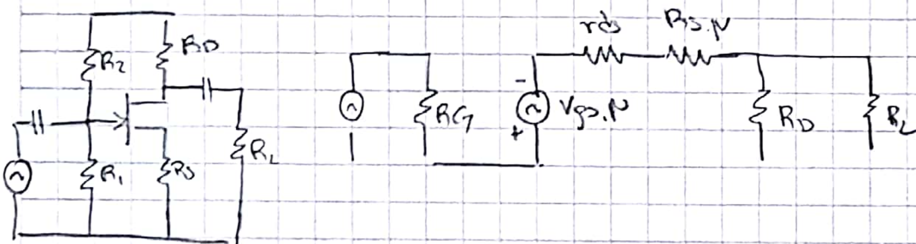
## Base común




$Z_i = R_E // h_{ib}$

$Z_o = R_c$

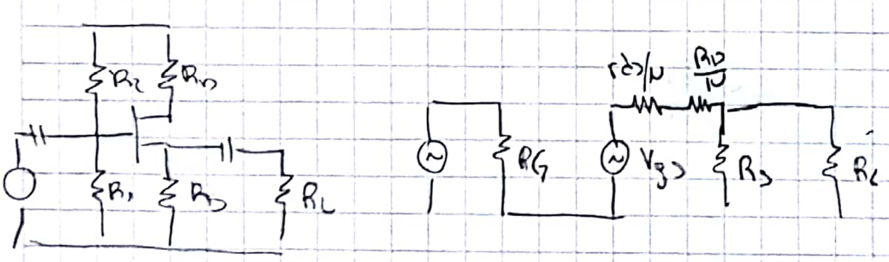
## Surtidor común




$Z_i = R_G$

$Z_o = R_D // (r_{ds} + R_S \mu)$

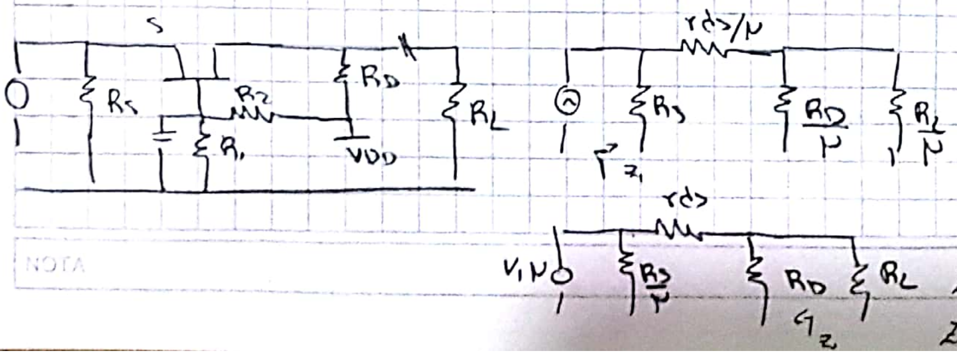
## Drenador común




$Z_i = R_G$

$Z_o = R_S // \frac{r_{ds}}{\mu}$

## Gate común




$Z_i = R_S // \left[ \frac{r_{ds}}{\mu} + \frac{R_D // R_L}{\mu} \right]$

$Z_o = R_D // r_{ds}$ sin $r_1$

$Z_o = R_D // [(R_S // r_1)\mu + r_{ds}]$ con $r_1$

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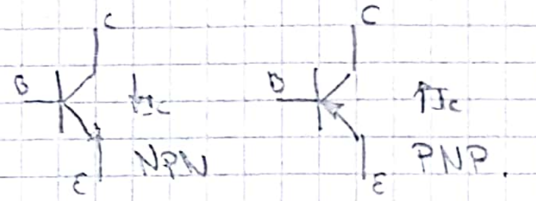
Diseño: hallar valores conociendo el pto Q
Analisis: " pto Q " los valores

# Transistores
## Amplificador de corriente

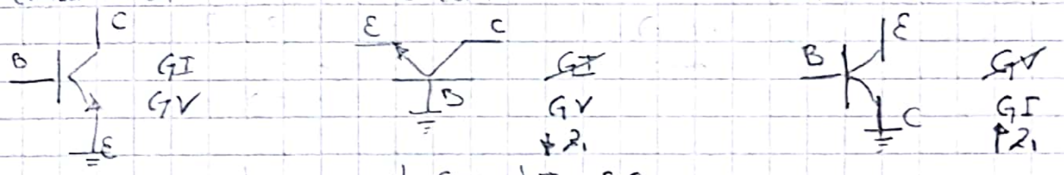


## Tipos:

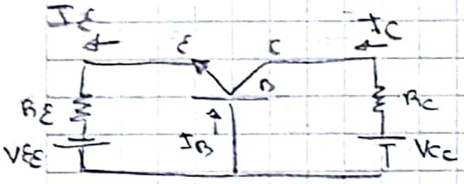
1




## Configuración




## Corrientes en el Tx




$\alpha$ = cte de proporcionalidad

$0{,}9 < \alpha < 0{,}99$

$I_{CBO} \rightarrow I_{CB}$ inver. polarizada, cuando $I_E = 0$

1) $I_C = \alpha I_E + I_{CBO}$.
2) $I_E = I_B + I_C$
3) $\alpha = \dfrac{I_C}{I_E} = \dfrac{\beta}{1+\beta}$
4) $\beta = \dfrac{I_C}{I_B} = \dfrac{\alpha}{1-\alpha}$

$$I_B = I_E - I_C = I_E - (\alpha I_E + I_{CBO}) = I_E(1-\alpha) - I_{CBO} \xrightarrow{\text{Remp } I_E} \frac{I_C - I_{CBO}}{\alpha}(1-\alpha) - I_{CBO}$$

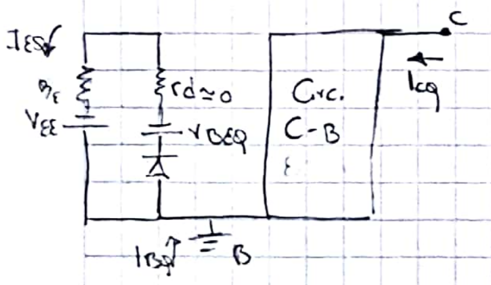
$$I_B = I_C\left(\frac{1-\alpha}{\alpha}\right) - I_{CBO}\left(\frac{1-\alpha}{\alpha}+1\right) = I_C\left(\frac{1}{\beta}\right) - I_{CBO}\left(\frac{1-\alpha+\alpha}{\alpha}\right)$$

$$\boxed{I_B = \frac{I_C}{\beta} - \frac{I_{CBO}}{\alpha}}$$

## Juntura de entrada (unión base-emisor)

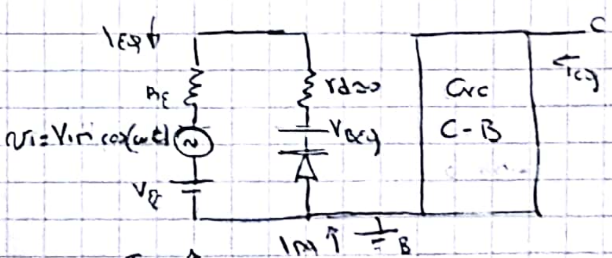
rd = pequeña $\Omega$.

Modelo lineal de entrada sin $v_i$



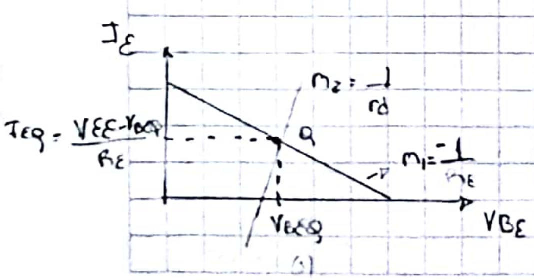

Modelo lineal de entrada con $v_i$ (trabajo en pto Q y trabajar en forma lineal p/ cualquier $V_{EE}$)

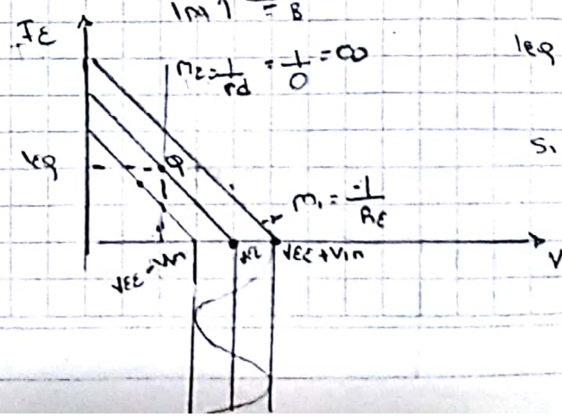
de esta forma, el pto de




$I_e = \dfrac{V_{in}\cos(\omega t)}{R_E}$

$I_{EQ} = \dfrac{V_{EE} - V_{BEQ}}{R_E}$




Si $(V_{EE} - V_{in}) > V_{BEQ}$

$rd << R_E$

NOTA

Juntura salida (Union Colector - Base)

como $I_C = I_{EQ} + I_{CBO}$


modelo local

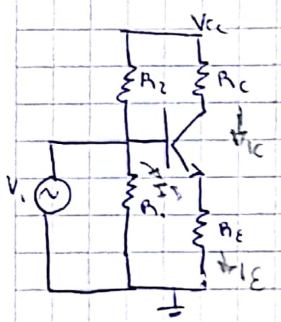
# Ganancia de corriente en continua y alterna

(Continua) $\beta = \frac{I_{CQ}}{I_{BQ}}$ ; (Alterna) $h_{fe} = \frac{I_c}{I_b} = \frac{\Delta I_c}{\Delta I_b} = \frac{\Delta I_B \cdot \beta + \Delta\beta \cdot I_b}{\Delta I_B} = \beta + \frac{\Delta\beta}{\Delta I_B} \cdot I_b$ ∴ $\boxed{h_{fe} \approx \beta}$

es pequeño comparado con $\beta$

# Polarización

Emisor común (circuito fundamental)




Ec. de entrada

$V_{bb} = \frac{I_{CQ}}{\beta} R_b + V_{BE} + I_{CQ} R_E$

Ec. de salida

$V_{CC} = I_{CQ}(R_C + R_E) + V_{CEQ}$

$V_{bb} = V_{CC} \frac{R_1}{R_1 + R_2}$

$R_b = R_1 // R_2$

Criterio de estabilidad (ante $\Delta\beta$)

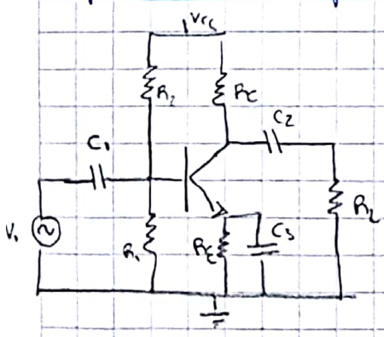
$R_E = 10 \frac{R_b}{\beta}$

en el diseño se elige $100 < R_E < 2k$

Si $V_{bb} = \frac{V_{CC} \cdot R_1}{R_1 + R_2}$ y $\frac{R_b}{R_2} = \frac{R_1}{R_1 + R_2}$ ∴ $V_{bb} = V_{CC} \cdot \frac{R_b}{R_2} \rightarrow \boxed{R_2 = \frac{V_{CC} R_b}{V_{bb}}}$

Si $V_{bb} = \frac{V_{CC} R_1}{R_1 + R_2} \rightarrow R_1 + R_2 = \frac{V_{CC}}{V_{bb}} \cdot R_1 \rightarrow R_1\left(1 - \frac{V_{CC}}{V_{bb}}\right) = \frac{V_{CC} R_b}{V_{bb}} \rightarrow R_1 = \frac{\frac{V_{CC} R_b}{V_{bb}}}{1 - V_{CC}/V_{bb}} \rightarrow \boxed{R_1 = \frac{R_b}{1 - V_{bb}/V_{CC}}}$

Capacitores de acoplamiento y desacople




$C_1$: Acopla la entrada con el circ. en CA

$C_2$: Acopla el circ. con la carga en CA

$C_3$: Desacopla en CA; p/ evitar q' se pierda potencia inutilmente en $R_E$

NOTA

**Maxima excursion simetrica**: es la eleccion del pto Q en la recta de carga. Lo que permite que la $I_C$ experimente la MES.
Asegura un func. lineal y el rango max de la señal de entrada.

