Amplificadores de Potencia

($P_O > 500mW$)

- Amplificadores lineales
  - Clase A (360°)
  - Clase B (180°)
  - Clase AB (<360° y >180°)

- Amplificadores clase C (< 180°)

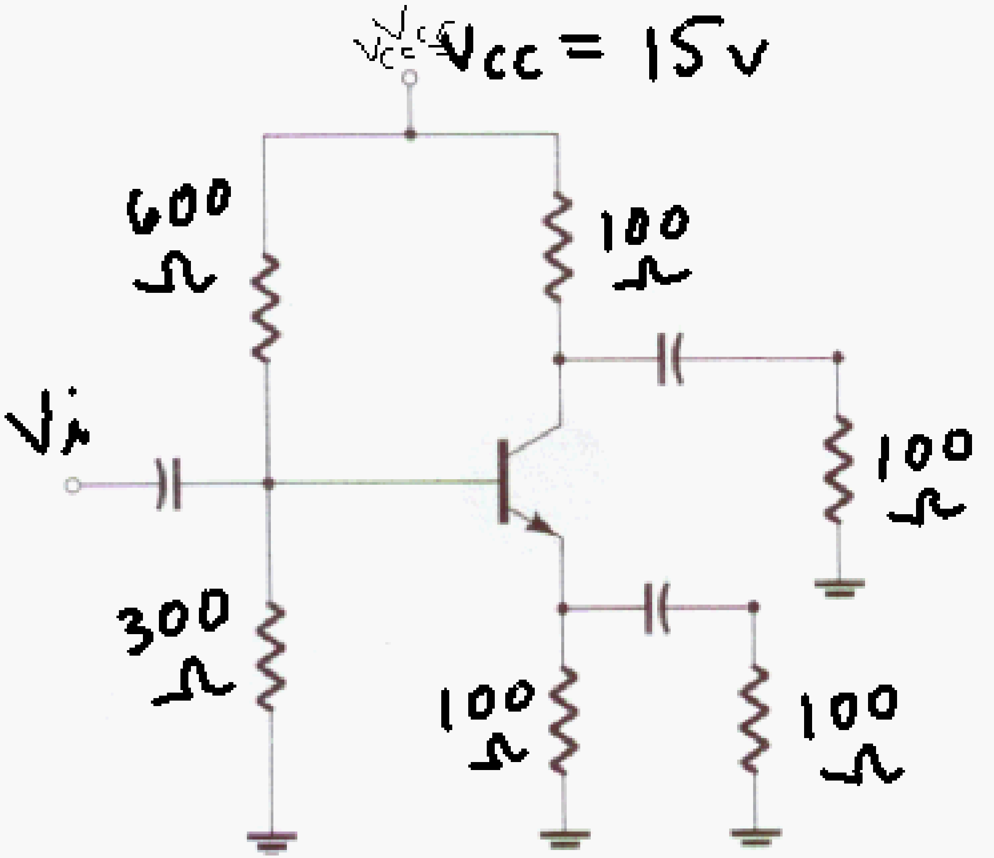
- Amplificadores por conmutación
  - Clase D
  - Clase E
  - Clase F
  - Clase S

Amplificadores lineales

Amplificador Clase A

- Conduce sobre los 360°
- Alta disipación de potencia
- Potencia de salida limitada
- Aplicación principal en etapas de baja potencia
- Eficiencia < 50%

Recta de carga de CA



$\beta R_E \geq 10 R_2$ ✓

$V_B = \frac{300}{900}(15)$

$\beta R_E \geq 10 R_2$

$V_B = 5\,v$

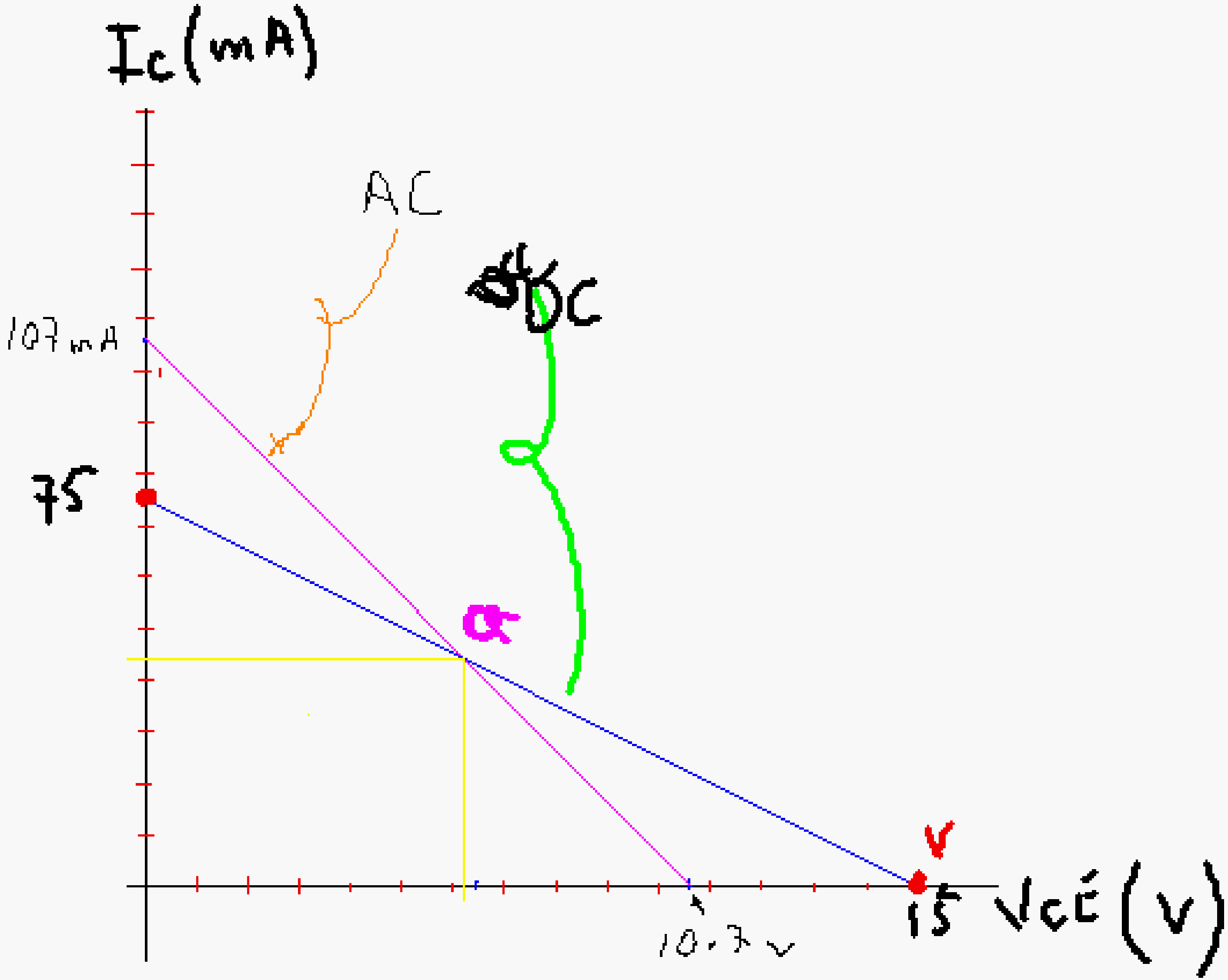
$V_B = \frac{390}{}$

$I_C \approx I_E = \frac{5v - 0.7}{100}$

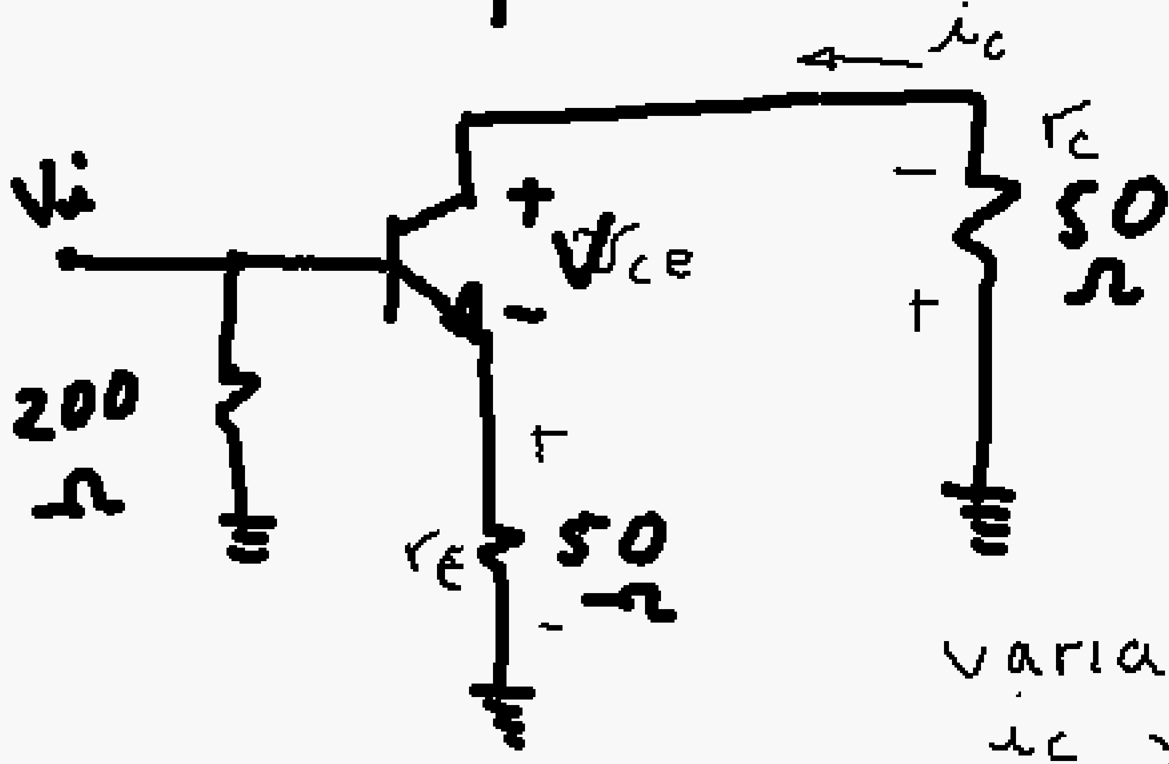
$I_{CQ} = 43\,mA$

$V_{CEQ} = V_{CC}\ 43mA(200\Omega)$

$V_{CEQ} = 6.4\,v$


Ic (mA)
AC
DC
107 mA
75
Q
10.7 v
15
VCE (V)

Modelo equivalente



$$v_{ce} + i_c(r_e + r_c) = 0$$

$$i_c = -\frac{v_{ce}}{r_e + r_c}$$

variaciones de i_c y v_{ce}

$$i_c = I_C - I_{CQ}$$

$$v_{ce} = V_{CE} - V_{CEQ}$$

$$I_C - I_{CQ} = -\frac{V_{CE} - V_{CEQ}}{r_e + r_c}$$

despejando I_c

$$\boxed{I_c = -\frac{V_{CE}}{r_E + r_c} + \frac{V_{CEQ}}{r_E + r_c} + I_{CQ}}$$

para $I_c = 0$

$$V_{CE_{corte}} = V_{CEQ} + I_{CQ}(r_E + r_c)$$
$$= 6.4 + 43mA(100)$$
$$= 10.7\ v$$

Para $V_{CE} = 0$

$$I_{C_{sat}} = \frac{V_{CEQ}}{r_E + r_c} + I_{CQ} = \frac{6.4}{100} + 43mA$$

$$I_{C_{sat}} = 107\ mA$$

$$I_{C_{sat}} = 2 I_{CQ}$$

$$V_{CE_{corte}} = 2 V_{CEQ} \quad \ldots\ldots \; \text{A}$$

considerando que

$$V_{CE_{corte}} = V_{CEQ} + I_{CQ}(r_E + r_C) \quad \ldots\ldots \; \text{B}$$

Sustituyendo B en A

$$2V_{CEQ} = V_{CEQ} + I_{CQ}(r_E + r_C)$$

$$\boxed{r_E + r_C = \frac{V_{CEQ}}{I_{CQ}}}$$

Máxima potencia de salida (P_o)

$$P_{o(MAX)} = V_{rms} I_{rms} = \frac{V_{CEQ}}{\sqrt{2}} \frac{I_{CQ}}{\sqrt{2}}$$

$$\boxed{P_{o(MAX)} = \frac{1}{2} V_{CEQ} I_{CQ}}$$

Para el ejem.

$P_o = 137.6\ mW$

Disipación de potencia (P_D)

$$P_D = V_{CEQ} I_{CQ}$$

$$P_{O_{MAX}} = \frac{1}{2} P_D$$

Para el ejemplo

$P_D = 275\ mW$

Eficiencia de salida (η)

Es la relación entre la potencia de salida de AB y la potencia de entrada de DC que se le proporciona al circuito colector - emisor.

$$\eta = \frac{P_o}{P_{DC}} \times 100$$

donde: $P_{DC} = V_{CC} I_{CQ}$

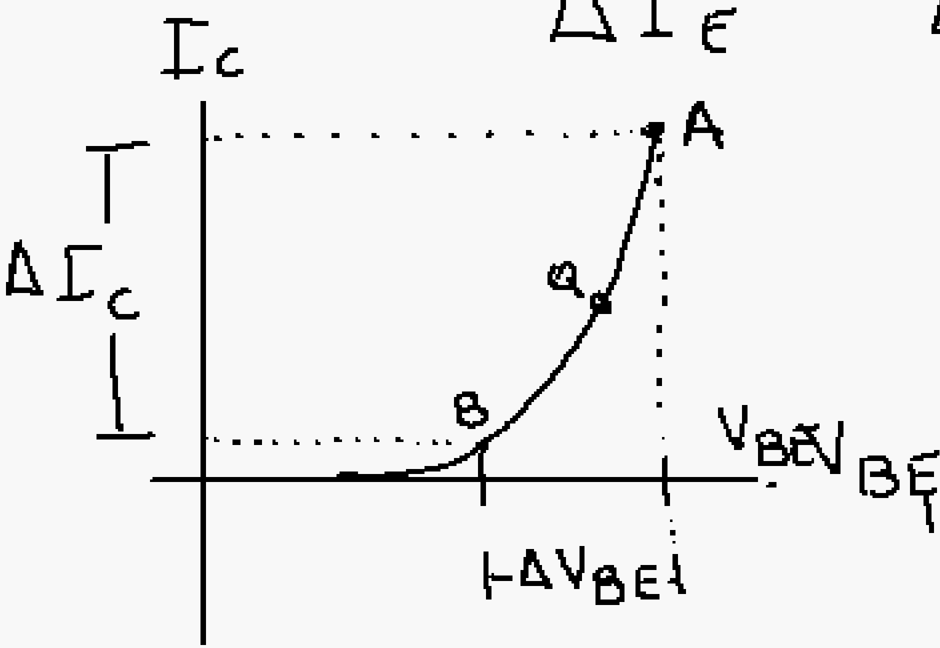
Para circuitos con doble fuente

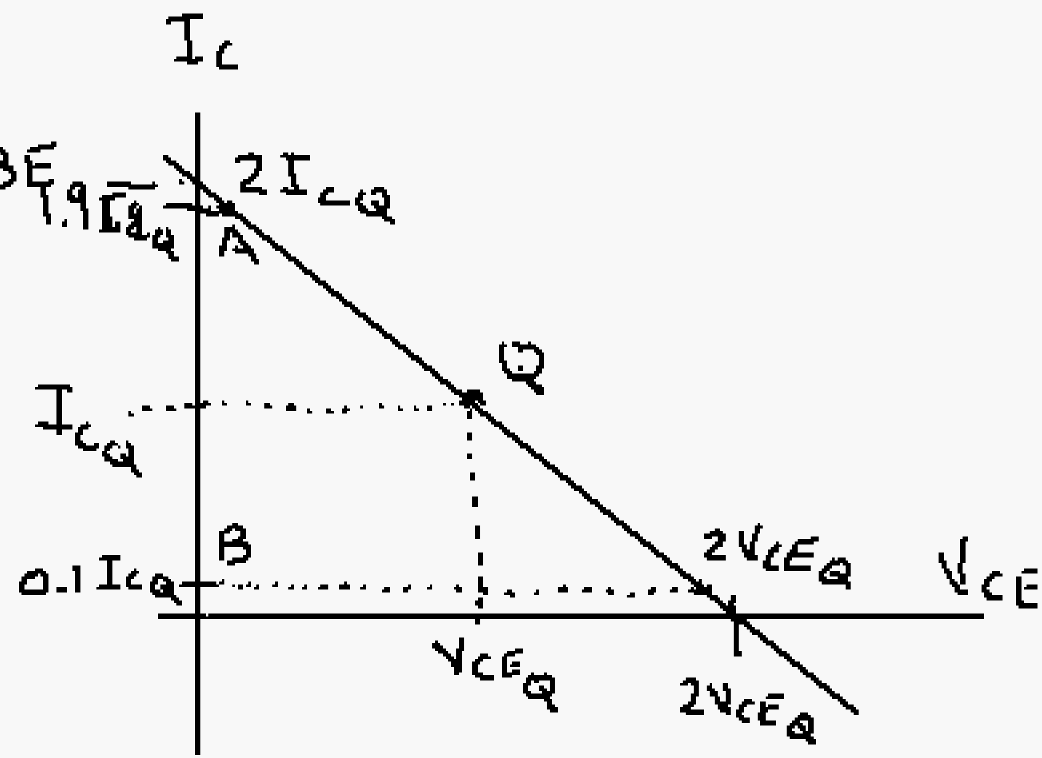
$$P_{DC} = (V_{CC} + V_{EE}) I_{CQ}$$

Ganancia e impedancia

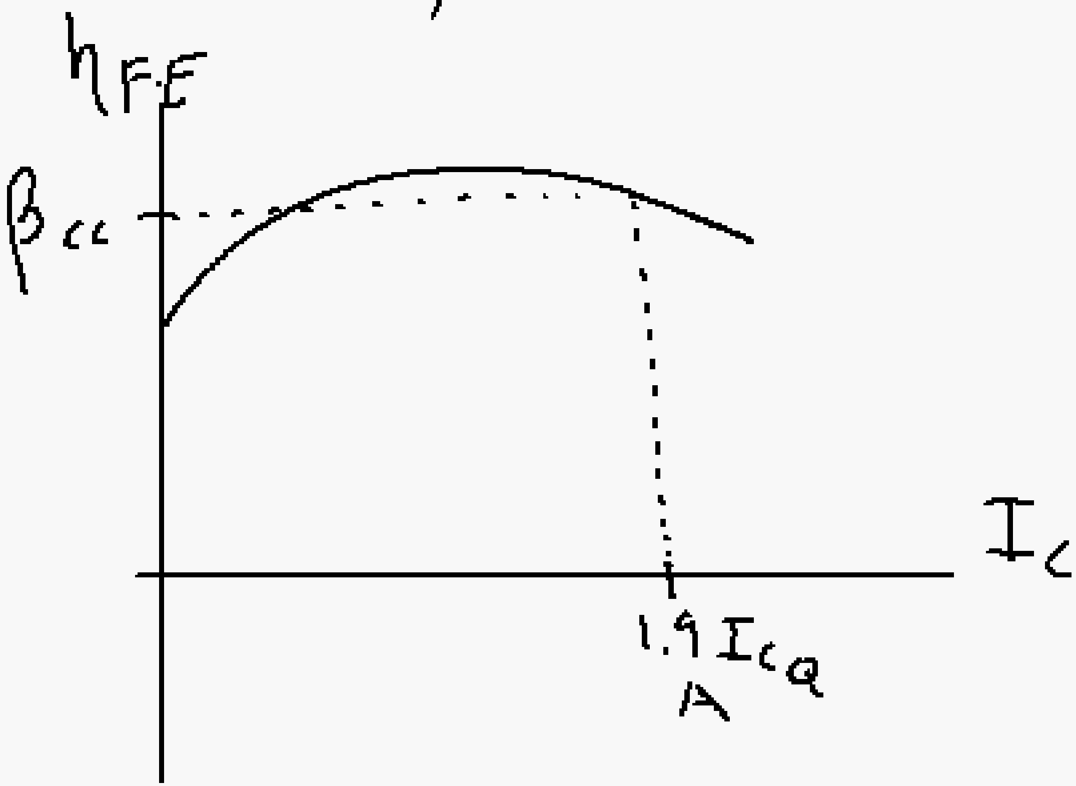
$$\cancel{r_e = \frac{26\,mV}{I_E}}$$

$$R_e \; \underline{r_e} \; \frac{\Delta V_{BE}}{\Delta I_E} \cong \frac{\Delta V_{BE}}{\Delta I_C}$$

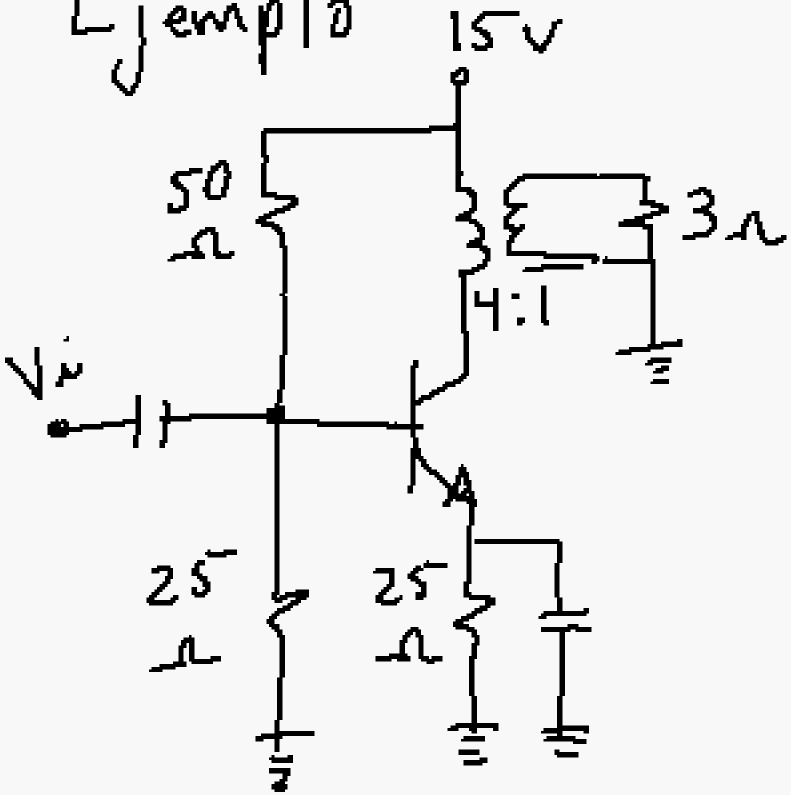




β_{cc} (h_{FE})



Ejemplo



✓ Transformador ideal

a) Recta de carga AC

b) Potencia de AC en primario de transf.

c) Potencia de AC en R_L

d) η e) P_D

a) $I_{C_{SAT}} = I_{CQ} + \dfrac{V_{CEQ}}{r_E + r_C}$

$V_{CE_{CORTE}} = V_{CEQ} + I_{CQ}(r_E + r_C)$

$V_B = \dfrac{25}{75}(15) = 5\,V$

$I_E = \dfrac{5 - 0.7}{25} = 172\,mA$

$\boxed{I_C \cong I_E = 172\,mA = I_{CQ}}$

$V_{CE} = V_{CC} - I_C(R_C + R_E)$

$V_{CE} = 15 - 172\,mA\,(25)$

$\boxed{V_{CEQ} = 10.7\,V}$

$$I_{c\,SAT} = 172\,\text{mA} + \frac{10.7}{48} = 394.9\,\text{mA}$$

$$r_c' = r_c(4)^2 = (4)^2(3)$$

$$\boxed{r_c = 48\,\Omega}$$

$$n = \frac{N_p}{N_s} = \frac{4}{1}$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p} = \frac{\frac{V_s}{R_s}}{\frac{V_p}{R_p}}$$

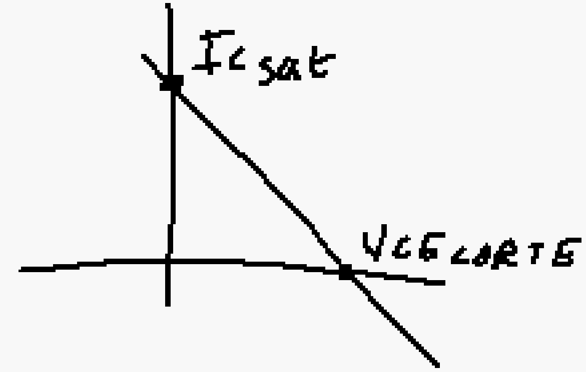
$$V_p = I_p R_p$$

$$\frac{V_p}{V_s} = \frac{V_s R_p}{V_p R_s} \Rightarrow \left(\frac{V_p}{V_s}\right)^2 = \frac{R_p}{R_s}$$