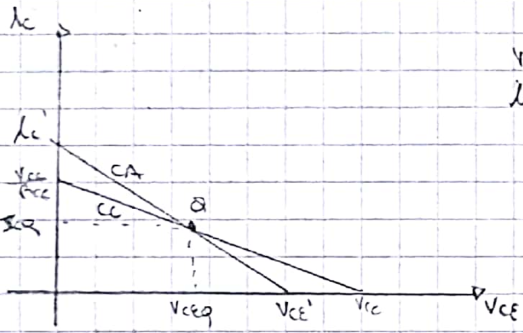
P/(CC) $V_{CC} - V_{CEQ} - I_{CQ} \cdot R_{CC} = 0$ (1)

P/(CA) $(\hat{V_{CE}})_{max} = (\hat{I_C})_{max} \cdot R_{CA}$ (2) P/mes $\begin{cases} \hat{V_{CE}}_{max} = V_{CEQ} \\ \hat{I_C}_{max} = I_{CQ} \end{cases}$ $\therefore$ (P/CA) $V_{CEQ} = I_{CQ} \cdot R_{CA}$ (3)

Meto (3) en (1)

$V_{CC} - I_{CQ} R_{CA} - I_{CQ} R_{CC} = 0 \rightarrow \boxed{I_{CQ_{mes}} = \frac{V_{CC}}{R_{CA} + R_{CC}}}$

**Recta de carga**: representa todos los puntos de funcionamiento del circuito de colector




$V_{CE}' = V_{CEQ} + I_{CQ} R_{CA}$
$I_C' = I_{CQ} + \frac{V_{CEQ}}{R_{CA}}$

**Analisis de potencia** P/ obtener la pot max $R_L >> R_E$

# Potencia ~~...~~ media suministrada por cualquier dispositivo lineal o no lineal

Valores medios

$V(t) = V_{AV} + v(t)$ → variable con el tiempo y comp media nula
$I(t) = I_{AV} + i(t)$
↳ periodicas y simetricas

$P = \frac{1}{T}\int_0^T V(t) I(t) dt \therefore P = \frac{1}{T}\int_0^T [V_{AV} + v(t)] \cdot [I_{AV} + i(t)] dt$

$= \frac{1}{T}\int_0^T V_{AV} I_{AV} dt + \cancel{\frac{1}{T}\int_0^T V_{AV}\, i(t) dt}^{=0} + \cancel{\frac{1}{T}\int_0^T v(t) I_{AV} dt}^{=0} + \frac{1}{T}\int_0^T v(t)\, i(t) dt$

$$\boxed{P = \underbrace{V_{AV} I_{AV}}_{CC} + \underbrace{\frac{1}{T}\int_0^T v(t) \cdot i(t)\, dt}_{CA}}$$

# Potencia media suministrada por la fuente

$I_C = I_{CQ} + i_c = I_{CQ} + \hat{I_c} \cos\omega t$

$P_{CC} = \frac{1}{T}\int_0^T V_{CC} I_C dt = \frac{1}{T}\int_0^T V_{CC} I_{CQ} dt + \cancel{\frac{1}{T}\int_0^T V_{CC} \hat{I_c} \cos\omega t\, dt}^{=0,\ \cos\omega t = 0}$

$$\boxed{P_{CC} = V_{CC} I_{CQ}}$$

P/mes $I_{CQ} = \frac{V_{CC}}{2(R_L + R_E)} \rightarrow P_{CC_{max}} = \frac{V_{CC}^2}{2(R_L + R_E)}$

NOTA

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# Potencia media suministrada en la carga (la max $P_c$ es cuando no hay señal p/ CA)

$$P_L = \frac{1}{T}\int_0^T i_c^2 R_L\, dt = \frac{1}{T}\int_0^T \hat{i}_c^2 \cos^2\omega t\, R_L\, dt =$$

$i_c = \hat{i}_c \cos\omega t$

$\cos^2\omega t = \frac{1+\cos 2\omega t}{2}$

$$= \frac{1}{T}\hat{i}_c^2 . R_L \int_0^T \frac{1+\cos 2\omega t}{2}\, dt \Rightarrow \boxed{P_L = \frac{\hat{i}_c^2 . R_L}{2}}$$

P/ máx: la $\hat{i}_L$ aumenta en forma cuadrática, entonces la $P_{max}$ disipada en la carga es $\hat{i}_{c\,max}$

$\therefore\ \hat{i}_c = I_{cq}$ $\quad P_{L_{max}} = \frac{I_{cq}^2 R_L}{2}$ $\quad$ si $I_{cq} = \frac{V_{cc}}{2(R_L+R_E)}$ $\quad \therefore P_{L_{max}} = \frac{V_{cc}^2 . R_L}{8(R_L+R_E)^2}$

# Potencia media suministrada en el colector

$$P_c = \frac{1}{T}\int_0^T V_{CE}\, I_c\, dt = \frac{1}{T}\int_0^T \left[V_{cc} - I_c(R_L+R_E)\right] I_c\, dt$$

$V_{CE} = V_{cc} - I_c(R_L+R_E)$

$I_c = I_{cq} + \hat{i}_c \cos\omega t$

$$P_c = \underbrace{\frac{1}{T}\int_0^T V_{cc}\, I_c\, dt}_{P_{cc}} - \underbrace{\frac{1}{T}\int_0^T I_c^2 (R_L+R_E)\, dt}_{P_L+P_E}$$

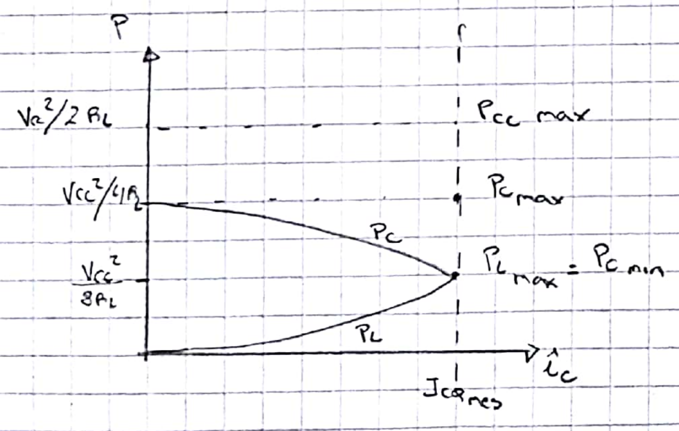
$$\frac{1}{T}\int_0^T I_c^2 = \frac{1}{T}\int_0^T (I_{cq} + \hat{i}_c \cos\omega t)^2 = I_{cq}^2 + \frac{\hat{i}_c^2}{2}$$

$$\therefore \boxed{P_c = P_{cc} - (R_L+R_E)\left(I_{cq}^2 + \frac{\hat{i}_c^2}{2}\right) = P_{cc} - (R_L+R_E) I_{cq}^2 - (R_L+R_E)\frac{\hat{i}_c^2}{2}}$$

$R_L \gg R_E$

$$\text{P/ máx}\quad P_{c_{max}}\Big|_{\hat{i}_c=0} = P_{cc} - (R_L+R_E) I_{cq}^2 = \frac{V_{cc}^2}{2R_L} - \frac{V_{cc}^2}{4(R_L+R_E)^2}\cdot(R_L+R_E) = \frac{V_{cc}^2}{2R_L} - \frac{V_{cc}^2}{4R_L^2} = \frac{V_{cc}^2}{4R_L}$$

Ausencia de señal $\quad P_{c_{max}}\Big|_{\hat{i}_c=0} = \frac{V_{cc}^2}{4R_L}$ $\qquad$ con max señal $\quad P_{c_{min}}\Big|_{\hat{i}_c=I_{cq}} = \frac{V_{cc}^2}{8R_L}$




## Rendimiento y factor de mérito

$$\eta = \frac{P_{L\,max}}{P_{cc\,max}} = \frac{\frac{V_{cc}^2}{8R_L}}{\frac{V_{cc}^2}{2R_L}} = 0{,}25 \rightarrow 25\%$$

$$FM = \frac{P_{c\,max}}{P_{L\,max}} = \frac{\frac{V_{cc}^2}{4R_L}}{\frac{V_{cc}^2}{8R_L}} = 2$$

Buscamos q' el FM sea bajo xq' queremos q' la $P_c$ sea lo mas pequeña posible

(205) Estabilidad de la polarización: p/ que el tx funcione en un margen determinado y asegurar q' se cumple la linealidad, y no se sobrepase $P_{c\,max}$

- Parámetros que producen inestabilidad
  - $\beta$ en un tipo particular de tx
  - $I_{CBO}$ debido su dependencia a la T
  - $V_{BEQ}$ " " " " T
  - Variaciones de las tensiones de alimentación

- Desplazamiento del pto Q debido al $\Delta\beta$: se estabiliza utilizando $R_E$

- Efecto de la temp. en el pto Q.

$I_{CQ} = f(V_{BE}, I_{CBO}, \beta \ldots)$ y a su vez, $f(T)$

$I_C = \alpha I_E + I_{CBO}$ $\longrightarrow$ $I_E = \dfrac{(I_C - I_{CBO})}{\alpha}$

$I_B = (1-\alpha) I_E - I_{CBO}$

$V_{bb} = I_b R_b + V_{BE} + I_E R_E$ $\longrightarrow$ $V_{bb} = (1-\alpha) I_E R_b - I_{CBO} R_b + V_{BE} + I_E R_E$

$V_{bb} = I_E[(1-\alpha) R_b + R_E] - I_{CBO} R_b + V_{BE}$

$$V_{bb} = \frac{(1-\alpha) R_b}{\alpha}(I_C - I_{CBO}) + \frac{I_C - I_{CBO}}{\alpha} R_E - I_{CBO} R_b + V_{BE}$$ mult. y div. $\alpha$

$$V_{bb} = \frac{(1-\alpha)}{\alpha} I_C R_b - \frac{(1-\alpha)}{\alpha} R_b I_{CBO} + \frac{I_C R_E}{\alpha} - \frac{I_{CBO} R_E}{\alpha} - I_{CBO} R_b \left(\frac{\alpha}{\alpha}\right) + V_{BE}$$

$$(V_{bb} - V_{BE}) = \frac{I_C}{\alpha}\left[R_b(1-\alpha) + R_E\right] - \frac{I_{CBO}}{\alpha}\left[R_b(1-\alpha) + R_E + R_b \alpha\right]$$

$$\boxed{I_{CQ} = \frac{(V_{bb} - V_{BE})\alpha + I_{CBO}(R_b + R_E)}{R_b(1-\alpha) + R_E}}$$

Ec. general (nos permite analizar $I_{CQ}$ cuando varía con la temp.) La T. me influye en $I_{CQ}$, deformando la señal en CA

\# Si $\alpha = 1$

$$I_{CQ} = \frac{(V_{bb} - V_{BE}) + I_{CBO}(R_b + R_E)}{R_E}$$

si $I_{CBO} = 0$

$$I_{CQ} = \frac{V_{bb} - V_{BE}}{R_E} \rightarrow \text{independiente de } \beta$$

\# Si $I_{CBO} = 0$

$$I_{CQ} = \frac{(V_{bb} - V_{BE})\alpha}{R_b(1-\alpha) + R_E} \therefore = \frac{V_{bb} - V_{BE}}{\frac{R_b}{\beta} + \frac{R_E}{\alpha}}$$

\# La $V_{BE}$ disminuye linealmente con la temp. $\Delta V_{BE} = V_{BE_2} - V_{BE_1} = -K(t_2 - t_1) = -K\Delta t$ $\quad 2{,}5\,\mathrm{m}\dfrac{V}{{}^\circ C}$

\# La $I_{CBO}$ se duplica cada $\uparrow 10\,{}^\circ C$ $\quad I_{CBO_2} = I_{CBO_1} e^{K\Delta t}$ $\quad \Delta I_{CBO} = I_{CBO}(e^{K\Delta t} - 1)$ $\quad K = 0{,}07 \dfrac{1}{{}^\circ C}$



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(219) **Factores de estabilidad** (Conviene que sean pequeños): Se basa en el supuesto de que, p/ variaciones pequeñas, la variable controlada es una f. lineal de las otras variables y puede expresarse en forma diferencial total.

$$S_I = \frac{\Delta I_{CQ}}{\Delta I_{CBO}} \qquad S_V = \frac{\Delta I_{CQ}}{\Delta V_{BE}} \qquad S_\beta = \frac{\Delta I_{CQ}}{\Delta \beta}$$

$$\therefore \Delta I_{CQ} = S_V \cdot \Delta V_{BE} + S_I \, \Delta I_{CBO} + S_\beta \, \Delta \beta$$

$S_I$ $\quad I_{CQ} = \dfrac{V_{bb} - V_{BE}}{R_E} + I_{CBO}\left(1 + \dfrac{R_B}{R_E}\right)$

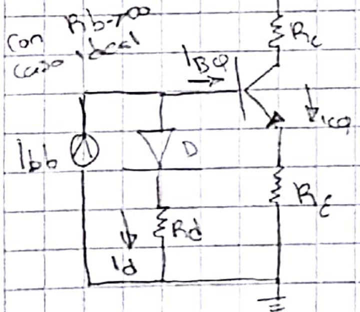
$$S_V = \frac{\Delta I_{CQ}}{\Delta V_{BE}} = \frac{\partial I_{CQ}}{\partial V_{BE}} = \frac{-1}{R_E} \qquad S_I = \frac{\Delta I_{CQ}}{\Delta I_{CBO}} = \frac{\partial I_{CQ}}{\partial I_{CBO}} = 1 + \frac{R_b}{R_E}$$

$$S_\beta = \frac{\Delta I_{CQ}}{\Delta \beta} = \frac{\partial I_{CQ}}{\partial \beta} = \frac{I_{CQ1}}{\beta_1}\left[\frac{R_b + R_E}{R_b + (\beta_2 + 1) R_E}\right]$$ → Tiene un desarrollo

(220) **Compensación de las variaciones de la temp. mediante la polarización por diodo**

P/ reducir las variaciones de la $V_{BE}$ consiste en utilizar un diodo

Con $R_b \to \infty$ caso ideal




$$\frac{\Delta V_D}{\Delta T} = \frac{\Delta V_{BE}}{\Delta T}$$

$$I_{BB} = I_D + I_{BQ} = I_D + \frac{I_{EQ}}{\beta + 1} \qquad V_B = V_D + I_D R_d = V_{BEQ} + I_{EQ} \cdot R_E$$

$$\therefore I_{EQ} = (I_{BB} - I_D)\,\beta + 1 \qquad \therefore I_D = \frac{V_{BEQ} + I_{EQ} R_E - V_D}{R_d}$$

$$\therefore I_{EQ} = \left[I_{BB}\frac{(R_d)}{(R_d)} - \left(\frac{V_{BEQ} + I_{EQ} \cdot R_E - V_D}{R_d}\right)\right](\beta+1) \rightarrow I_{EQ} \cdot R_d = (I_{BB} \cdot R_d - V_{BEQ} - I_{EQ} R_E + V_D)(\beta+1)$$

$$\frac{I_{EQ} R_d}{(\beta+1)} + I_{EQ} R_E = I_{BB} \cdot R_d - V_{BEQ} + V_D \rightarrow I_{EQ}\left[\frac{R_d + R_E(\beta+1)}{\beta+1}\right] = I_{BB} \cdot R_d - V_{BEQ} + V_D$$

$$\boxed{I_{EQ} \simeq I_{CQ} = \frac{I_{BB} R_d - V_{BEQ} + V_D}{\dfrac{R_d + R_E(\beta+1)}{(\beta+1)}}}$$

como $I_{BB} = \text{cte}$

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{\Delta I_{EQ}}{\Delta T} = \frac{\dfrac{\Delta V_D}{\Delta T} - \dfrac{\Delta V_{BEQ}}{\Delta T}}{\dfrac{R_d + R_E(\beta+1)}{\beta+1}} = 0$$

$\therefore I_{CQ} = I_{EQ}$ es insensible a las variac. de la Temp

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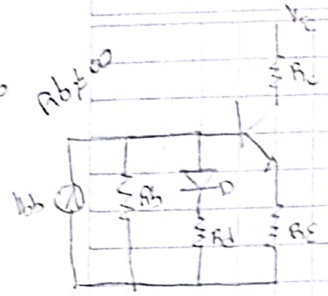
Caso real $R_b \neq \infty$




se desprecia

$$I_{bb} = \frac{V_b}{R_b} + \frac{V_b - V_d}{R_d} + \cancel{I_{BQ}}$$

elegimos p/ que $I_{BQ}$ se desprecie $\begin{cases} R_b \to I_{BQ} \ll \dfrac{V_b}{R_b} \\ R_d \to I_{BQ} \ll \dfrac{V_b - V_d}{R_d} \end{cases}$

$$I_{bb} = \frac{V_b}{R_b} + \frac{V_b}{R_d} - \frac{V_d}{R_d} = V_b\left(\frac{1}{R_b} + \frac{1}{R_d}\right) - \frac{V_d}{R_d} \to I_{bb} + \frac{V_d}{R_d} = V_b \frac{R_b + R_d}{R_b R_d}$$

$$\therefore V_b = \left(I_{bb} + \frac{V_d}{R_d}\right) \cdot \frac{R_b R_d}{R_b + R_d} \to V_b = \left(\frac{I_{bb} R_d + V_d}{R_d}\right) \frac{R_b R_d}{R_b + R_d}$$

$$V_b = \frac{\overbrace{I_{bb} R_b}^{V_{cc}} R_d + V_d R_b}{R_b + R_d}$$

si $I_{EQ} \simeq I_{CQ} \simeq \dfrac{V_b - V_{BE}}{R_E}$

$$\therefore I_{EQ} \simeq I_{CQ} = \left(\underbrace{\frac{V_{cc} R_b}{R_b + R_d}}_{\approx 0 \text{ cuando derivo}} + \frac{V_d R_b}{R_b + R_d} - V_{BE}\right) \frac{1}{R_E}$$

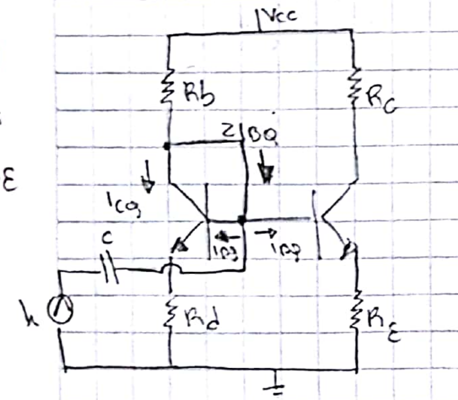
$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{1}{R_E}\left(\frac{R_b}{R_b + R_d} \frac{\Delta V_d}{\Delta T} - \frac{\Delta V_{BE}}{\Delta T}\right)$$

si $\dfrac{\Delta V_d}{\Delta T} = \dfrac{\Delta V_{BE}}{\Delta T} = -k$

$$\frac{\Delta I_{CQ}}{\Delta T} = \frac{k}{R_E}\left(\frac{R_b}{R_b + R_d} - 1\right) = \frac{k}{R_E}\left(\frac{\cancel{R_b} - \cancel{R_b} - R_d}{R_b + R_d}\right) \to \boxed{\frac{\Delta I_{CQ}}{\Delta T} = \frac{-k}{R_E} \frac{R_d}{(R_b + R_d)}}$$

no varia mas con la temp.

## Polarización balanceada: Espejo de corrientes




condicion $R_d = R_E$

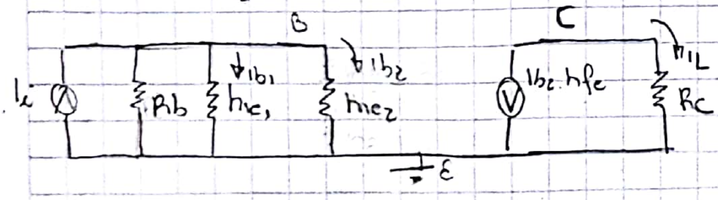
$$V_{cc} = (I_{CQ} + 2 I_{BQ}) R_b + V_{BE} + I_{CQ} R_E \to V_{cc} - V_{BE} = I_{CQ}\left(R_b + \frac{2}{\beta} R_b + R_E\right)$$

$$I_{CQ} = \frac{V_{cc} - V_{BE}}{R_b + \frac{2 R_b}{\beta} + R_E} = \frac{V_{cc} - V_{BE}}{R_b\left(\frac{\beta + 2}{\beta}\right) + R_E} \quad \text{si } \beta \gg 2$$

$$\therefore \boxed{I_{CQ} = \frac{V_{cc} - V_{BE}}{R_b + R_E}}$$

Variación de la temp

$$\boxed{\frac{\Delta I_{CQ}}{\Delta T} = \frac{k}{R_b + R_E} \frac{\cancel{R_d}}{\cancel{R_E}} = \frac{k}{R_b + R_E}}$$




$$A_I = \frac{I_L}{I_i} \frac{I_{b2}}{I_{b2}}$$

$V_{Rc} = V_o$

$I_L R_c = -I_{b2} h_{fe} R_c$

$$\frac{I_L}{I_{b2}} = -h_{fe} \frac{\cancel{R_c}}{\cancel{R_c}}$$

$V_{hie_2} = V_1$

$I_{b2} h_{ie2} = I_i (R_b // h_{ie1} // h_{ie2})$

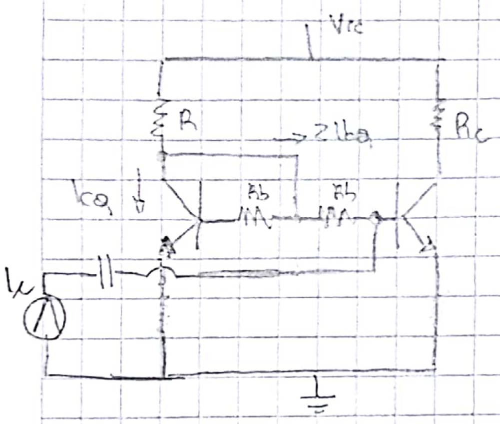
$$\frac{I_{b2}}{I_i} = \frac{R_b // h_{ie1} // h_{ie2}}{h_{ie2}}$$

según yo → $A_I = -h_{fe} \cdot \dfrac{R_b // h_{ie1} // h_{ie2}}{h_{ie2}}$

según el profe → $A_I = \dfrac{-h_{fe}}{2}$, porque no considera $R_b$ p/ el analisis

NOTA

\# Espejo corrientes con 2 resistencias en la base ($R$ fija la I de salida)



$$V_{cc} = \left(I_{cq} + 2\frac{I_{cq}}{\beta}\right)R + \frac{I_{cq}}{\beta}R_b + V_{BE}$$

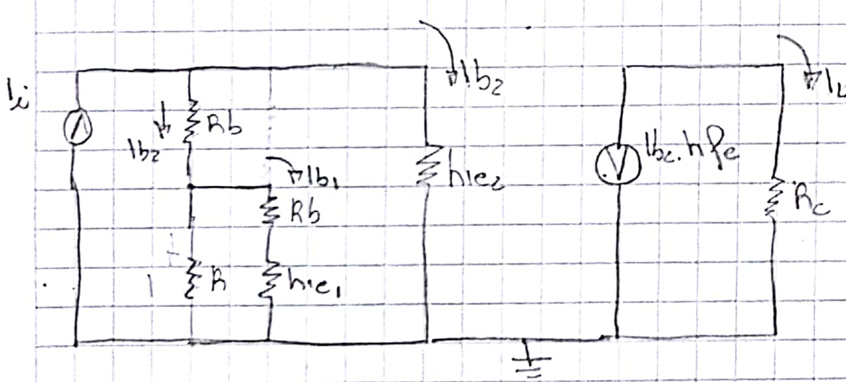
$$V_{cc} - V_{BE} = I_{cq}\left(R + \frac{2R}{\beta} + \frac{R_b}{\beta}\right)$$

$$I_{cq} = \frac{V_{cc} - V_{BE}}{R\left(1+\frac{2}{\beta}\right) + \frac{R_b}{\beta}} = \frac{V_{cc} - V_{BE}}{R\left(\frac{\beta+2}{\beta}\right) + \frac{R_b}{\beta}} \quad \text{si } \beta >> 2$$

$$\therefore \boxed{I_{cq} = \frac{V_{cc} - V_{BE}}{R + R_b/\beta}} \quad \text{si } \beta >> 2$$

$$\boxed{I_{cq} = \frac{V_{cc} - V_{BE}}{R}} \quad \text{si } R >> \frac{R_b}{\beta}$$

$$\boxed{\frac{\Delta I_{cq}}{\Delta T} = \frac{-\Delta V_{BE}}{\Delta T}\frac{1}{R} = \frac{k_1}{R}}$$ Variación con la temp



$$\boxed{A_I = \frac{I_L}{I_i}\frac{I_{b2}}{I_{b2}} = -h_{fe}}$$

$$V_{RC} = V_o$$

$$I_L R_C = -I_{b2} h_{fe} R_C$$

$$\frac{I_L}{I_{b2}} = -h_{fe}\frac{\cancel{R_C}}{\cancel{R_C}}$$

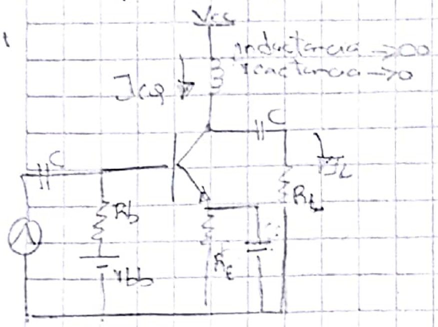
(24/4) Amplificador de Potencia: clase A

HOJA Nº 5

FECHA

Acoplamiento por bobina (inductor): se reemplaza la $R_C$ por una bobina de alto valor (llamada choque) lo que elimina parte de la disipación e incrementa la eficiencia max (rend) hasta 50%.