$$R_p = \left(\frac{V_p}{V_s}\right)^2 R_s = n^2 R_s$$

$$V_{CE_{CORTE}} = 10.7\,V + 172\,mA(48)$$

$$\boxed{V_{CE_{CORTE}} = 18.97\,V}$$



b) Potencia AC en primario

$$P_o = \frac{V_{CEQ}\, I_{CQ}}{2} = \frac{(10.7)(172\,mA)}{2}$$

$$\boxed{P_o = 0.92\,W}$$

c) Potencia de AC en secundario

Para transformador ideal

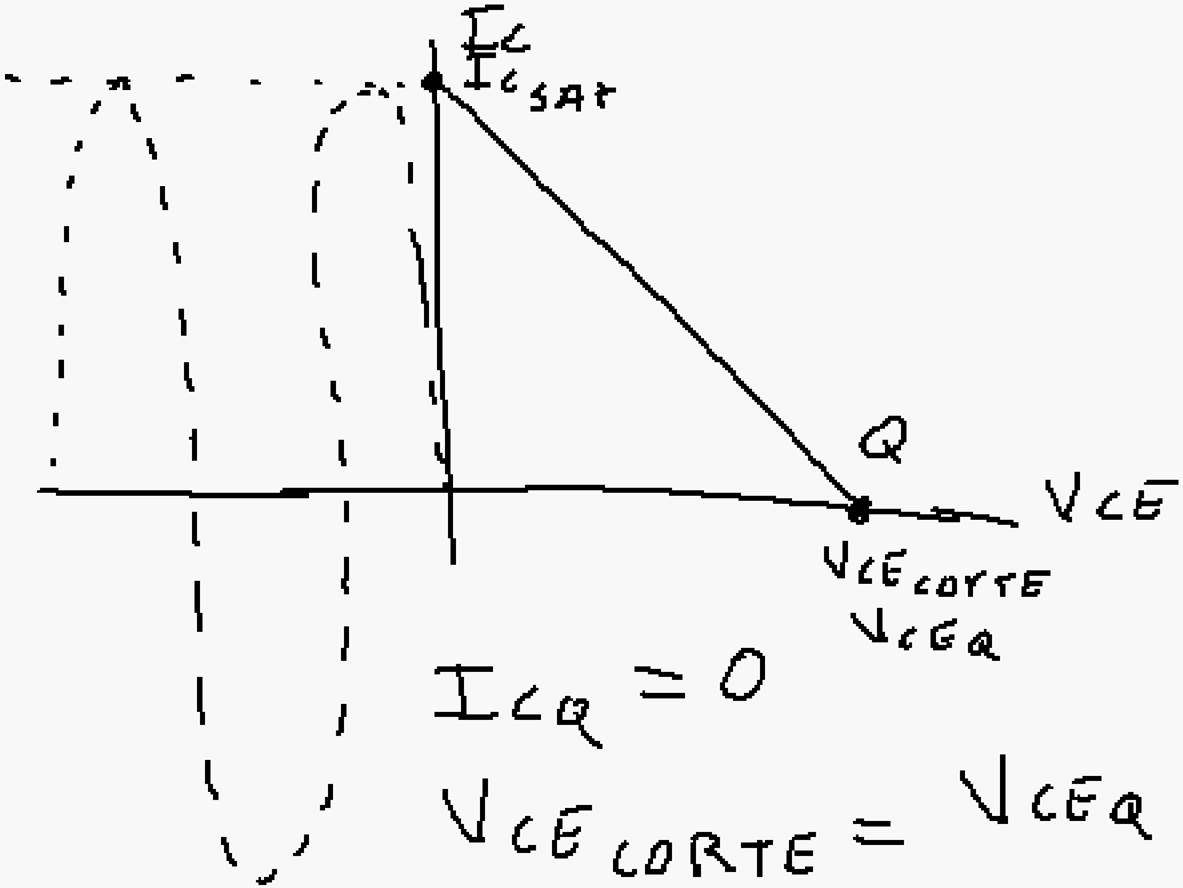
$$P_s = P_p = 0.92\,W$$

d) $\eta = 35.65\%$

e) $P_D = 1.84\ W$

Amplificadores clase B en oposición de fase

- P_D es la quinta parte de la potencia de carga
- Consumo de corriente sin señal de aproximadamente 1% de $I_{C sat}$



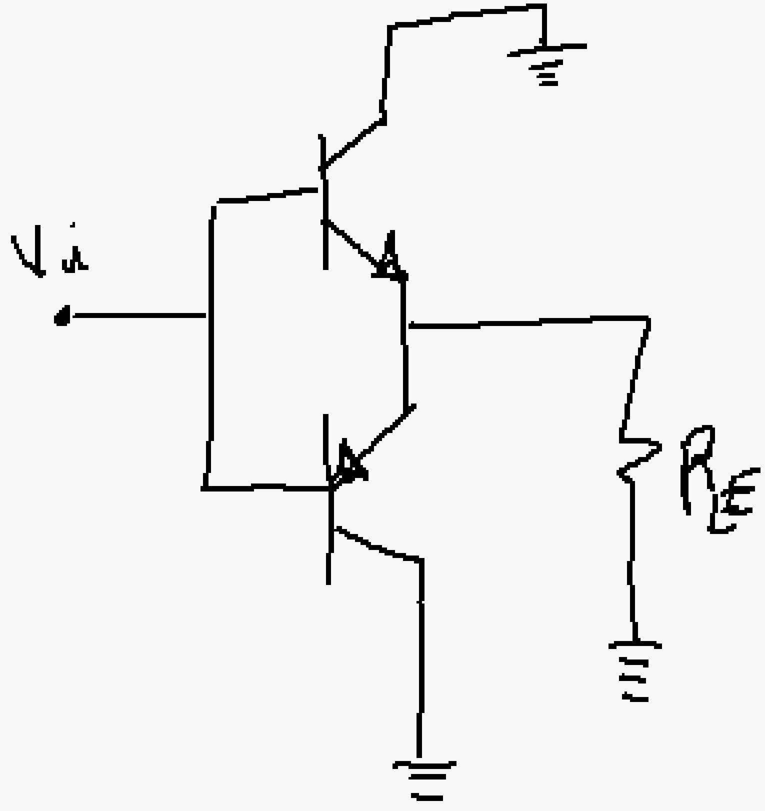
$$I_{CQ} = 0$$

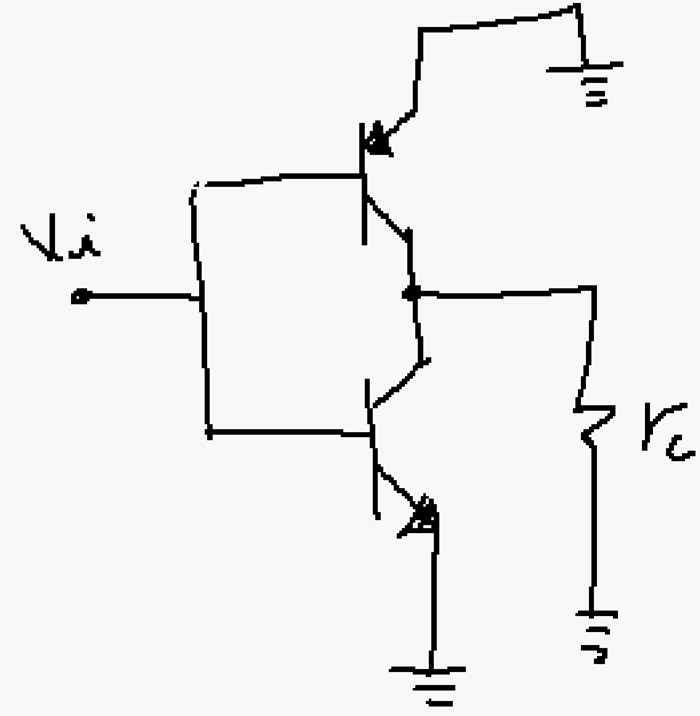
$$V_{CE_{CORTE}} = V_{CEQ} + I_{CQ}(r_E + r_C)$$

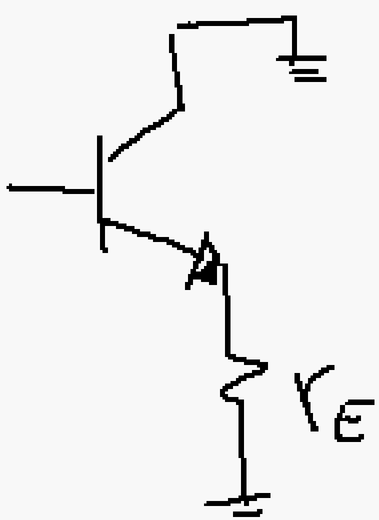
$$\boxed{V_{CE_{CORTE}} = V_{CEQ}}$$

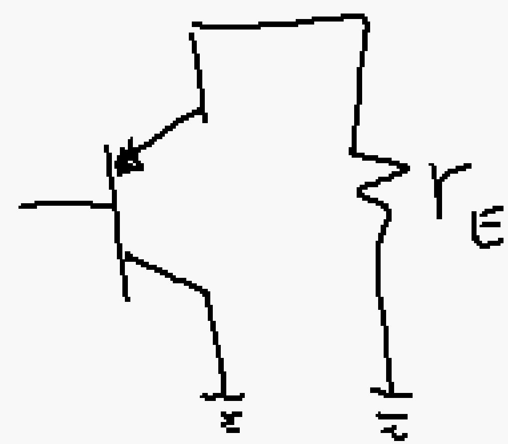
$$I_{C_{sat}} = I_{CQ} + \frac{V_{CEQ}}{r_E + r_C}$$

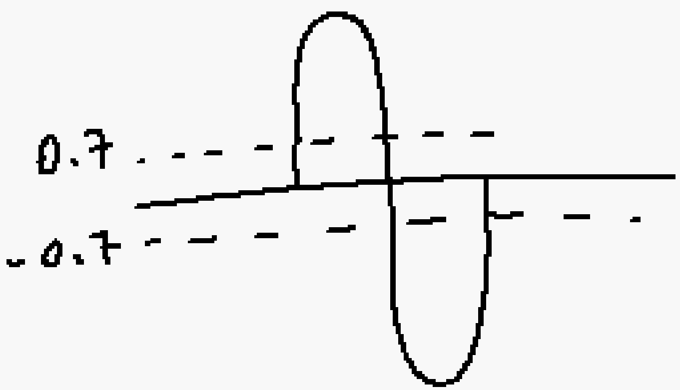
$$\boxed{I_{C_{sat}} = \frac{V_{CEQ}}{r_E + r_C}}$$