En Corr Alt
$L \to CC$.
$C \to CA$




$$V_{bb} + I_{bq} R_b - V_{BE} - I_{CQ} R_E = 0 \rightarrow I_{CQ}\left(\frac{R_b}{\beta} - R_E\right) = V_{bb} - V_{BE}$$

$$\boxed{I_{CQ} = \frac{V_{bb} - V_{BE}}{\frac{R_b}{\beta} - R_E}}$$

$$V_{CC} - V_{CE} - I_{CQ} R_E \rightarrow \boxed{V_{CE} = V_{CC} - I_{CQ} R_E}$$

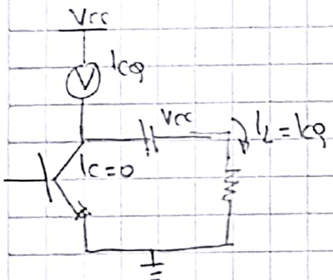
$$I_{CQ_{max}} = \frac{V_{CC}}{R_{CC} + R_{CA}} = \frac{V_{CC}}{R_E + R_L}$$

Si $R_E \to 0$, $R_{CC} \approx 0$ $\therefore$ $\overline{V_{CEQ} \simeq V_{CC}}$

$$\boxed{I_{CQ_{max}} = \frac{V_{CC}}{R_L} = \frac{V_{CEQ}}{R_L}}$$

se la hace pequeña p/ minimizar la pérdida de Pot en el circ de polarización al mismo tiempo una estabilidad

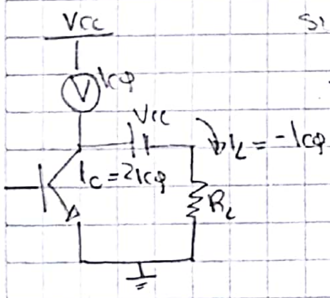
# Circuito equivalente caso 1




Si $I_C = I_{CQ} + i_L = 0$

$$\therefore V_{CE} = V_{CC} + i_L R_L = V_{CC} + I_{CQ} R_L = V_{CC} + \frac{V_{CC}}{R_L} R_L = 2V_{CC} \rightarrow \boxed{V_{CE} = 2V_{CC}}$$

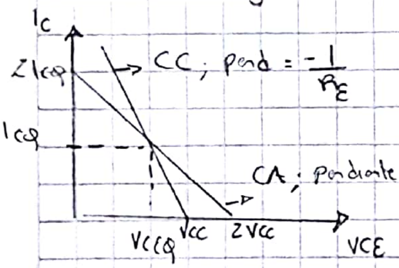
# Circuito equivalente caso 2




Si $I_C = 2 I_{CQ}$

$$\therefore V_{CE} = V_{CC} + i_L R_L = V_{CC} - I_{CQ} R_L = V_{CC} - \frac{V_{CC} R_L}{R_L} = 0 \rightarrow \boxed{V_{CE} = 0}$$

# Recta de carga



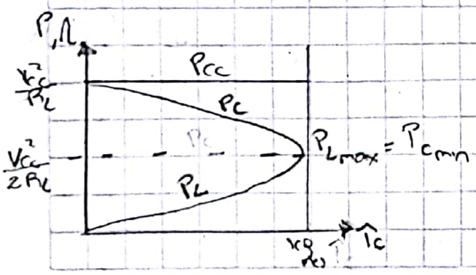

# Análisis de Potencia

$$P_{CC_{max}} = V_{CC} I_{CQ} = V_{CC}\frac{V_{CC}}{R_L} = \frac{V_{CC}^2}{R_L} \rightarrow \boxed{P_{CC_{max}} = \frac{V_{CC}^2}{R_L}}$$

$$P_{L_{max}} = i_L^2 R_L = i_C^2 R_L = \left(\frac{\hat{I}_C}{\sqrt{2}}\right)^2 R_L = \frac{1}{2}\hat{I}_C^2 R_L = \frac{I_{CQ}^2}{2} R_L$$

$$P_{L_{max}} = \frac{1}{2}\frac{V_{CC}^2}{R_L^2} R_L = \frac{V_{CC}^2}{2 R_L} \rightarrow \boxed{P_{L_{max}} = \frac{V_{CC}^2}{2 R_L}}$$

$$P_{C_{min}} = P_{CC_{max}} - P_{L_{max}} = \frac{V_{CC}^2}{R_L} - \frac{V_{CC}^2}{2R_L} = \frac{V_{CC}^2}{2R_L} \rightarrow \boxed{P_{C_{min}} = \frac{V_{CC}^2}{2R_L}}$$




$$P_{C_{max}} = P_{CC_{max}} - P_L = \frac{V_{CC}^2}{R_L} - 0 \rightarrow \boxed{P_{C_{max}} = \frac{V_{CC}^2}{R_L}}$$

$$\eta = \frac{P_L}{P_{CC}} = \frac{V_{CC}^2/2R_L}{V_{CC}^2/R_L} = \frac{1}{2} \rightarrow 50\%$$

NOTA

$$F_m = \frac{P_{C_{max}}}{P_{L_{max}}} = 2$$

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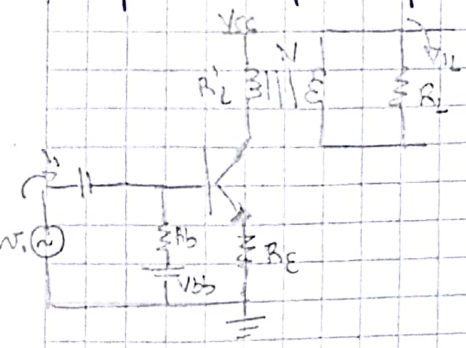
256) Acoplamiento por trafo




$$\begin{cases} R_{cc} = 0 \\ R_{CA} = R'_L \end{cases}$$

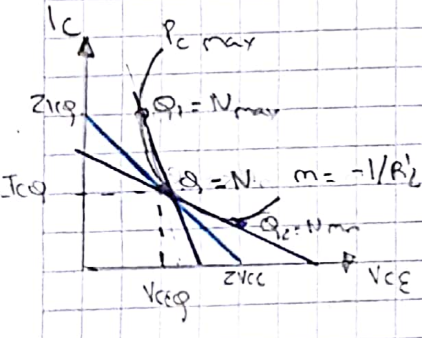
$$N = \frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p} = \sqrt{\frac{Z_p}{Z_s}}$$ si $Z_p = R'_L$, $Z_s = R_L$

$$N = \sqrt{\frac{R'_L}{R_L}} \rightarrow N^2 = \frac{R'_L}{R_L} \rightarrow \boxed{R'_L = N^2 R_L}$$

$$I_{CQ} = \frac{V_{CC}}{R'_L}\left(1 - \frac{R_E}{R'_L}\right) \quad \xrightarrow{\text{si } R_E \to 0} \quad I_{CQ} = \frac{V_{CC}}{R'_L}$$

$$V_{CEQ} = V_{CC}\left(1 - \frac{R_E}{R'_L}\right) \quad \xrightarrow{\text{si } R_E \to 0} \quad V_{CEQ} = V_{CC}$$

# Recta de carga (debe estar entre $Q_1$ y $Q_2$, ya que si N es mayor a $N_{max}$ ~~se~~ quema por $V_{CE}$ y si N es menor a $N_{min}$, se quema por $I_{CQ}$)




$$N = \frac{N_{max} + N_{min}}{2}$$

$$N_{max} = \sqrt{\frac{2 P_{c\,max}}{I_{CQ_2}^2 R_L}}$$ con $I_{CQ_2}$

$$N_{min} = \sqrt{\frac{2 P_{c\,max}}{I_{CQ_1}^2 R_L}}$$

# Analisis de potencia (igual al de acop. por bobina reemplazando $R'_L$ por $R_L$)

$$\boxed{P_{CC\,max} = \frac{V_{CC}^2}{R'_L}}$$

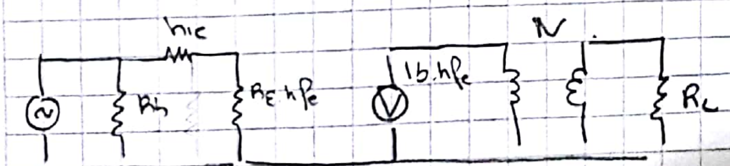
$$P_{L\,max} = I_L^2 R_L = (N I_c)^2 R_L = \left(N \frac{I_{CQ}}{\sqrt{2}}\right)^2 R_L = \frac{1}{2} I_{CQ}^2 N^2 R_L \rightarrow \boxed{P_{L\,max} = \frac{I_{CQ}^2}{2} R'_L = \frac{V_{CC}^2}{2R'_L}}$$

$$\boxed{P_{C\,max} = \frac{V_{CC}^2}{R'_L} = V_{CEQ}\, I_{CQ}}$$

$$FM = \frac{P_{c\,max}}{P_{L\,max}} = 2$$

$$\eta = \frac{1}{2}$$

# Circ equivalente




$$A_V = \frac{V_L}{I_b} \cdot \frac{I_b}{V_i}$$

$$V_c = N \cdot V_L$$

$$-I_b \cdot h_{fe} R'_L = V_L N \Rightarrow \frac{V_L}{I_b} = \frac{-h_{fe} R'_L}{N}$$

$$A_V = \frac{-h_{fe} R'_L}{N} \cdot \frac{1}{h_{ie}}$$

$$V_i = I_b\, h_{ie} \rightarrow \frac{I_b}{V_i} = \frac{1}{h_{ie}}$$

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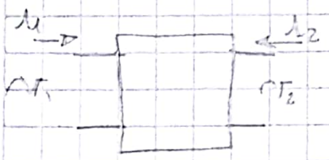
$i$: entrada    $r$: reverso    $h_i$: impedancia de entrada
$f$: directo    $o$: salida    $h_r$: ganancia inversa de voltaje
$h_f$: " directa de corriente
$h_o$: admitancia de salida

HOJA N° 6
FECHA

(291) Parametros hibridos

- Son parametros internos del Tx en alterna
- Representa el comportamiento del Tx en alterna