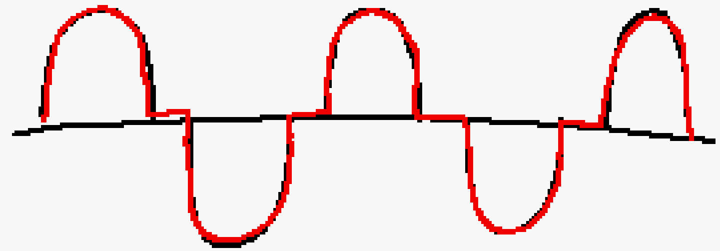

Vi
R_E


Vi
r_c

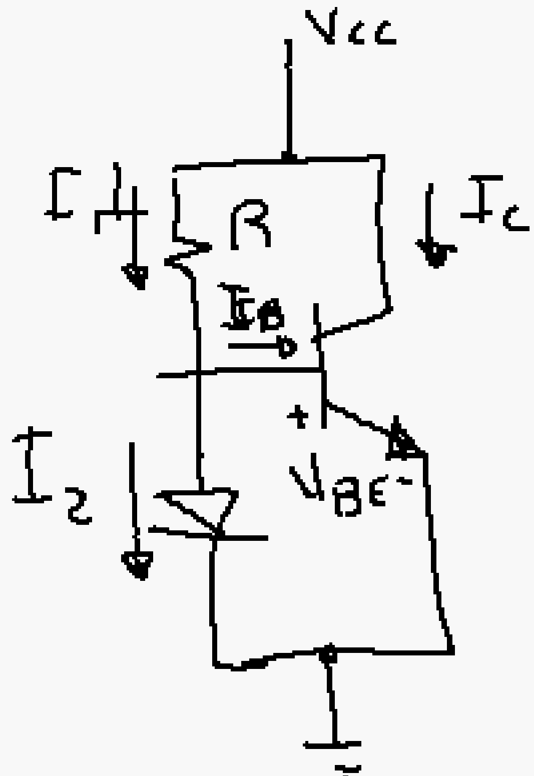

r_E

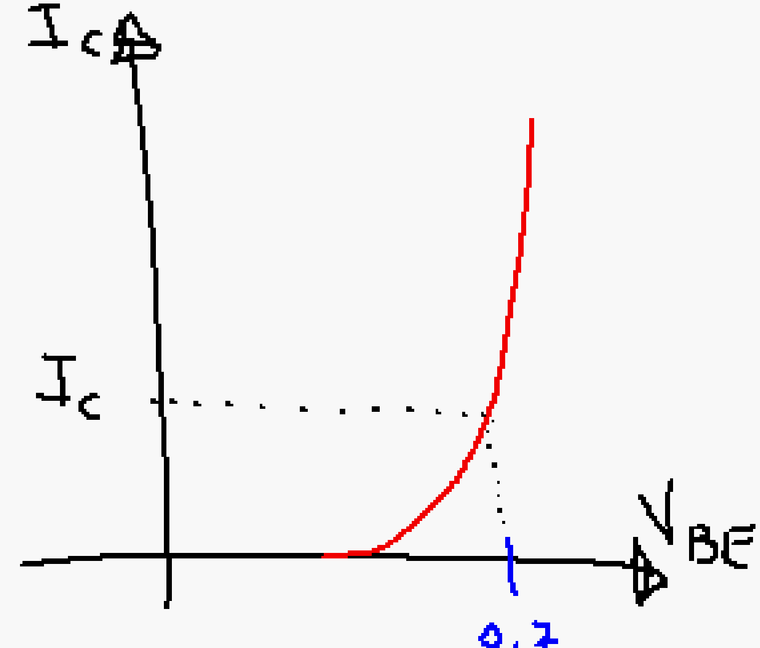

r_E





Circuito espejo de corriente



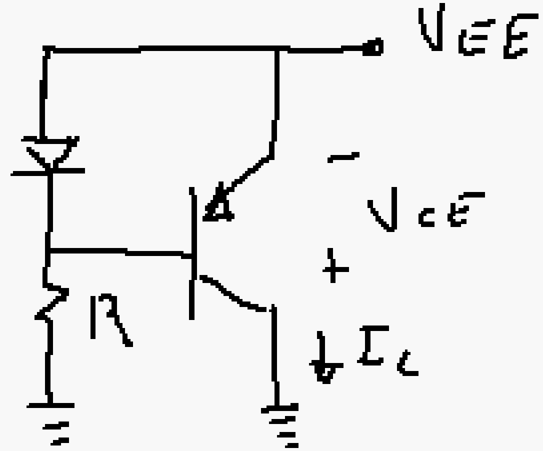


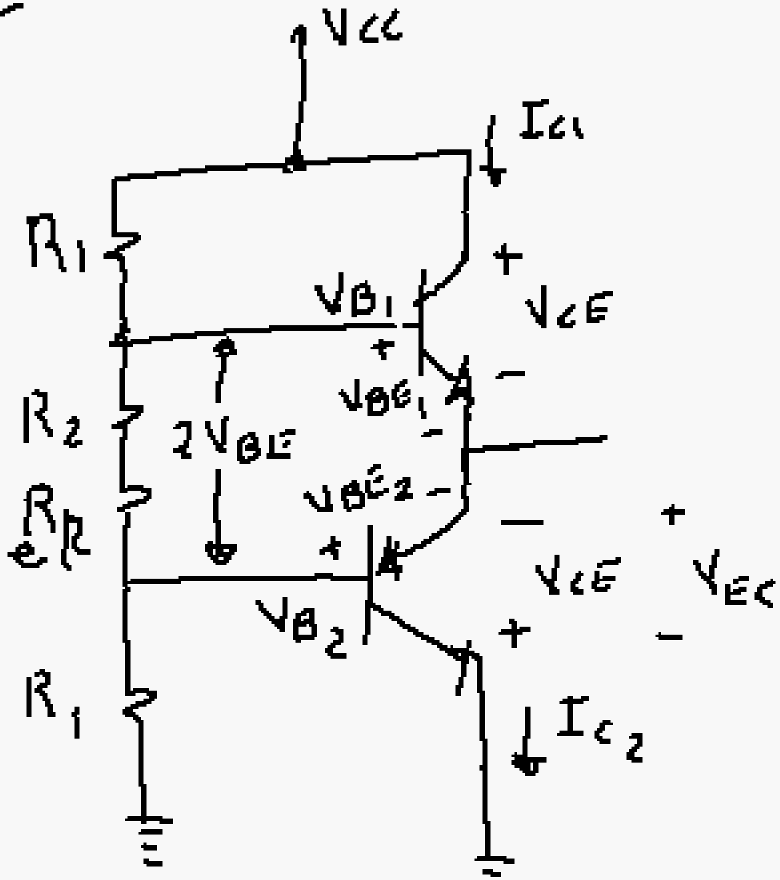
$I_2 = I_C$

$I_2 >> I_B$

$I_R = I_2 + I_B \Rightarrow I_1 \simeq I_2$

PNP





Punto de operación para el
para el amplificador clase B

$V_{CE} = \frac{1}{2} V_{CC}$

$V_{BE_1} = 0.7\,V$

$V_{BE_2} = -0.7\,V$

$V_{BE} = V_B - V_E$

$V_{B_1} = V_{BE_1} + V_{E_1}$

pero $V_{E_1} = V_{E_2} = V_{EC_2} = V_{CE_1}$

$\boxed{V_{B_1} = 0.7 + \frac{1}{2} V_{CC}}$

$V_{B_2} = V_{BE_2} + V_{E_2}$

$\boxed{V_{B_2} = -0.7 + \frac{1}{2} V_{CC}}$

$$V_{B_1} - V_{B_2} = 0.7 + \frac{1}{2}V_{cc} - \left(-0.7 + \frac{1}{2}V_{cc}\right)$$

$$V_{B_1} - V_{B_2} = 2(0.7) = 2\left|V_{BE}\right|$$

$$V_{R_1} = I_{R_1}R_1 = V_{cc} - V_{B_1} = V_{cc} - 0.7 - \frac{1}{2}V_{cc}$$

$$\boxed{V_{R_1} = \frac{1}{2}V_{cc} - 0.7 = V_{B_2}}$$

$$I_{R_1} = \frac{\frac{1}{2}V_{cc} - 0.7}{R_1} = \frac{V_{cc} - 2(0.7)}{2R_1}$$

$$\boxed{I_{R_1} = \frac{V_{cc} - 2V_{BE}}{2R_1}} \qquad I_{R_1} = I_{C_r}$$

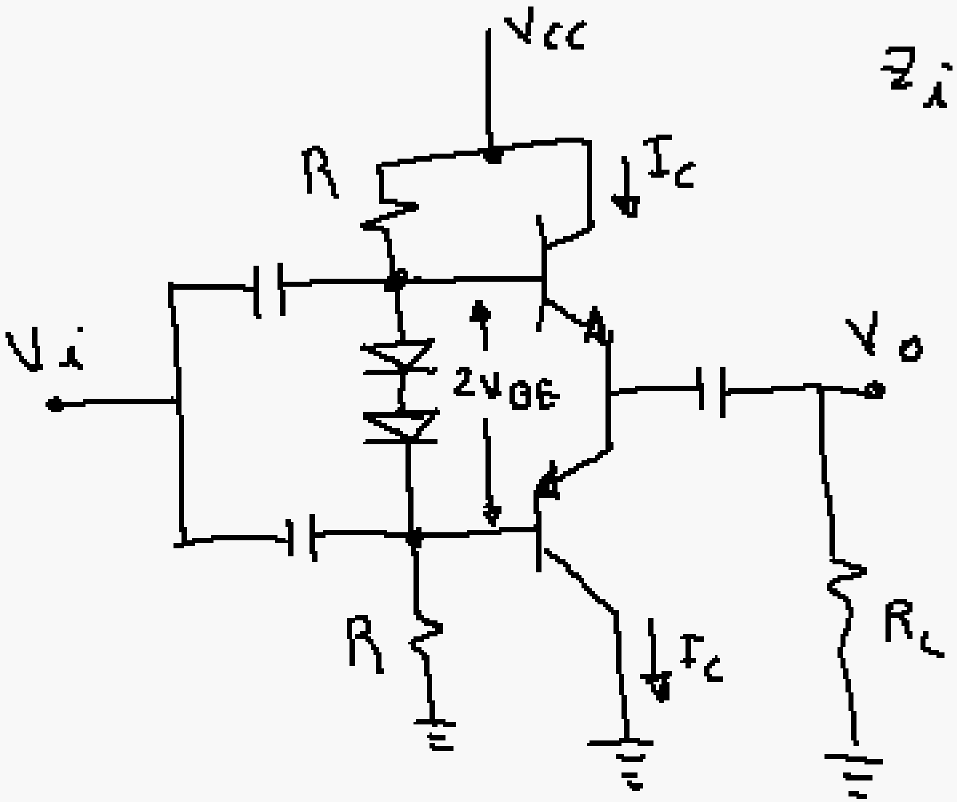
$$2V_{BE} = 2R_2 I_{C_r}$$

$$\boxed{R_2 = \frac{V_{BE}}{I_{C_r}}}$$

$$I_{cr} = (1\% - 5\%)\, I_{c\,sat}$$

$$I_{c\,sat} = \frac{V_{CEQ}}{r_E + r_C} \qquad r_E = R_L$$

Polarización por diodos



r_e

$$Z_i = R \parallel R \parallel \left(h_{FE}\left(r_E + R_e\right)\right)$$

$$A_v = \frac{r_E}{r_E + R_e} = \frac{R_L}{R_L + R_e}$$

Ganancia en potencia

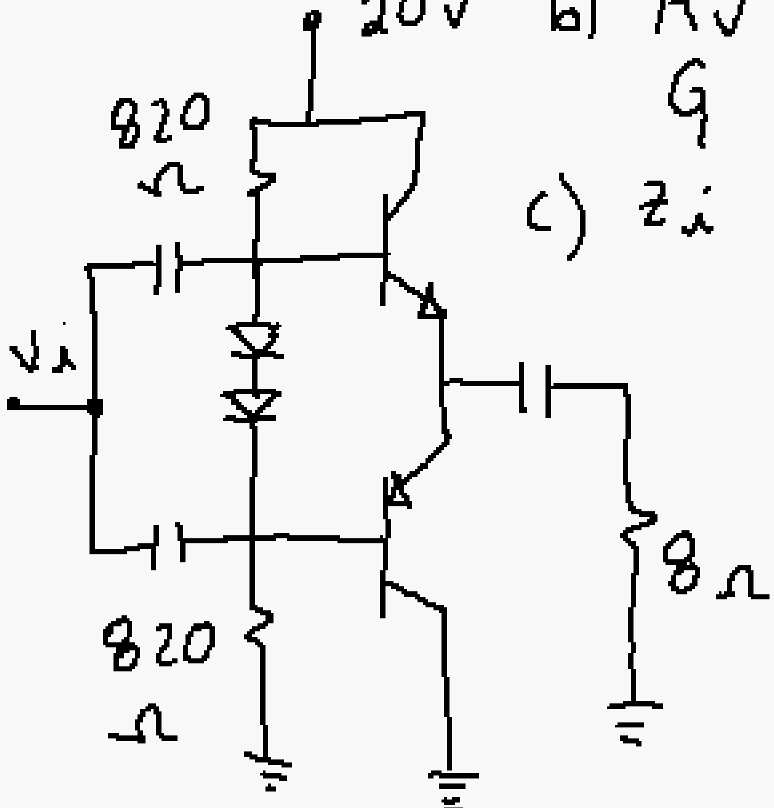
$$G = h_{FE}\left(\frac{R_L}{R_L + R_e}\right)$$

Ejemplo: a) I_{C_r}

b) A_v

G

c) z_i



$h_{FE} = 60$

$R_e = 0.5\,\Omega$

a) $I_R = I_{C_r} = \dfrac{V_{CC} - 2V_{BE}}{2R}$

$\boxed{I_{C_r} = 11.3\ mA}$ $\approx 1\%\ I_{C_{sat}}$

$I_{C_{sat}} = \dfrac{V_{CEQ}}{r_E + R_C} = \dfrac{10}{8}$

$\boxed{I_{C_{sat}} = 1.25\ A}$

b) $A_v = \dfrac{R_L}{R_L + R_e} = 0.94$

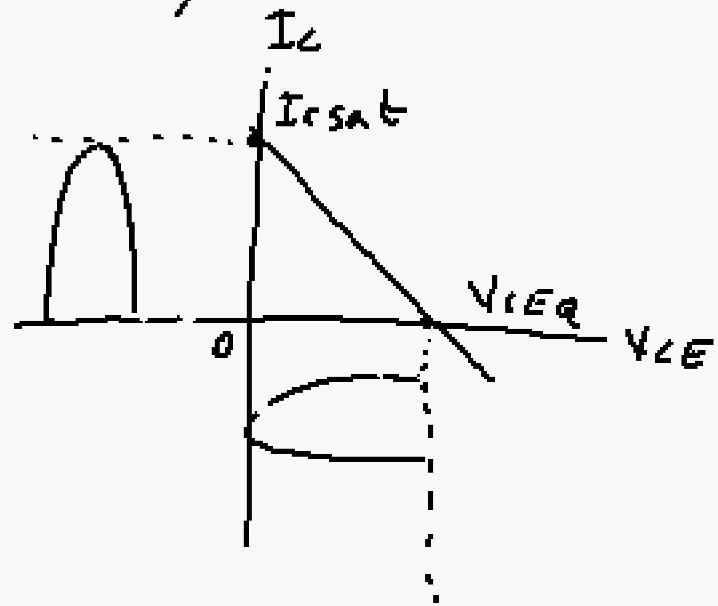
$G = h_{FE} A_v = 56.4$

c) $z_i = \frac{1}{2}R \,\|\, h_{FE}(r_E + R_e)$

$\boxed{z_i = 227.21\,\Omega}$

Potencia de salida (P_o)

$$\boxed{P_{o\,MAX} = \frac{V_{CEQ}\, I_{Csat}}{2}}$$



Eficiencia (η)

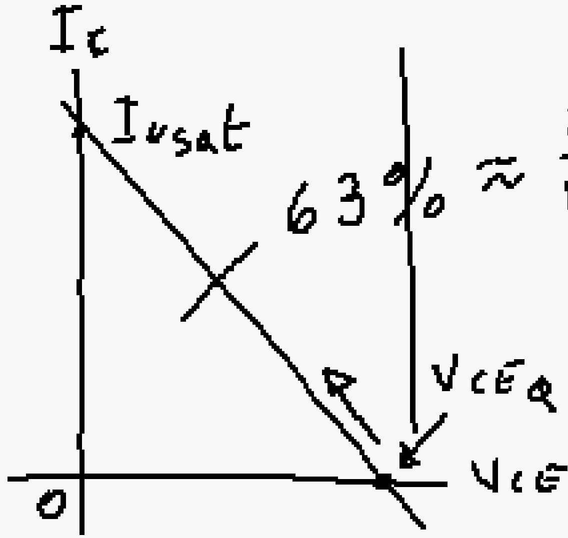
$$\eta = \frac{P_o}{P_{DC}} \times 100 \qquad P_{DC} = \frac{V_{CC}\, I_{Csat}}{\pi}$$

pero $V_{CEQ} = \frac{1}{2} V_{CC}$

$$\eta = \frac{\frac{V_{CEQ}\, I_{Csat}}{2}}{\frac{V_{CC}\, I_{Csat}}{\pi}} = \frac{\frac{V_{CC}\, I_{Csat}}{4}}{\frac{V_{CC}\, I_{Csat}}{\pi}} = \frac{\pi}{4} = 0.785 \Rightarrow 78.5\%$$

pero $V_{CEQ} = \frac{1}{2} V_{CC}$

Potencia disipada (P_D)



$63\% \approx \frac{2}{\pi}$

$$P_{D_{MAX}} = \frac{\left(\frac{2}{\pi}\frac{V_{CEQ}}{\sqrt{2}}\right)\left(\frac{2}{\pi}\frac{I_{Csat}}{\sqrt{2}}\right)}{2}$$

$$P_{D_{MAX}} = \frac{V_{CEQ}\, I_{Csat}}{\pi^2}$$

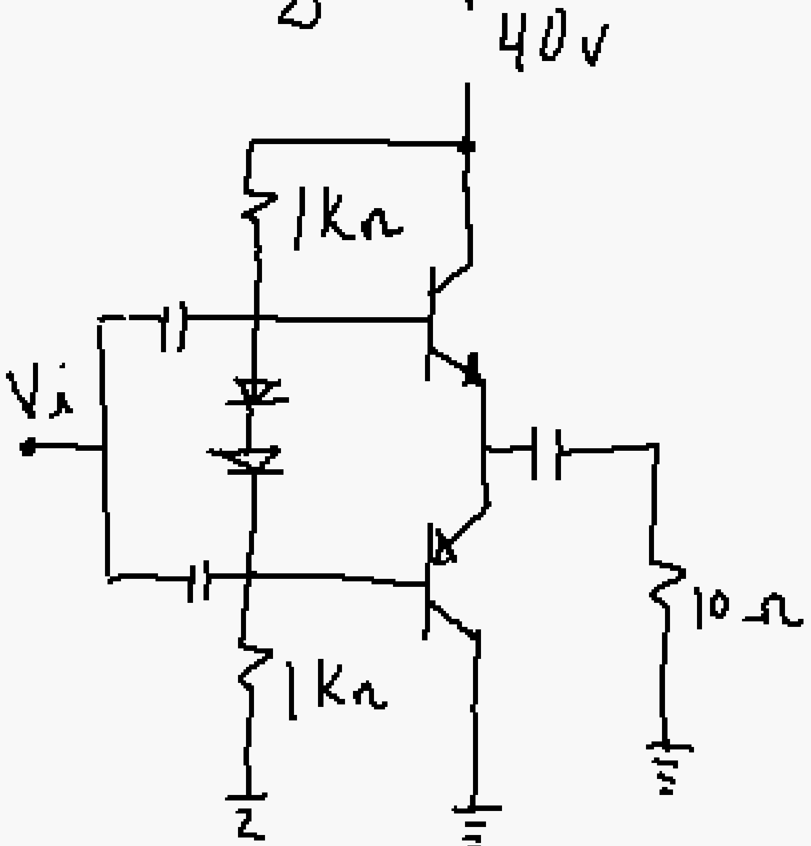
$$P_{D_{MAX}} \cong \frac{V_{CEQ}\, I_{Csat}}{10}$$

Si $P_o = \frac{V_{CEQ}\, I_{Csat}}{2}$ $\Rightarrow$ $P_D = \frac{2\, P_o}{10}$

entonces

$$\boxed{P_{D_{MAX}} = \frac{P_o}{5}}$$

Ejemplo



Obtener $P_{o\,max}$, $P_{D\,max}$

$P_{o\,max}$

$P_{D\,max}$

η

$$P_{o\,max} = \frac{V_{CEQ}\, I_{Csat}}{2}$$

$$V_{CEQ} = \frac{1}{2} V_{CC} = \frac{40}{2} = 20$$

$$I_{Csat} = \frac{V_{CEQ}}{r_E}$$

$$P_{o\,max} = \frac{V_{CEQ}^2}{2 r_E} = \frac{(20)^2}{2(10)}$$

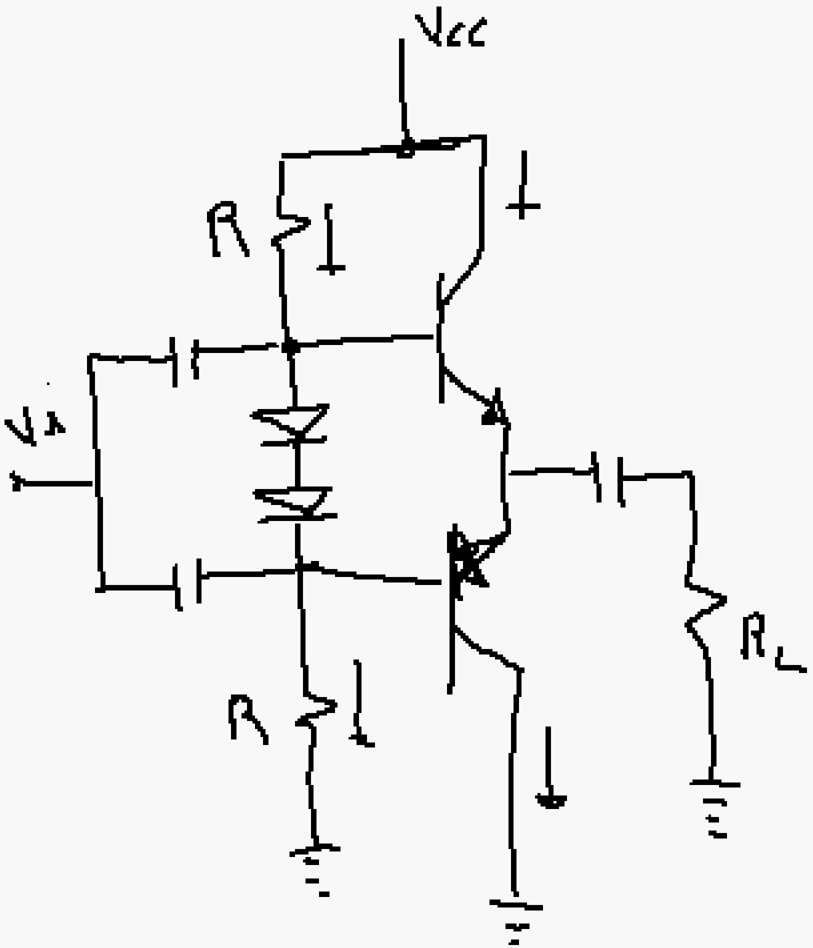
$$\boxed{P_{o\,max} = 20\ W}$$

$$\boxed{P_{D\,max} = \frac{20}{5} = 4\ W}$$

$$\eta = 78.5\%$$

Ejemplo

Diseñar un amplificador clase B en oposición de fase de 25 W de salida para una carga de 8 Ω.



$$P_o = \frac{V_{CEQ}\, I_{Csat}}{2}$$

$$I_{Csat} = \frac{V_{CEQ}}{r_E} = \frac{V_{CEQ}}{R_L} = 2.5\ A$$

$$P_o = \frac{V_{CEQ}^2}{2R_L} \quad \text{pero } V_{CEQ} = \frac{1}{2} V_{CC}$$

$$P_o = \frac{V_{CC}^2}{8R_L} \Longrightarrow \boxed{V_{CC} = 40\ V}$$

$$I_{Csat} = \frac{V_{CEQ}}{R_L} = \frac{20}{8} = 2.5\ A$$

$$I_{Cr} = (2.5\%)\, I_{Csat} = 62.5\ mA$$

$$I_{C_r} = \frac{V_{CC} - 2V_{BE}}{2R}$$

$$R = 308.8\ \Omega$$

$$P_{D_{max}} = \frac{25}{5} = 5\ W \qquad h_{FE} = 70$$

$$A_i = \frac{I_o}{I_i} \simeq h_{FE} = 70$$

$$I_i = \frac{2.5}{70} = 35.7\ mA$$

Ejemplo: Obtener

- P_O y P_D
- I_{CQ} en la etapa de salida
- A_V total considerando β_{CC} = 100 para todos los transistores y una R_e = 1Ω,
- Estimar la amplitud máxima de salida y amplitud máxima de entrada de la señal de AC.

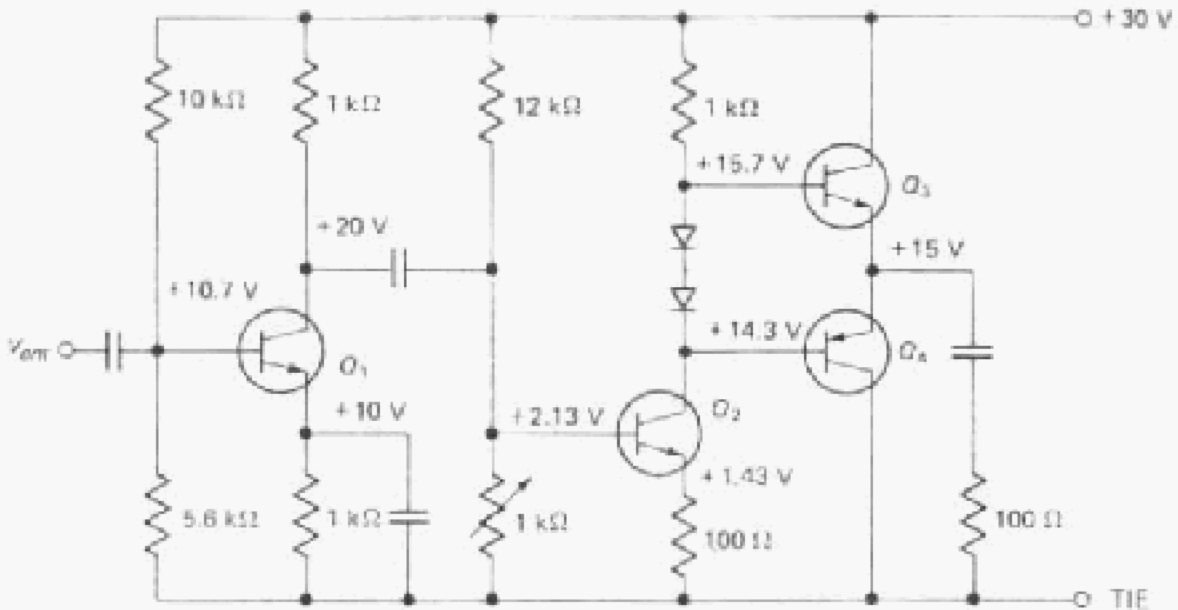


Figura 11-16. Ejemplo de un amplificador completo.