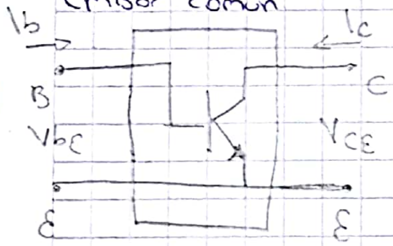

general
$v_1 = h_{11} i_1 + h_{12} v_2$
$i_2 = h_{21} i_1 + h_{22} v_1$

P/ transistor
$v_1 = h_i i_1 + h_r v_2$
$i_2 = h_f i_1 + h_o v_2$

no depende de la configuracion del transistor

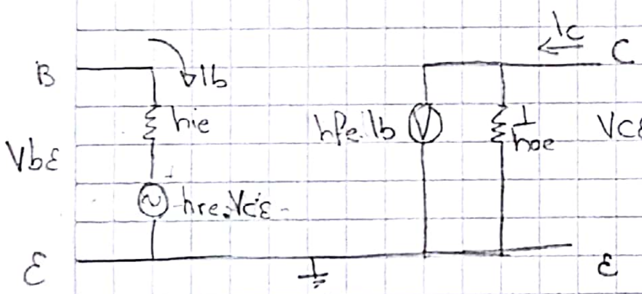
$\therefore$ $h_i = \left.\frac{v_1}{i_1}\right|_{v_2=0}$ imp. de entrada    $h_r = \left.\frac{v_1}{v_2}\right|_{i_1=0}$ ganancia inv. de V    $h_f = \left.\frac{i_2}{i_1}\right|_{v_2=0}$ ganancia direct. de I    $h_o = \left.\frac{i_2}{v_2}\right|_{i_1=0}$ admitancia de salida

## Emisor común

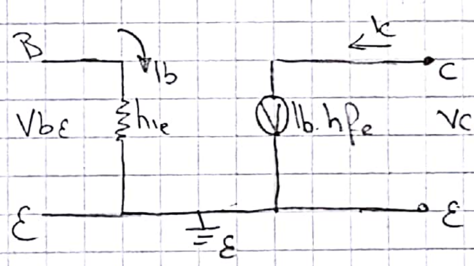



$V_{be} = h_{ie}\, I_b + h_{re}\, V_{CE}$ → LKV a la entrada del circ.
$I_c = h_{fe}\, I_b + h_{oe}\, V_{CE}$ → LKI " " salida " "

Modelo completo



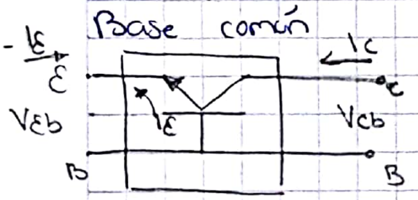

modelo simplificado ⇐ $h_{re} \simeq 0$, $h_{oe} = 0 \therefore \frac{1}{h_{oe}} \to \infty$ Circ. abierto




$\therefore$ $h_{ie} = \left.\frac{V_{be}}{I_b}\right|_{\substack{V_{CE}=0 \\ V_{CEQ}=cte}}$ salida en corto    $h_{re} = \left.\frac{V_{bE}}{V_{CE}}\right|_{\substack{I_b=0 \\ I_{bQ}=cte}}$ entrada abierta

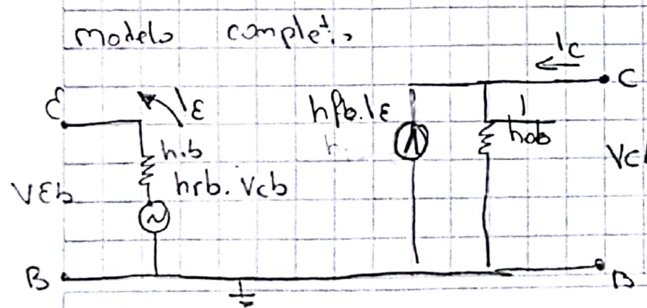
$h_{fe} = \left.\frac{I_c}{I_b}\right|_{\substack{V_{CE}=0 \\ V_{CEQ}=cte}}$ salida en corto    $h_{oe} = \left.\frac{I_c}{V_{CE}}\right|_{\substack{I_b=0 \\ I_{bQ}=cte}}$ entrada abierta

## Base común

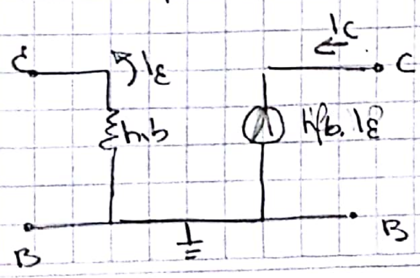



$V_{Eb} = h_{ib}(-I_E) + h_{rb}\, V_{cb}$
$I_c = h_{fb}(-I_E) + h_{ob}\, V_{cb}$

modelo completo




modelo simplificado




NOTA

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$\therefore\ h_{ib} = \left.\frac{V_{eb}}{-I_E}\right|_{V_{cb}=0}$ $\qquad h_{rb} = \left.\frac{V_{eb}}{V_{cb}}\right|_{I_E=0}$

$h_{fb} = \left.\frac{I_c}{-I_E}\right|_{V_{cb}=0}$ $\qquad h_{ob} = \left.\frac{I_c}{V_{cb}}\right|_{I_E=0}$

Relacion de los parametros h de emisor común y base común

$h_{ib} = \frac{-h_{ie}}{-(h_{fe}+1)}\ \frac{I_b}{I_b} = \frac{h_{ie}}{h_{fe}+1}$ $\qquad h_{rb} = \frac{h_{re}}{h_{fe}+1} \simeq 0$

$h_{fb} = -\frac{h_{fe}}{h_{fe}+1} \simeq -1$ $\qquad h_{ob} = \frac{h_{oe}}{h_{fe}+1} \simeq 0$

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(159) FET

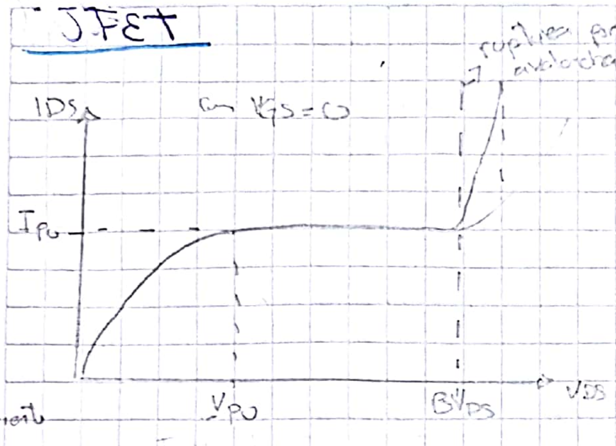
G, D, S

↑ $Z_{in} \simeq 10^{14}\,\Omega$
↓ $Z_{o}$
no amplifica I

HOJA Nº 7

FECHA

# JFET




$V_{Po}$: V de estrangulamiento

$$I_D = I_{Po}\left[1 + 3\frac{V_{GS}}{V_{Po}} + 2\left(\frac{-V_{GS}}{V_{Po}}\right)^{3/2}\right]$$

$V_{DS(saturación)} = V_P = V_{Po} + V_{GS}$

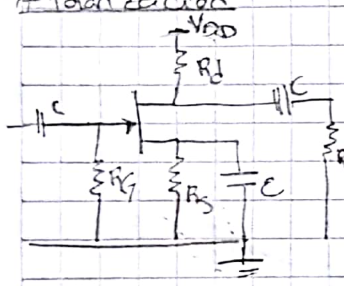
## # Relación entre $I_{Po}$ y la temp

$$I_{Po} = I'_{Po}\left(\frac{T}{T_o}\right)^{3/2}$$

con $\begin{cases} T_o = \text{temp ambiente} \\ I'_{Po} = I_{Po}\big|_{T=T_o} = I_D\big|_{V_{GS}=0,\ T=T_o} \end{cases}$

## # Polarización

RG PAP




$\boxed{V_{DD} = V_{DSQ} - I_{DQ}(R_d + R_S)}$ Ec de salida

$\boxed{V_{GSQ} = -I_{DQ}\,R_S}$ Ec de salida (es neg xq la I tiene sentido inverso)

## # Analisis

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 \qquad V_{GS} = -R_S \cdot I_D \qquad V_{DS} = V_{DD} - I_D(R_d + R_S)$$

## # Diseño

$$I_{DQ_{MES}} = \frac{V_{DD}}{R_{CC} + R_{CA}} = \frac{V_{DD}}{R_d + R_S + (R_d // R_L)}$$

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2 = I_{DSS}\left(\frac{V_{GSoff} - V_{GS}}{V_{GS\,off}}\right)^2 \rightarrow \sqrt{\frac{I_D}{I_{DSS}}} \cdot V_{GSoff} = V_{GSoff} - V_{GS}$$

$$\therefore V_{GS} = V_{GSoff}\left(1 - \sqrt{\frac{I_D}{I_{DSS}}}\right)$$

$$R_S = -\frac{V_{GS}}{I_{DQ}}$$

## # Parametros internos

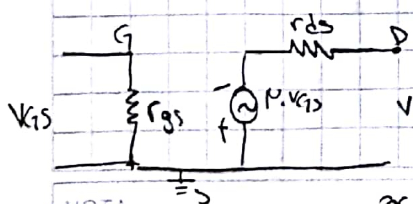
$r_{gs} = \frac{\Delta V_{GS}}{\Delta I_G}\Big|_Q \rightarrow \infty$ imp de entrada

$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}\Big|_{I_D = cte}$ ganancia de voltaje

$r_{ds} = \frac{\Delta V_{DS}}{\Delta I_D}\Big|_{V_{GS} = cte}$ imp. de salida

$g_m = \frac{\Delta I_D}{\ldots}\Big|$ Transconductancia

## # Circ equivalente





por norton

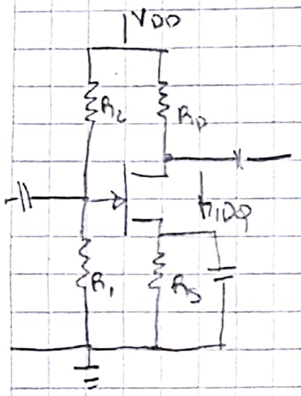
NOTA

(165) **MosFET** Puede ser manejado con tensiones (+) o (-)

$$I_D = I_{DSS}\left(1 + \frac{V_{GS}}{V_{p0}}\right)^2 \quad \text{Ec. de Shockley}$$

$$V_{GS(off)} = -V_{p0}$$

# Polarizacion



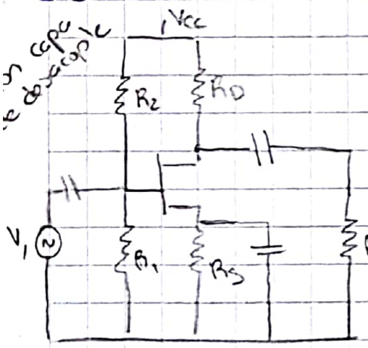

$$\boxed{V_{GG} = \frac{V_{DD}}{R_1+R_2} \cdot R_1}$$

$$\boxed{V_{DD} = V_{DS} + I_{DQ}(R_D + R_S)} \quad \text{Ec. de salida}$$

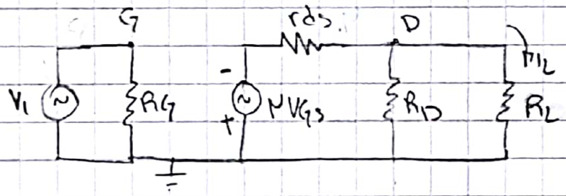
$$\boxed{V_{GSQ} = V_{GG} - I_{DQ}(R_S)} \quad \text{Ec. de entrada}$$

**Etapa Amplificadora:**

328) Surtidor Común




# Circ. equivalente




# Impedancias

$Z_I = R_G = R_1 \| R_2$

$Z_O = R_D \| r_{ds}$

# Ganancias

$$A_V = \frac{V_L}{V_1} = \frac{V_L}{V_{GS}} \cdot \frac{V_{GS}}{V_1}$$

$$V_1 = V_{GS} \rightarrow \frac{V_{GS}}{V_1} = 1$$

$$\boxed{A_V = \left[\frac{-\mu}{r_{ds} + (R_D \| R_L)} \cdot R_D \| R_L\right] \cdot [1]}$$

$V_L = V_{DS}$

$$V_L = \left(\frac{\mu \cdot V_{GS}}{r_{ds} + (R_D \| R_L)}\right)(R_D \| R_L)$$

$V = I \cdot R$

$$\frac{V_L}{V_{GS}} = \frac{\mu}{r_{ds} + (R_D \| R_L)} \cdot R_D \| R_L$$

Si
- $r_{ds} \ll R_D \| R_L \rightarrow A_V = -\mu$
- $r_{ds} \gg R_D \| R_L \rightarrow A_V = \frac{-\mu}{r_{ds}} \cdot R_D \| R_L$
- $R_L \ll R_D \rightarrow A_V = -g_m R_L$

$$\boxed{A_I = A_V \frac{Z_I}{R_L} = \left(\frac{-\mu\,(R_D \| R_L)}{r_{ds} + R_D \| R_L}\right) \cdot \frac{R_G}{R_L}}$$

Si
- $R_D \| R_L \ll r_{ds} \rightarrow A_I = \frac{-\mu\,(R_D \| R_L)}{r_{ds}}$
- $R_L \ll R_D \rightarrow A_I = -g_m R_G$

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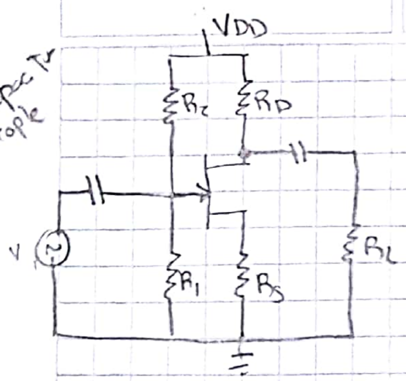
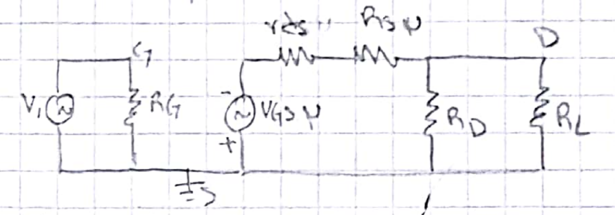
Sin capacitor de desacople



# Circ. equivalente



# Impedancias

$Z_i = R_G = R_1 // R_2$

$Z_o = R_D // [r_{ds} + R_S \mu]$

# Ganancias

$A_v = \frac{V_L}{V_1} = \frac{V_L}{V_{GS}} \cdot \frac{V_{GS}}{V_1}$

$V_{GS} = V_1 \rightarrow \frac{V_{GS}}{V_1} = 1$

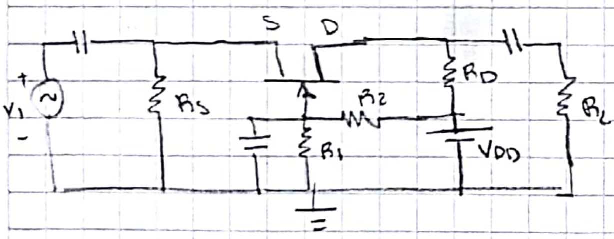
$V_L = V_{DS}$

$V_L = \frac{-V_{GS}\, \mu}{(r_{ds} + R_S \mu) + (R_D // R_L)} \cdot R_D // R_2$

$$\boxed{A_v = \left[\frac{-\mu \; R_D // R_L}{r_{ds} + R_S \mu + (R_D // R_L)}\right] \cdot [1]}$$

$$\boxed{A_i = A_v \cdot \frac{Z_i}{R_L}}$$

(34a) - Compuerta común (Gate común)



Diseño

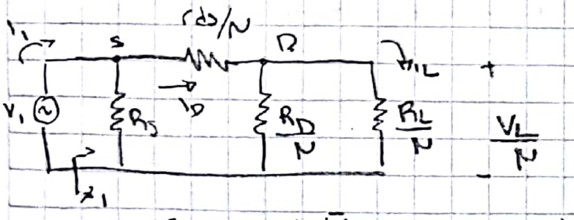
$I_{DQ_{max}} = \frac{V_{DD}}{R_{CC} + R_{CA}} = \frac{V_{DD}}{(R_D + R_S) + (R_D // R_L + R_S)}$

$V_{DSQ} = V_{DD} - I_{DQ}(R_S + R_D)$

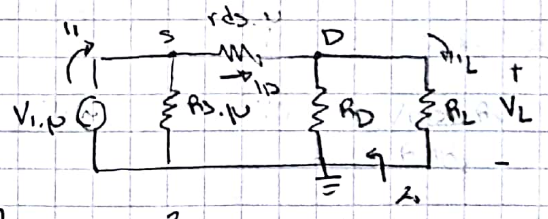
$V_{GSQ} = V_{GG} - I_{DQ} R_S$

# Circ. equivalente

Reflejado al surtidor



Reflejado al drenador



$Z_i = R_S // \left[\left(r_{ds} + R_D // R_L\right) \frac{1}{\mu}\right]$

$Z_o = R_D // r_{ds}$ sin $r_1$

$Z_o = R_D // [(R_S // r_1)\mu + r_{ds}]$ con $r_1$

# Ganancias

Uso el ref. al drenador

$A_I = \frac{I_L}{I_i} = \frac{I_L}{I_D} \cdot \frac{I_D}{I_i}$

$V_{R_L} = V_{R_D}$

$I_L R_L = I_D (R_D // R_L) \rightarrow \frac{I_L}{I_D} = \frac{R_D R_L}{R_D + R_L} \cdot \frac{1}{R_L}$

$$\boxed{A_I = \left(\frac{R_D}{R_D + R_L}\right)\left(\frac{\mu R_S}{\mu R_S + r_{ds} + R_D // R_L}\right)}$$

$V_1 = V_D$

$[(R_D // R_L + r_{ds}) // R_S \mu]\, I_i = [R_L // R_D + r_{ds}]\, I_D$

$\frac{I_D}{I_i} = \frac{(R_S \mu) // (R_D // R_L + r_{ds})}{R_L // R_D + r_{ds}} = \frac{\mu R_S}{\mu R_S + r_{ds} + R_D // R_L}$

$$\boxed{A_V = A_I \cdot \frac{R_L}{Z_i}}$$

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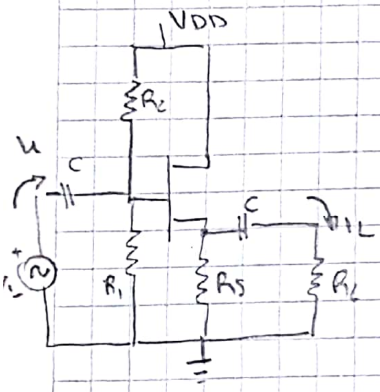
Drenador común



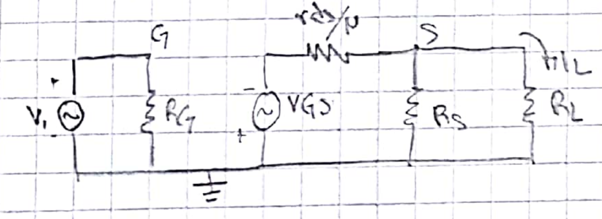

# Diseño

$$I_{DQ_{max}} = \frac{V_{cc}}{R_{cc}+R_{CA}} = \frac{V_{cc}}{R_S + (R_S // R_L)}$$

$$V_{DD} = V_{DS} - I_{DQ} R_S$$

$$V_{GG} = V_{GS} + I_{DQ} R_S \rightarrow V_{GS} = V_{GG} - I_{DQ} R_S$$

# Circ. equivalente S reflejado al gate




# Impedancias

$$Z_i = R_G$$

$$Z_o = R_S // \frac{r_{ds}}{\mu}$$

# Ganancias

$$A_V = \frac{V_L}{V_1} = \frac{V_L}{V_{GS}} \frac{V_{GS}}{V_1}$$

$$V_1 = V_{GS} \rightarrow \frac{V_{GS}}{V_1} = 1$$

$$V_L = V_S \qquad V = IR$$

$$V_L = \left[\frac{V_{GS}}{\frac{r_{ds}}{\mu} + (R_S // R_L)}\right] \cdot \left[R_S // R_L\right]$$

$$\frac{V_L}{V_{GS}} = \frac{R_S // R_L}{\frac{r_{ds}}{\mu} + R_S // R_L}$$

$$\boxed{A_V = \left(\frac{R_S // R_L}{\frac{r_{ds}}{\mu} + R_S // R_L}\right) \quad (1)}$$

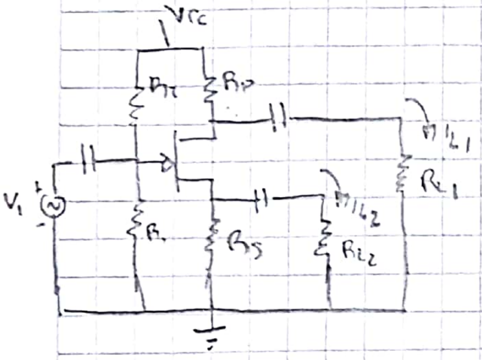
$$A_I = A_V \frac{Z_i}{R_L} \qquad A_P = A_V A_I$$

NOTA

## Circuito inversor de fase

posee 2 salidas de igual amplitud pero de opuestas en fase

### #FET

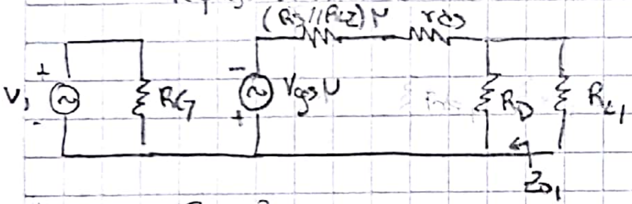



condición → $\begin{cases} (R_D // R_{L1}) = R_S // R_{L2} \\ V_{L1} = -V_{L2} \end{cases}$

las ganancias son iguales

### # Circ equivalente

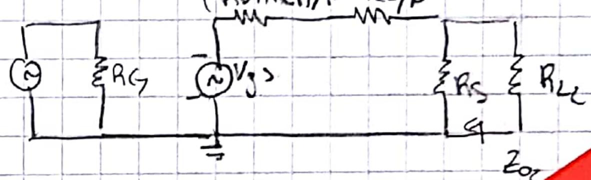
reflejado en el drenador




$Z_i = R_G$

$Z_{o1} = R_D // [r_{ds} + (R_S // R_{L2})\mu]$

ref. en el surtidor




$Z_i = R_G$

$Z_{o2} = R_S // \left[ \dfrac{r_{ds} + (R_D // R_{L1})}{\mu} \right]$

### # Ganancias

$A_{v1} = \dfrac{V_{L1}}{V_1} = \dfrac{V_{L1}}{V_{gs}} \cdot \underbrace{\dfrac{V_{gs}}{V_1}}_{=1}$

$V_{L1} = V_D$ $\quad V = IR$

$V_{L1} = \dfrac{-V_{gs}\,\mu}{[(R_S // R_{L2})\mu + r_{ds}] + [R_D // R_{L1}]} \cdot (R_D // R_{L1})$

$$\boxed{A_{v1} = \frac{-\mu\,(R_D // R_{L1})}{[(R_S // R_{L2})\mu + r_{ds}] + [R_D // R_{L1}]}}$$

$A_{v2} = \dfrac{V_{L2}}{V_1} = \dfrac{V_{L2}}{V_{gs}} \cdot \underbrace{\dfrac{V_{gs}}{V_1}}_{=1}$

$V_{L2} = V_D$

$V_{L2} = \dfrac{-V_{gs}}{\left(\dfrac{R_D // R_{L1}}{\mu} + \dfrac{r_{ds}}{\mu}\right) + (R_S // R_{L2})} \cdot R_S // R_{L2}$

$$\boxed{A_{v2} = \frac{-(R_S // R_{L2})}{\left[\dfrac{R_D // R_{L1}}{\mu} + \dfrac{r_{ds}}{\mu}\right] + (R_S // R_{L2})}}$$