Solución

Datos: $h_{FE} = 100$, $R_e = 1\,\Omega$

a) P_o , P_D

$$P_o = \frac{V_{CEQ}\, I_{C\,sat}}{2} = \frac{V_{CEQ}^2}{2 r_E} = \text{pero } V_{CEQ} = \frac{1}{2} V_{CC}$$

$$\boxed{P_o = 1.125\, W}$$

$$\boxed{P_D = \frac{1.125}{.5} = 0.25\, mW}$$

b) $$I_{C_r} = \frac{1.43}{100} = 14.3\, mA$$

c) $$A_i = \frac{1k\Omega \| 12k\Omega \| 1k\Omega \| 100(100) +}{2.6}$$

$$\boxed{A_i = 176}$$

$$I_{R_A} = \frac{10}{1000} = 10\, mA$$

$$r_e = \frac{26\, mV}{10\, mA} = 2.6\, \Omega$$

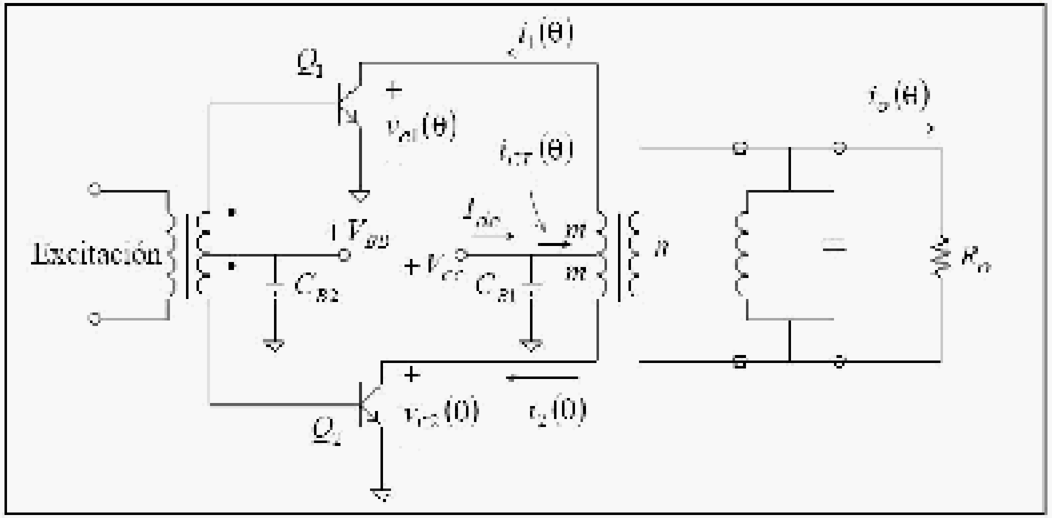
$$A_2 = \frac{r_c}{r_E} = \frac{1k\Omega \| 100(1+100)}{1+100} = 9$$

$$A_3 = \frac{R_L}{R_L + R_e} = \frac{100}{100+1} = 0.99$$

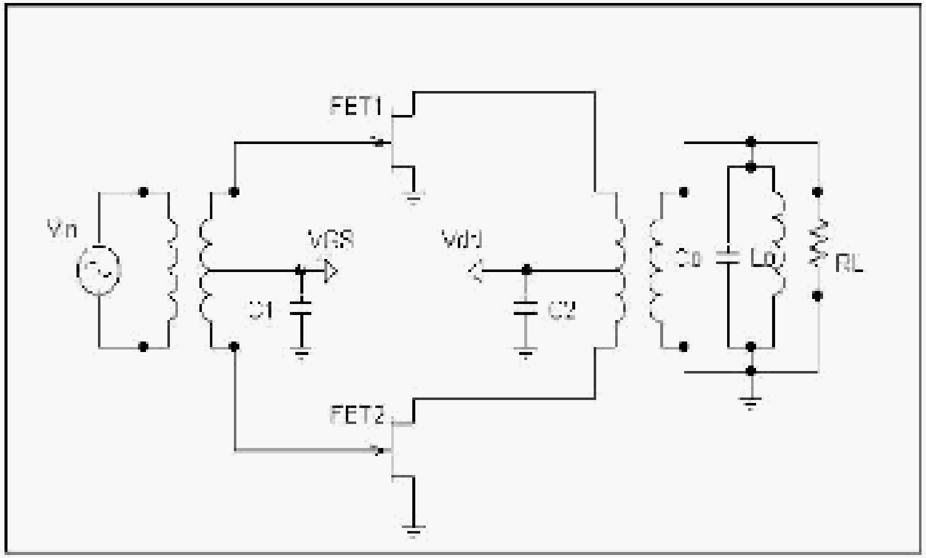
$$A_v = A_1 A_2 A_3 = 1568$$

d) $V_{CEQ} = \frac{1}{2} V_{CC} = 15v$ (Salida máx)

$$V_o = V_i A_v \Rightarrow V_i = \frac{V_o}{A_v} = 9.57\,mV$$



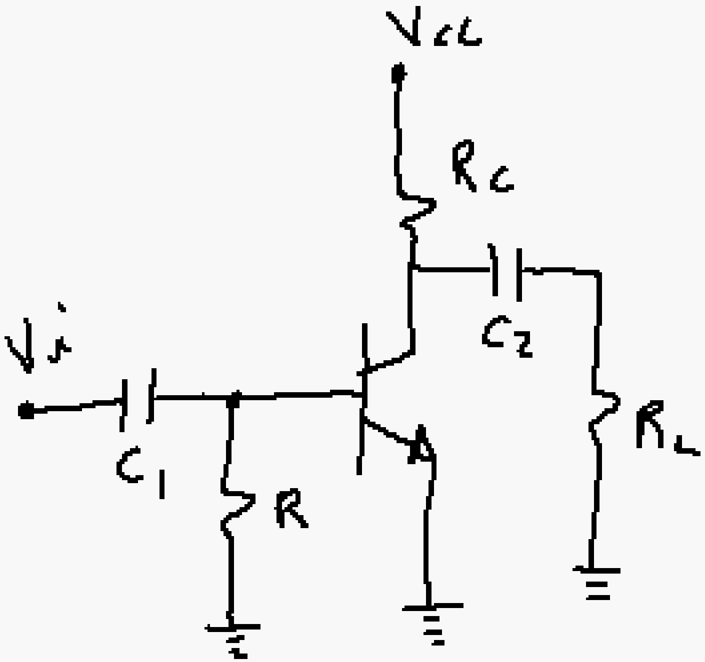
Q_1
$i_1(\theta)$
$v_{c1}(\theta)$
$i_o(\theta)$
$i_{cT}(\theta)$
Excitación
V_{BB}
I_{dc}
$+V_{CC}$
C_{B2}
C_{B1}
m
m
n
R_o
Q_2
$v_{c2}(\theta)$
$i_2(\theta)$

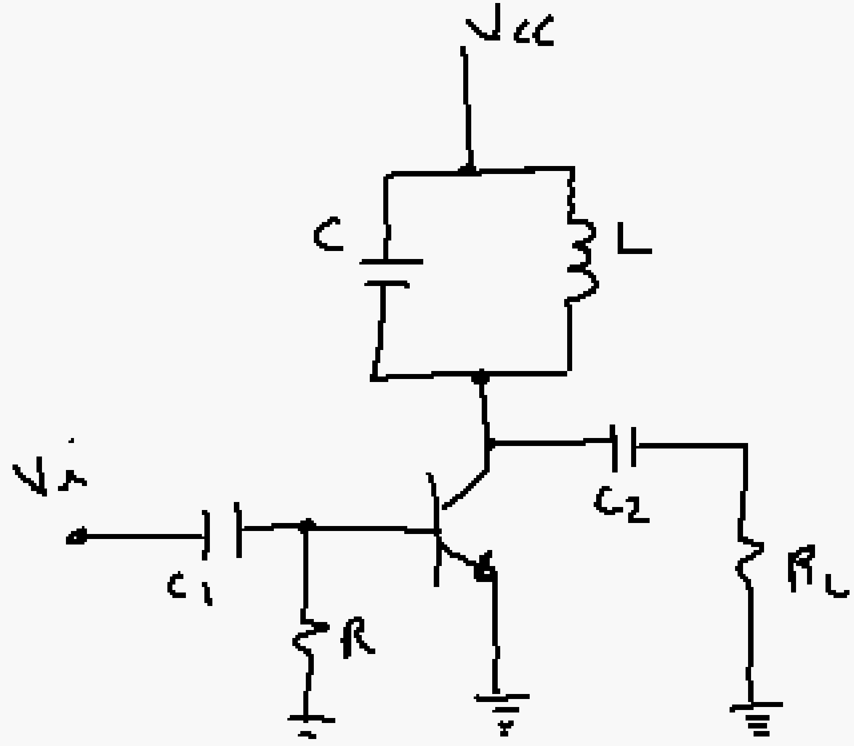


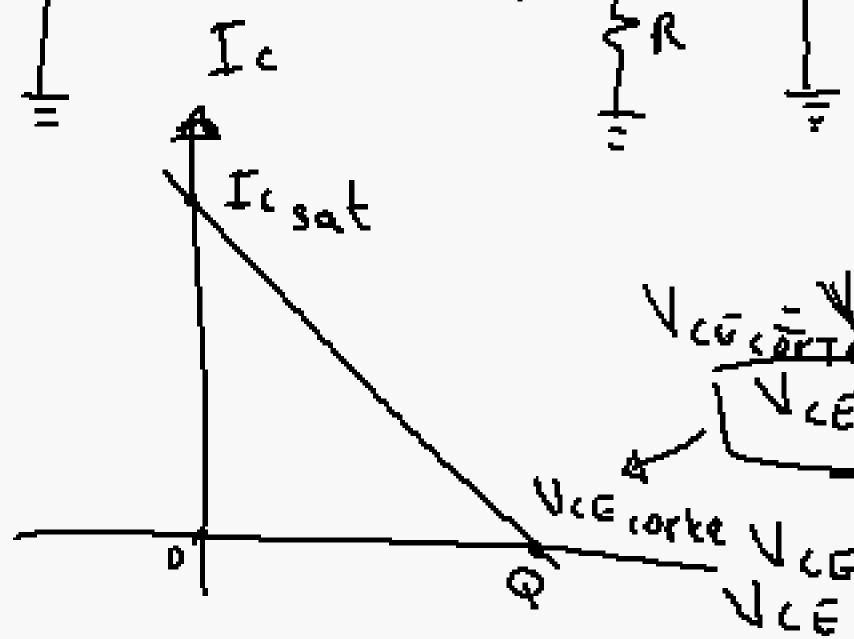
FET1
Vin
VGS
Vdd
C1
C2
C0
L0
RL
FET2

Amplificadores clase C

- La corriente del colector circula menos de 180° de la señal de AC



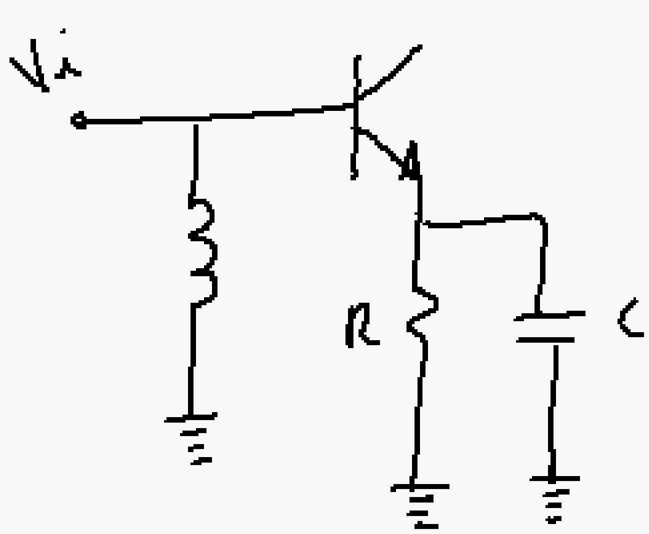


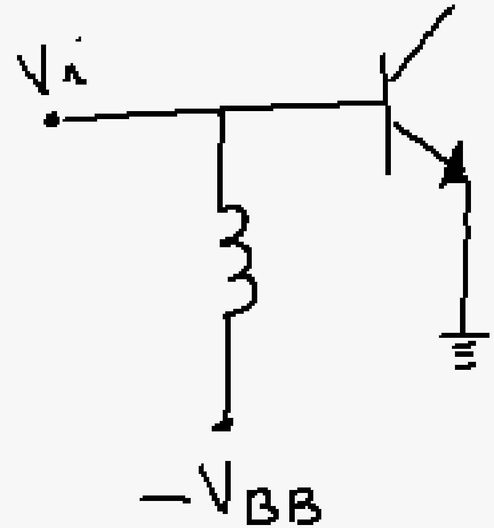


$$I_{c_{sat}} = \frac{V_{CE_Q}}{r_C}$$

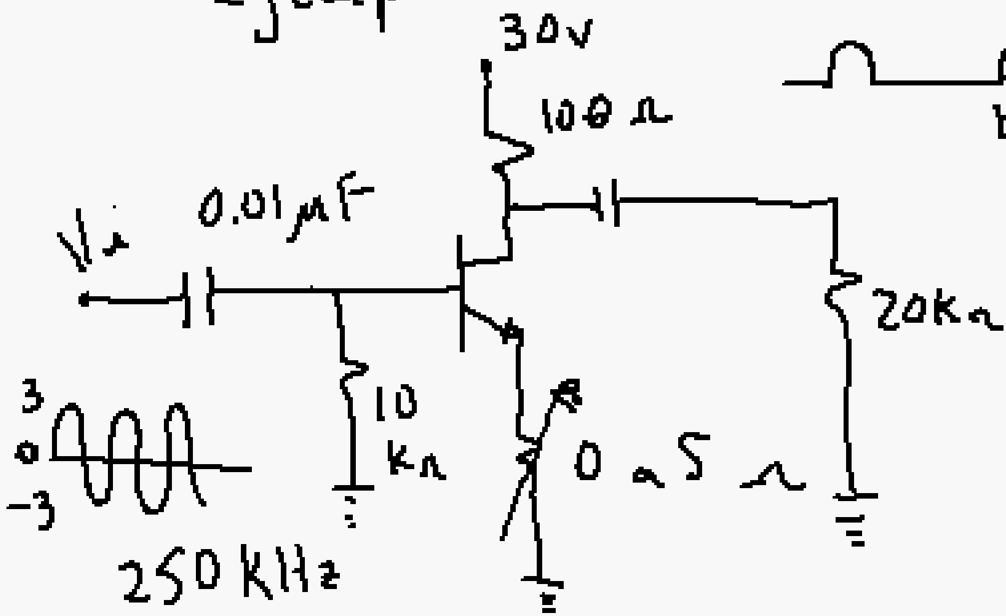
$$V_{CE_{corte}} = \cancel{V_{CE_{corte}}} - I_C R_C$$