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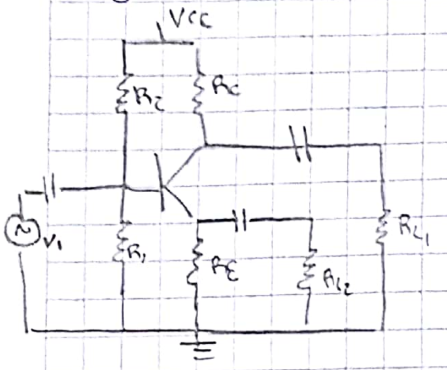
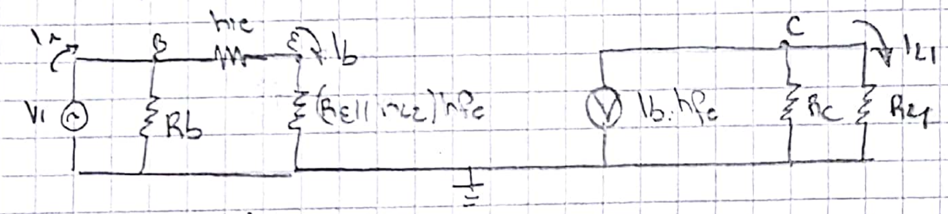
# BJT




condiciones $\begin{cases} R_E // R_{L2} = R_C // R_{L1} \\ V_{L1} = -V_{L2} \end{cases}$

# Circ. equivalente

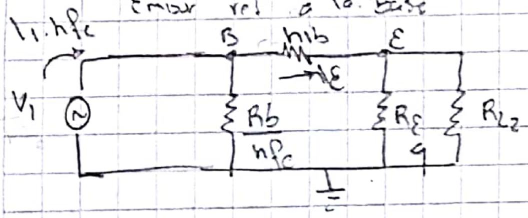
base refl. al emisor




$Z_1 = R_b // [h_{ie} + (R_E // R_{L2}) h_{fe}]$

$Z_{o1} = R_C$

Emisor ref. a la base




$Z_{o2} = R_E // h_{ib}$

# Ganancias

$A_{V1} = \frac{V_{L1}}{V_1} = \frac{V_{L1}}{I_b} \frac{I_b}{V_1}$

$V_1 = V$

$V_1 = \frac{I_b}{(R_E // R_{L2}) h_{fe} + h_{ie}} \rightarrow \frac{I_b}{V_1} = \frac{1}{(R_E // R_{L2}) h_{fe} + h_{ie}}$ $V = IR$

$V_{L1} = V$

$V_{L1} = (-I_b . h_{fe}) . R_C // R_{L1}$

$$\boxed{A_{V1} = (-h_{fe} \, R_C // R_{L1}) \left( \frac{1}{(R_E // R_{L2}) h_{fe} + h_{ie}} \right)}$$

$V = IR$

$A_{V2} = \frac{V_{L2}}{V_1} =$

$V_{L2} = \left( \frac{V_1}{[R_E // R_{L2} + h_{ib}] // \frac{R_b}{h_{fe}}} \right) . R_E // R_{L2}$

$$\boxed{A_{V2} = R_E // R_{L2} \frac{1}{(R_E // R_{L2} + h_{ib}) // \frac{R_b}{h_{fe}}}}$$

NOTA

$h_{ie_1} + h_{ie_2} h_{fe}$ $\qquad h_{ie_1} = h_{ie_2} h_{fe}$

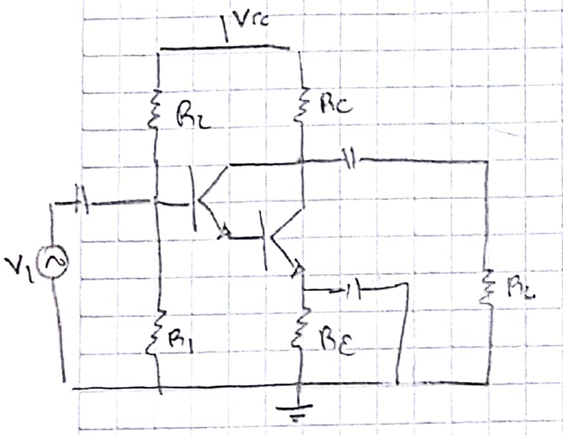
$h_{ie_2} h_{fe} + h_{ie} h_{fe}$



# Darlington

## Salida por colector

$$I_{b_1} = \frac{I_{cq_1}}{\beta} = \frac{I_{cq_2}}{\beta^2} \qquad I_{cq_1} = I_{b_2} = \frac{I_{cq_2}}{\beta} \qquad V_{CEQ_1} = V_{CEQ_2} - V_{bE}$$




### # Análisis

$$V_{cc} - I_{cq_2}(R_C + R_E) - V_{CE} = 0 \rightarrow \boxed{V_{CEQ} = V_{cc} - I_{Q_2}(R_C + R_E)}$$

$$V_{BB} - I_{b_1} R_b - 2V_{bE} - I_{cq_2} R_E = 0$$

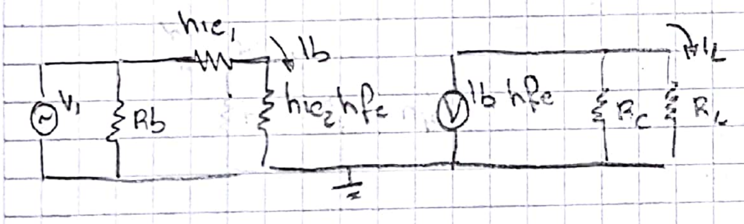
$$I_{cq_2}\left(R_E + \frac{R_b}{\beta}\right) = V_{bb} - 2V_{bE}$$

$$\boxed{I_{cq_2} = \frac{V_{bb} - 2V_{bE}}{R_E + R_b/\beta}} \qquad V_c$$

### # Diseño

$$R_b = \frac{\beta^2 R_E}{10}$$

### # Circuito equivalente




$$Z_1 = R_b // (h_{ie_1} + h_{ie_2} h_{fe}) - R_b // 2h_{ie}$$
$$= R_b // 2h_{ie_2} h_{fe}$$
$$= R_b // 2h_{ie_1}$$

$$Z_0 = R_C$$

### # Ganancias

$$A_I = \frac{I_L}{I_i} = \frac{I_L}{I_b} \frac{I_b}{I_i}$$

$$V_L = V$$
$$I_L R_L = (-I_b \cdot h_{fe})\, R_C // R_L$$
$$\frac{I_L}{I_b} = -h_{fe} \frac{R_C // R_L}{R_L}$$

$$\boxed{A_I = \left(-h_{fe} \frac{R_C // R_L}{R_L}\right)\left(\frac{R_b // 2h_{ie_1}}{2h_{ie_1}}\right)}$$

$$V_1 = V$$
$$I_i \cdot (R_b // 2h_{ie_1}) = I_b \cdot 2h_{ie_1}$$
$$\frac{I_b}{I_i} = \frac{R_b // 2h_{ie_1}}{2h_{ie_1}}$$

$$\boxed{A_V = A_I \frac{R_L}{Z_1}}$$

NOTA

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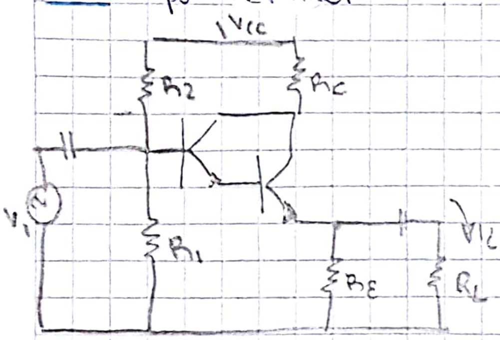
Salida por emisor

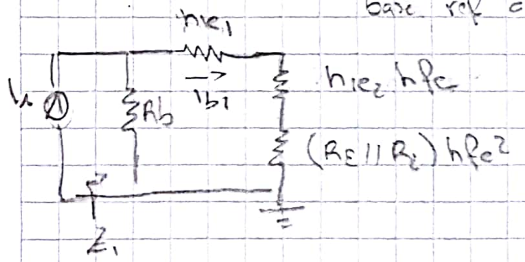



# Analisis

$$I_{CQ_{máx}} = \frac{V_{cc}}{R_{CC}+R_{CA}} = \frac{V_{cc}}{(R_C+R_E)(R_C+R_E\|R_L)}$$

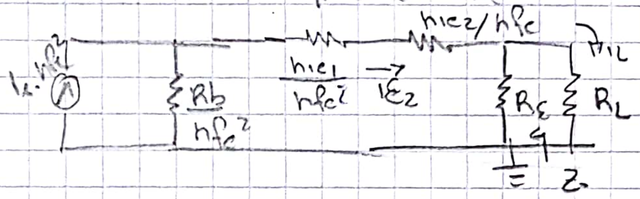
# Circ equivalente

base ref al emisor




emisor ref a la base

$\frac{hie_2}{hfe} = hib_2$




$$Z_1 = Rb \,//\, (2hie_1 + (R_E\|R_L)hfe^2)$$

$$Z_0 = \left(\frac{Rb}{hfe^2} + 2hib_2\right) // R_E$$

# Ganancias

$$A_I = \frac{I_L}{I_i} = \frac{I_L}{I_{E_2}} \cdot \frac{I_{E_2}}{I_i}$$

$V_L = V_E$

$$I_L R_L = I_{E_2} R_E\|R_L \rightarrow \frac{I_L}{I_E} = \frac{R_E\|R_L}{R_L}$$

$V_1 = V_1$

$$I_{E_2}\left[\frac{Rb}{hfe^2} + 2hib_2 + (R_E\|R_L)\right] = I_i hfe^2 \frac{Rb}{hfe^2}$$

$$\frac{I_{E_2}}{I_i} = \frac{\frac{Rb}{hfe^2}}{\frac{Rb}{hfe^2} + 2hib_2 + (R_E\|R_L)} \cdot hfe^2$$

$$\boxed{A_I = \frac{R_E\|R_L}{R_L} \cdot \frac{\frac{Rb}{hfe^2} \cdot hfe^2}{\frac{Rb}{hfe^2} + 2hib_2 + R_E\|R_L}}$$

Si $\frac{Rb}{hfe^2} >> 2hib_2 + R_E\|R_L$

$\therefore$

$$\boxed{A_I = \frac{R_E\|R_L}{R_L} \cdot hfe^2}$$

NOTA

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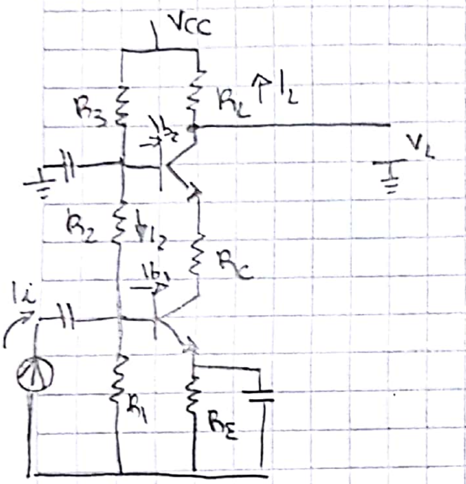
Cascodo como amplificador { Mejora el ancho de banda
{ Evita la disminución de ganancia por realimentación

como desplazador de nivel de CC { sin variación en AV

# Como amplificador en altas frec.




$$V_{b_2} = \frac{V_{cc}(R_2+R_1)}{R_1+R_2+R_3} \qquad V_{b_1} = \frac{V_{b_2}\, R_1}{R_1+R_2}$$

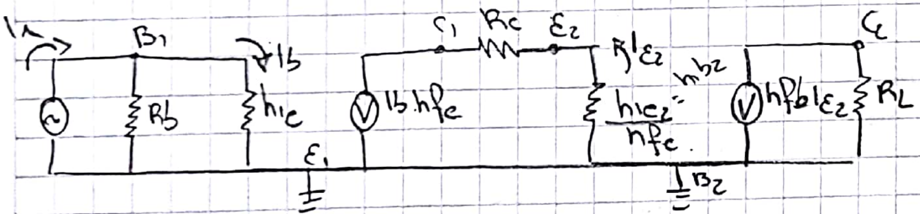
$$I_{CQ_1} = I_{CQ_2} = \frac{V_{B_1} - V_{BE}}{R_E}$$

$$V_{CEQ_1} = V_{b_2} - V_{BE} - I_{CQ_1}(R_C + R_E)$$

$$V_{CEQ_2} = V_{cc} - V_{CEQ_1} - I_{CQ_1}(R_L + R_C + R_E)$$

p/CA $R_3$ no existe

# Circuito eq.




$$A_I = \frac{I_L}{I_i} = \frac{I_L}{I_{E_2}} \cdot \frac{I_{E_2}}{I_b} \cdot \frac{I_b}{I_i}$$

$$I_L \cdot R_L = -I_{E_2}\, h_{fb}\, R_L$$

$$\frac{I_L}{I_{E_2}} = -h_{fb}$$

$$\boxed{A_I = \underbrace{-h_{fb}}_{\text{Ganancia de B-C}} \cdot \underbrace{h_{fe} \cdot \frac{R_b // h_{ie}}{h_{ie}}}_{\text{Ganancia del E C}}}$$

$$I_{E_2} = +I_b\, h_{fe} \rightarrow \frac{I_{E_2}}{I_b} = +h_{fe}$$

$$V = V_{h_{ie}}$$

$$I_i \cdot (R_b // h_{ie}) = I_b\, h_{ie} \rightarrow \frac{I_b}{I_i} = \frac{R_b // h_{ie}}{h_{ie}}$$



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#Como desplazador de nivel (no creo; me dio fiaca)

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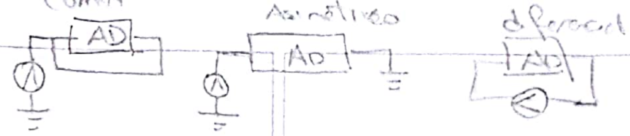





# Diferencial

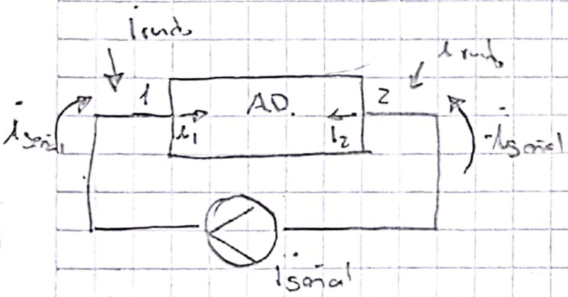
↳ Tipos → Simétrico : $R_L$ se conecta entre los colectores, elimina el ruido
↳ Asimétrico : Atenúa el ruido

Circ. diferencia entre corrientes

$i_c = \frac{i_1 + i_2}{2}$ corriente modo común → es el ruido

$i_d = i_2 - i_1$ corr. modo diferencial → señal en sí

$A_d \gg A_c$ p/que el ruido se amplifique muy poco respecto a la señal




- la señal entra desfasada 180° en las entradas y el ruido entra en fase en ambas entradas

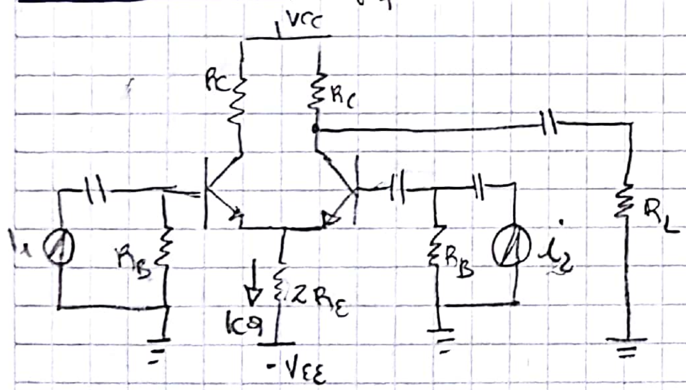
- $A_c = \left.\frac{i_L}{i_c}\right|_{i_d=0}$ ganancia modo común

- $A_d = \left.\frac{i_L}{i_d}\right|_{i_c=0}$ ganancia modo diferencial

$i_L = \underbrace{A_c i_c}_{\text{ruido}} + \underbrace{A_d i_d}_{\text{señal}}$ corriente de salida

$RRMC = \frac{A_d}{A_c} \to \infty$

# Salida Asimétrica (porque la salida está en el colector de $T_1$ solo)




$$\boxed{V_{RE} = 2R_E I_{cq_1} = 2R_E I_{cq_2}}$$

$V_{EE} - I_{bq} R_b - V_{bE_1} - I_{cq}\, 2R_E = 0$

$I_{cq}\left(\frac{R_b}{\beta} + 2R_E\right) = V_{EE} - V_{bE_1}$

$$\boxed{I_{cq_1} = I_{cq_2} = \frac{V_{EE} - V_{bE_1}}{\frac{R_b}{\beta} + 2R_E}}$$

$V_{CE_1} = V_{CE_2}$ si Rc son =

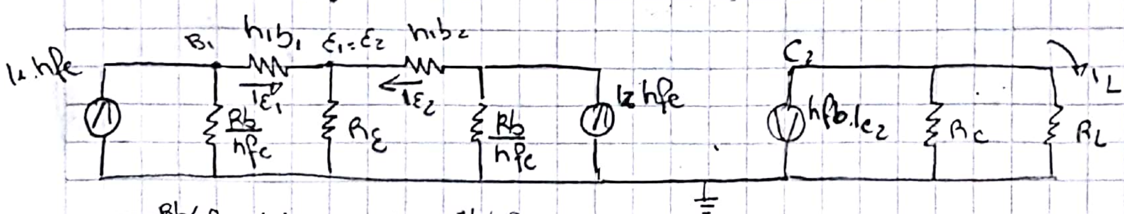
$V_{cc} - I_{cq}(R_c + 2R_E) - V_{CE_1} - (-V_{EE}) = 0 \to \boxed{V_{CE_1} = V_{CE_2} = V_{cc} + V_{EE} - I_{cq}(R_c + 2R_E)}$

# Circuito equivalente

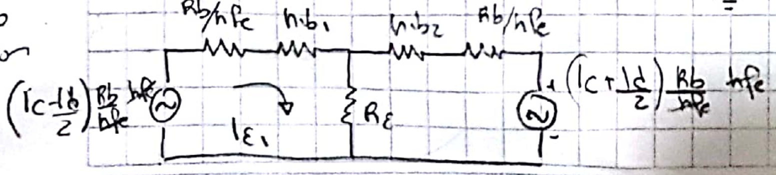
Base Reflejada al emisor

$i_1 = i_c - \frac{i_d}{2}$

$i_2 = i_c + \frac{i_d}{2}$




Aplico Norton




NOTA

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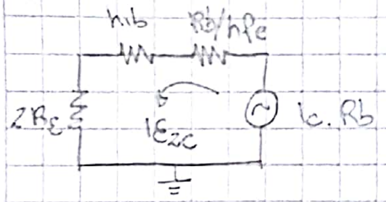
# Malla de salida: $I_L = f(I_{E2})$ y $I_{E2} = f(I_c, I_d)$

# Si $I_1 = I_2 = I_c \therefore I_d = 0 \therefore I_{E1} = I_{E2}$

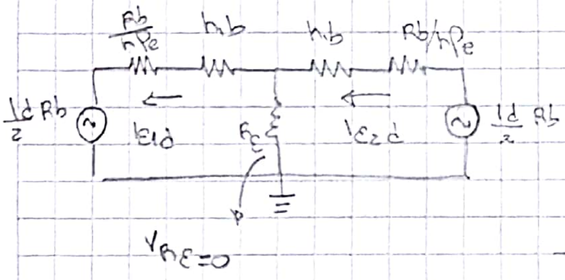



V = I R

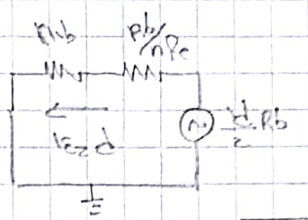
$$(I_c\, R_b) = I_{E2c} \cdot \left(\frac{R_b}{h_{fe}} + h_{ib} + 2R_E\right) \rightarrow \boxed{I_{E2c} = \frac{I_c\, R_b}{\frac{R_b}{h_{fe}} + h_{ib} + 2R_E}}$$

# Si $I_1 = -I_2 \therefore I_c = 0 \therefore I_{E1} = -I_{E2}$

$I_d = 2 I_1 = -2 I_2$




Si $V_{RE} = 0$




V = I R

$$\frac{I_d}{2} R_b = I_{E2d}\left(h_{ib} + \frac{R_b}{h_{fe}}\right) \rightarrow \boxed{I_{E2d} = \frac{I_d \cdot R_b}{2\cdot\left(h_{ib} + R_b/h_{fe}\right)}}$$

# Corrientes y RRMC

$$I_{E2} = I_{E2c} + I_{E2d} = \frac{R_b}{\frac{R_b}{h_{fe}} + h_{ib} + 2R_E} \cdot I_c + \frac{R_b}{2\left(h_{ib} + \frac{R_b}{h_{fe}}\right)} \cdot I_d$$

$$V_L = V \rightarrow (I_L) \cdot R_L = (I_{E2} h_{fb}) \cdot R_c // R_L \rightarrow \boxed{I_L = I_{E2} h_{fb} \cdot \frac{R_c \cdot R_L}{R_c + R_L} \cdot \frac{1}{R_L}}$$

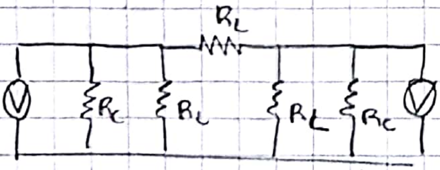
$$\therefore \boxed{I_L = \underbrace{\frac{h_{fb}\, R_c}{R_c + R_L} \cdot \frac{R_b}{\frac{R_b}{h_{fe}} + h_{ib} + 2R_E}}_{A_c} \cdot I_c + \underbrace{\frac{h_{fb}\, R_c}{R_c + R_L} \cdot \frac{R_b}{2\left(h_{ib} + \frac{R_b}{h_{fe}}\right)}}_{A_d} \cdot I_d}$$

si $I_L = A_c I_c + A_d \cdot I_d$

$$RRMC = \frac{A_d}{A_c} = \frac{\frac{R_b}{R_b/h_{fe} + h_{ib} + 2R_E}}{\frac{R_b}{2h_{ib} + 2R_b/h_{fe}}} \quad \text{si } R_E \gg h_{ib} + \frac{R_b}{h_{fe}} \quad \boxed{RRMC = \frac{R_E}{h_{ib} + \frac{R_b}{h_{fe}}}}$$

# Impedancias

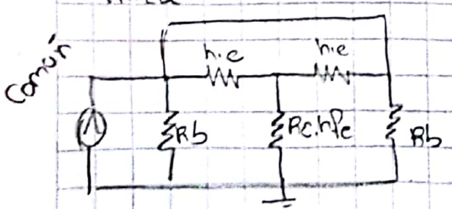
# Salida

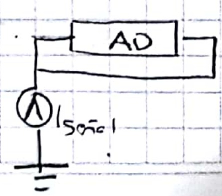



$Z_o = R_c$ asimetrica

$Z_o = 2R_c$ diferencial o simetrica

# Entrada




cortocircuito

NO $Z_i = \frac{R_b}{2} // \left(\frac{h_{ie}}{2} + R_E \cdot h_{fe}\right)$

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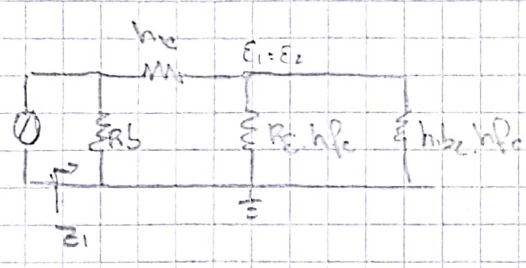
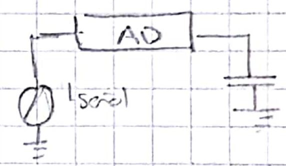
HOJA N° 13

FECHA

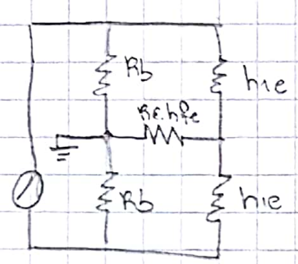
Asimetrica



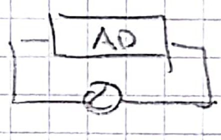

$Z_i = Rb // [h_{ie} + (h_{ib_2} h_{fe} // Re\, h_{fe})]$




Diferencial




$Z_i = 2\,(Rb // h_{ie})$

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