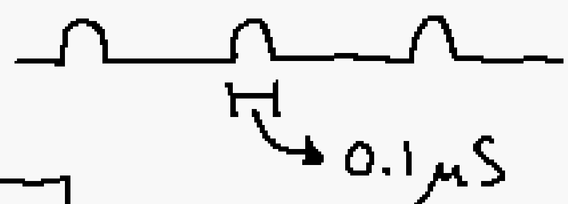
$$\boxed{V_{CE_{cT}} = V_{CC}}$$





Ejemplo:



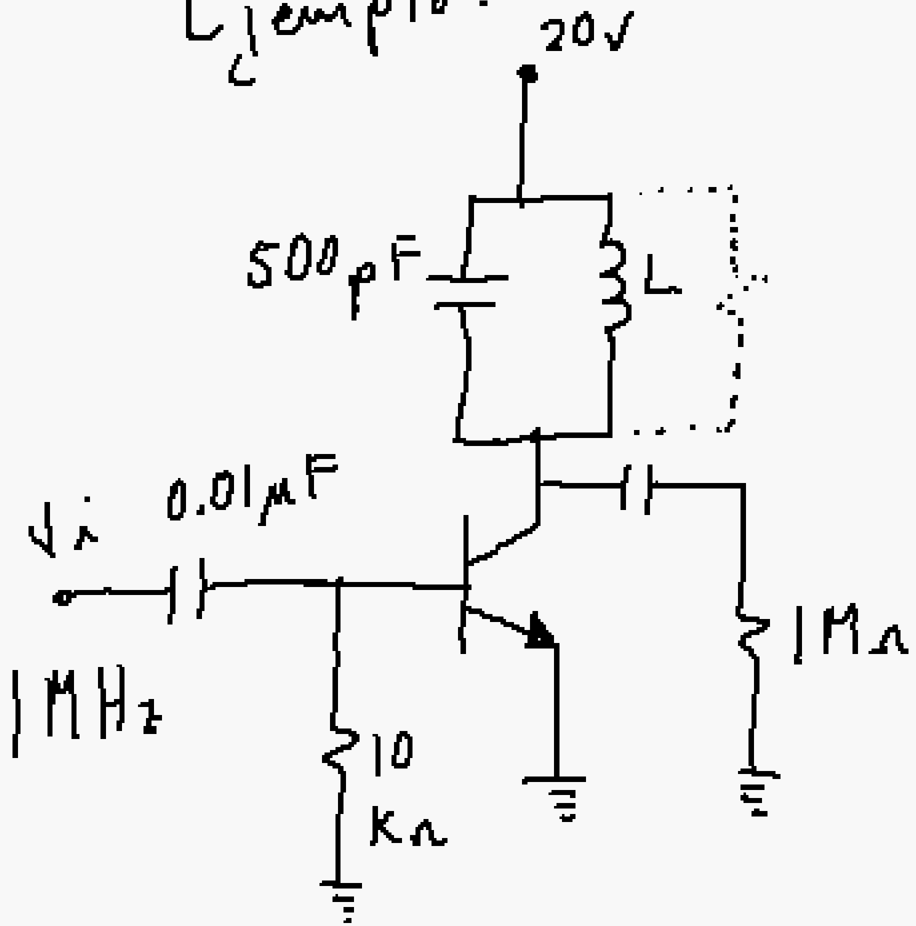


a) Recta de carga

b) CT de la forma de onda de salida.

c) Dibujar forma de onda de la base del tr.

Ejemplo:



a) Obtener el valor de L para 1 MHz

b) Si el inductor tiene una resistencia serie de 10Ω a 1 MHz, obtener la Q del circuito.

Solución

a) $$L = \frac{1}{4\pi^2 f^2 C}$$

$$\boxed{L = 50.66\,\mu H}$$

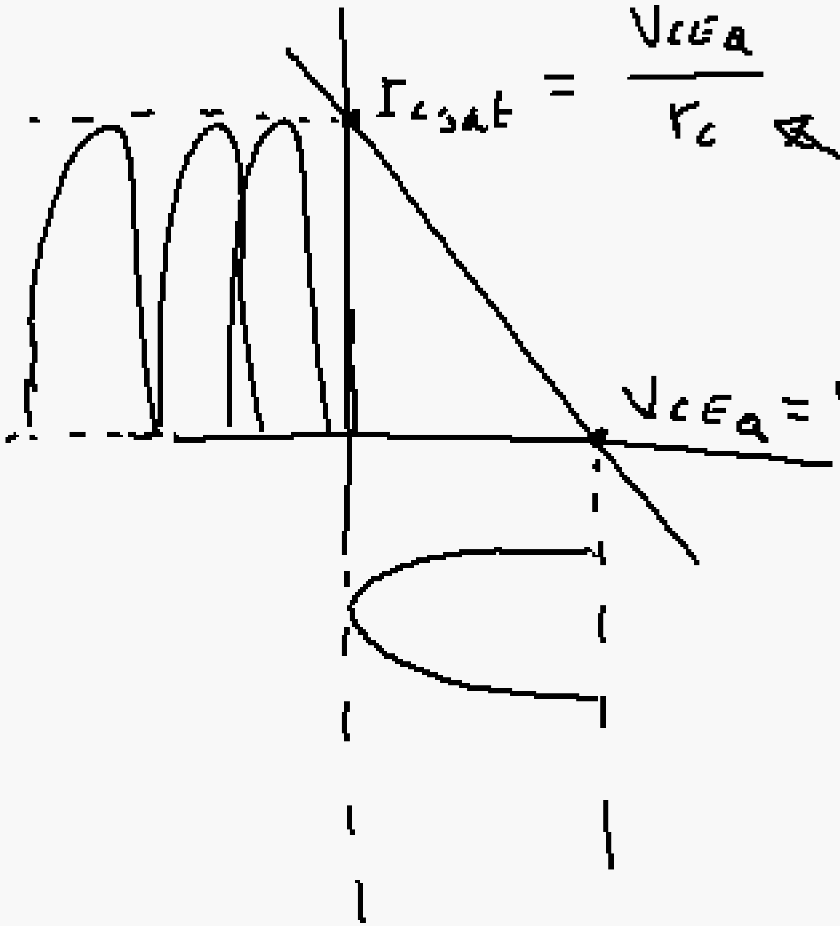
b) $$Q_L = \frac{\omega L}{R_s}$$

$$Q = \frac{R_{sh}}{\omega L}$$

$$Q_L = \frac{R_p}{\omega L} \Rightarrow R_p = Q\omega L$$

$$R_{sh} = R_p \| R_L$$

Potencia de salida



$$I_{csat} = \frac{V_{CEQ}}{r_c}$$

$$P_{o\,máx} = \frac{V_{CEQ}\, I_{csat}}{2}$$

pero

entonces

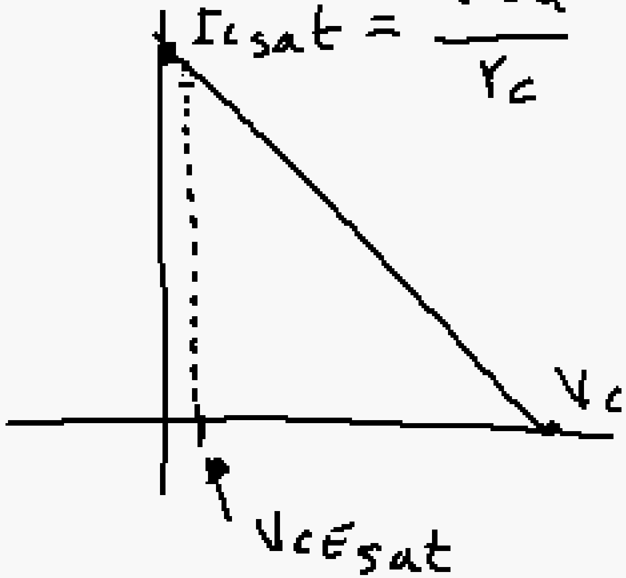
$V_{CEQ} = V_{CC}$

$$\boxed{P_{o\,max} = \frac{V_{CC}^2}{2 r_c}}$$

donde $r_c = R_p \| R_L$

Potencia disipada

$$I_{Csat} = \frac{V_{CEQ}}{r_c}$$



$$\boxed{P_D \cong \frac{V_{CEsat}\, V_{CC}}{2 r_c}}$$

Potencia disipada mínima

Peor caso, potencia de disipación máxima (50% de la recta de carga)

$$P_D = \frac{I_{sat}\, V_{CC}}{2\sqrt{2}\; 2\sqrt{2}} = \frac{I_{sat}\, V_{CC}}{8}$$

$$\boxed{P_D = \frac{V_{CC}^2}{8 r_c}}$$

$$\frac{P_D}{P_{o_{max}}} = \frac{\frac{V_{CEsat} V_{CC}}{2 r_c}}{\frac{V_{CC}^2}{2 r_c}} = \frac{V_{CEsat}}{V_{CC}}$$

por lo que:

$$\boxed{P_D = \frac{V_{CEsat}}{V_{CC}} P_{o_{max}}}$$

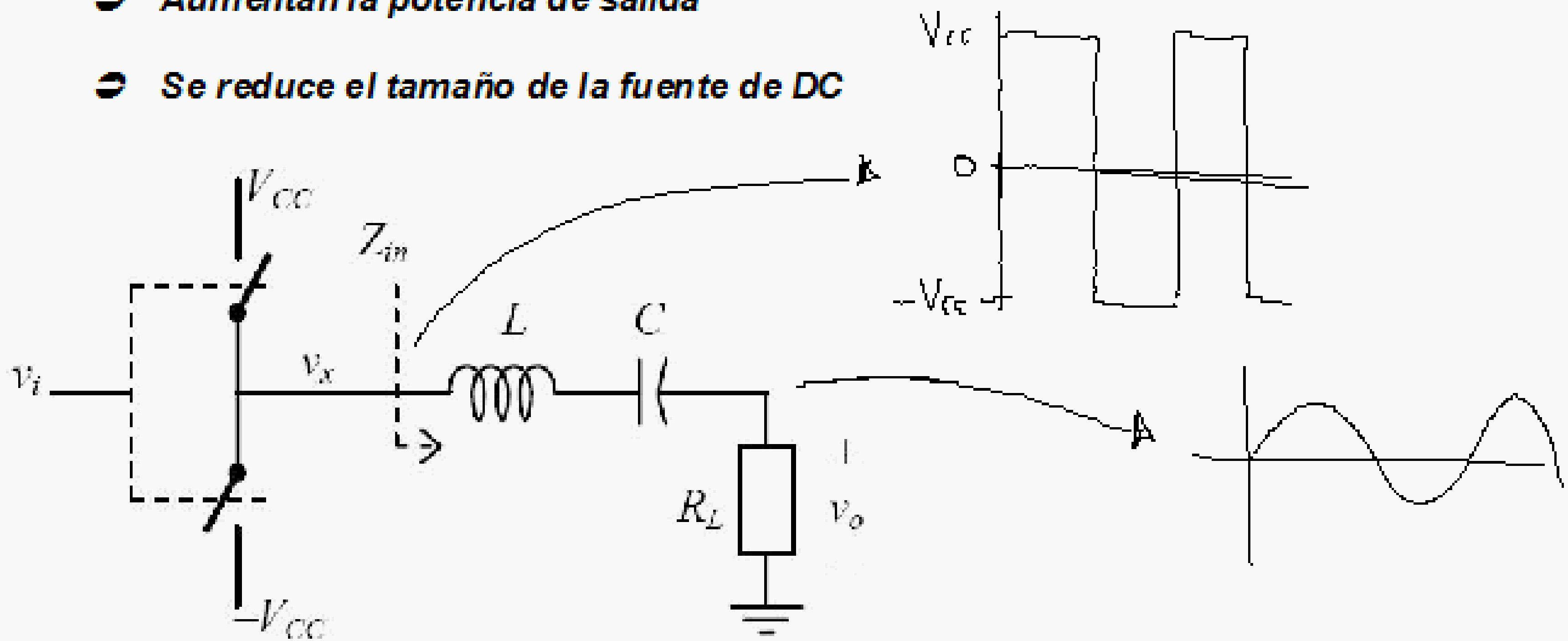
Eficiencia

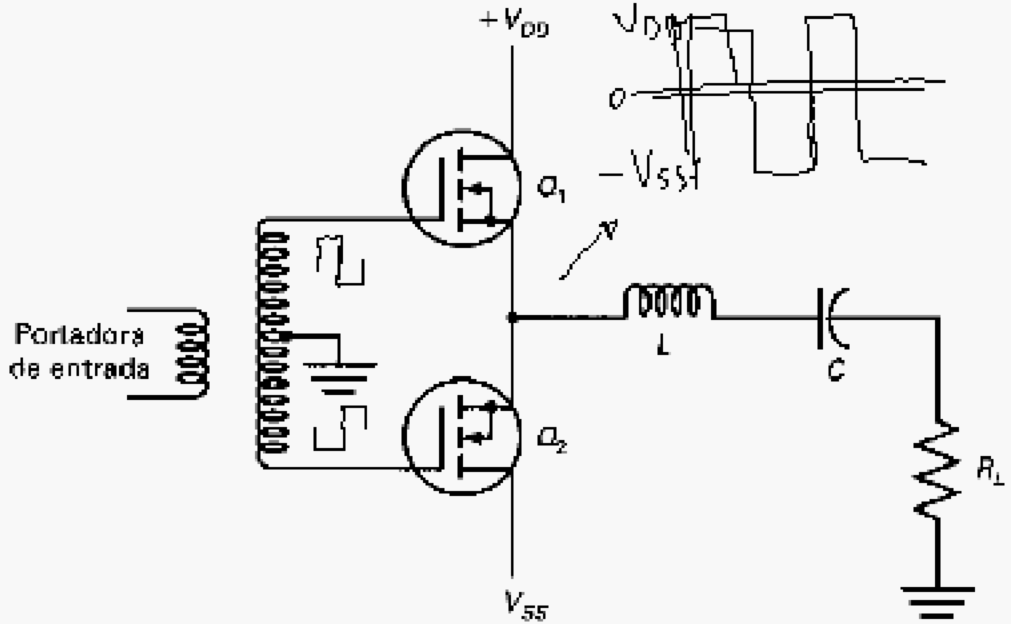
$$P_{DC} = P_{o_{max}} + P_D$$

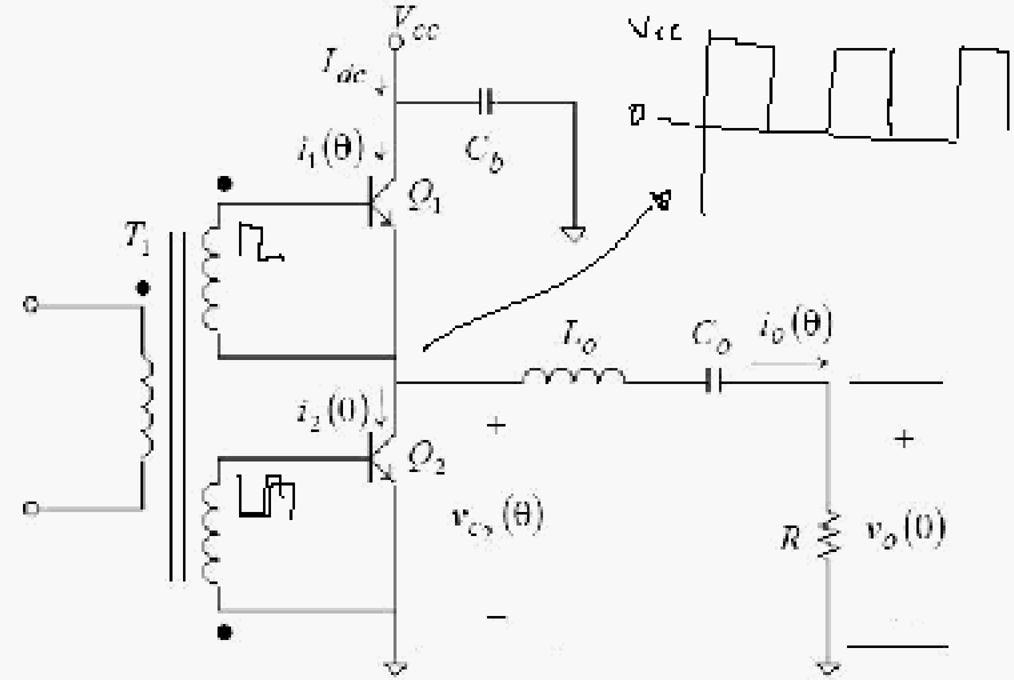
entonces $\eta = \frac{P_{o_{máx}}}{P_{DC}} = \frac{P_{o_{max}}}{P_{o_{max}} + P_D} = \frac{V_{CC}}{V_{CC} + V_{CEsat}}$

Amplificador clase D

- Amplificadores por conmutación
- Los dispositivos activos se utilizan como interruptores en lugar de fuente de corriente
- Mejoran la eficiencia
- Aumentan la potencia de salida
- Se reduce el tamaño de la fuente de DC







$$V_{c2} = \frac{1}{2}V_{cc} + \frac{1}{2}V_{cc}\,S(\theta)$$

donde $S(\theta) = \frac{4}{\pi}\left(\text{sen}\,\theta + \frac{1}{3}\text{sen}\,3\theta + \frac{1}{5}\text{sen}\,5\theta + \ldots\right)$

$$V_o(\theta) = \frac{1}{2}V_{cc}\frac{4}{\pi}\,\text{sen}\,\theta = \frac{2V_{cc}}{\pi}\,\text{sen}\,\theta$$

$$i_o(\theta) = \frac{2V_{cc}}{\pi R_L} \operatorname{sen}\theta$$

Potencia de salida

$$P_o = \frac{V_o}{\sqrt{2}} \frac{i_o}{\sqrt{2}} = \frac{1}{2} \frac{V_o^2}{R_L}$$

$$\boxed{P_o = \frac{1}{2R_L}\left(\frac{2V_{cc}}{\pi}\right)^2 = \frac{2V_{cc}^2}{R_L \pi^2}}$$

Las corrientes en los colectores son medias sinoides con valor pico de $\frac{2V_{cc}}{\pi R_L}$

La corriente de entrada es el promedio de $\frac{2V_{cc}}{\pi R_L}$, es decir

$$I_{DC} = \frac{\frac{2V_{cc}}{\pi R_L}}{\pi} = \frac{2V_{cc}}{\pi^2 R_L}$$

entonces:

$$\boxed{P_{DC} = V_{cc} I_{DC} = \frac{2V_{cc}^2}{\pi^2 R_L}}$$

por tanto

$$\boxed{\eta = \frac{P_o}{P_{DC}} = 100\%}$$

Ejemplo:

Determinar V_{cc} e I_{DC} para un amplificador de potencia clase D de voltaje complementario para que proporcione 25 W a una carga de 50 Ω

Solución

Si $P_o = \frac{2V_{cc}^2}{\pi^2 R} \Rightarrow V_{cc} = \sqrt{\frac{\pi^2 P_o R}{2}} = 78.53 \text{ V}$

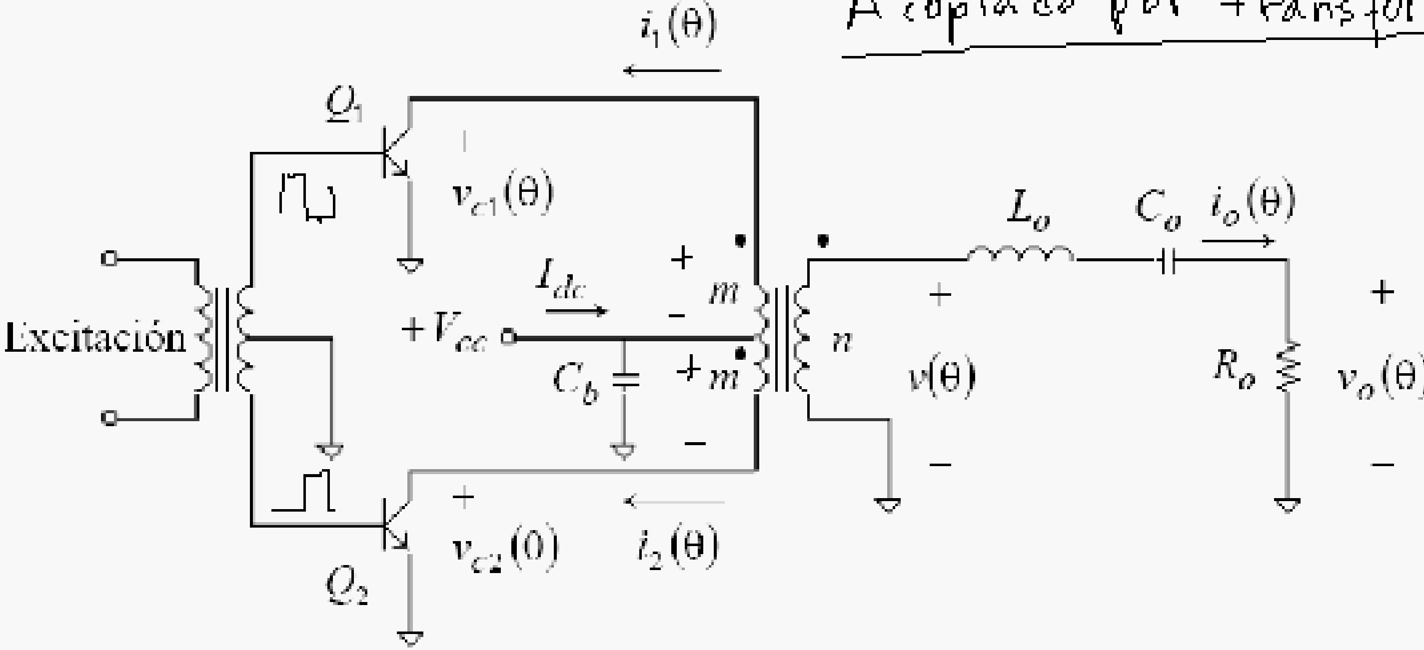
$\Downarrow$

BV_{CBO}

Voltaje de ruptura

$I_{DC} = \frac{2V_{cc}}{\pi^2 R} \simeq 0.318 \text{ mA}$

Acoplado por transformador



Cuando Q_2 se satura $\Rightarrow \frac{n}{m} V_{cc}$

Cuando Q_1 se satura $\Rightarrow -\frac{n}{m} V_{cc}$

$$V(\theta) = \frac{n}{m} V_{cc}\, S(\theta) = \frac{n}{m} V_{cc} \frac{4}{\pi}\left(\operatorname{sen}\theta + \frac{1}{3}\operatorname{sen}3\theta + \cdots\right)$$

$$\boxed{V_o(\theta) = V_{cc}\,\frac{n}{m}\,\frac{4}{\pi}\,\operatorname{sen}\theta}$$ pero $i_o(\theta) = \dfrac{V_o(\theta)}{R_o}$

Potencia de salida es:

$$\boxed{P_o = \frac{V_o}{\sqrt{2}}\,\frac{i_o}{\sqrt{2}} = \frac{1}{2}\,\frac{V_o^2}{R_o} = \frac{8}{R_o}\left(\frac{V_{cc}}{\pi}\,\frac{n}{m}\right)^2}$$

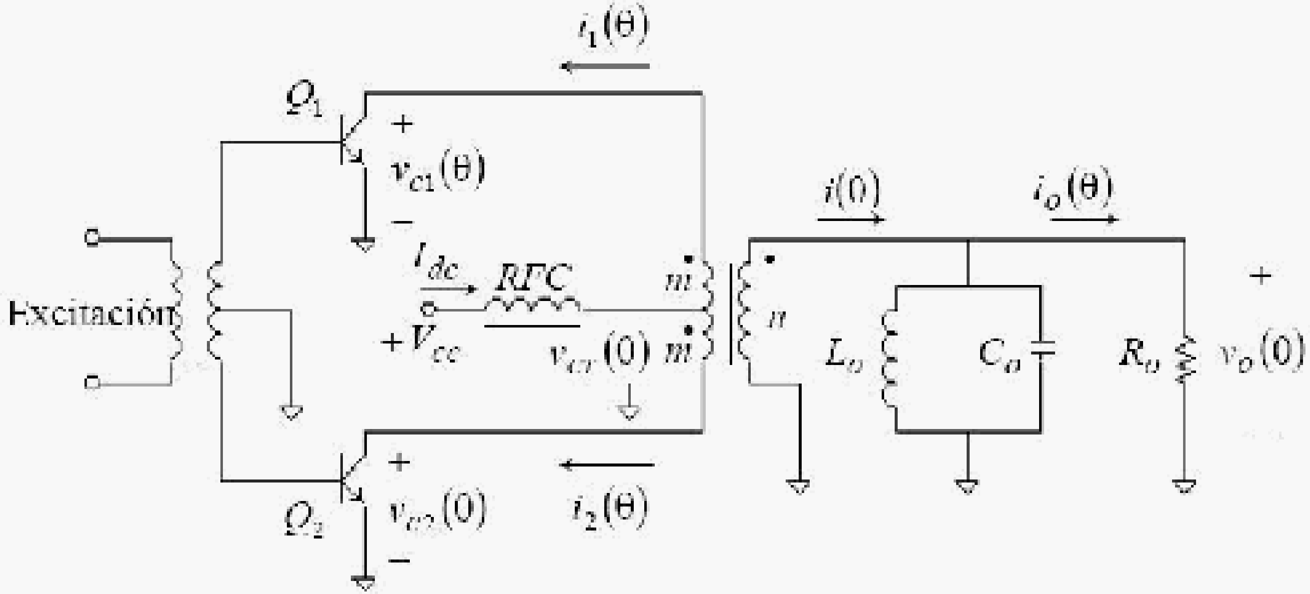
Si $I_C = i_o\,\dfrac{n}{m}$ e $I_{DC} = \dfrac{2\,I_C}{\pi}$

entonces.

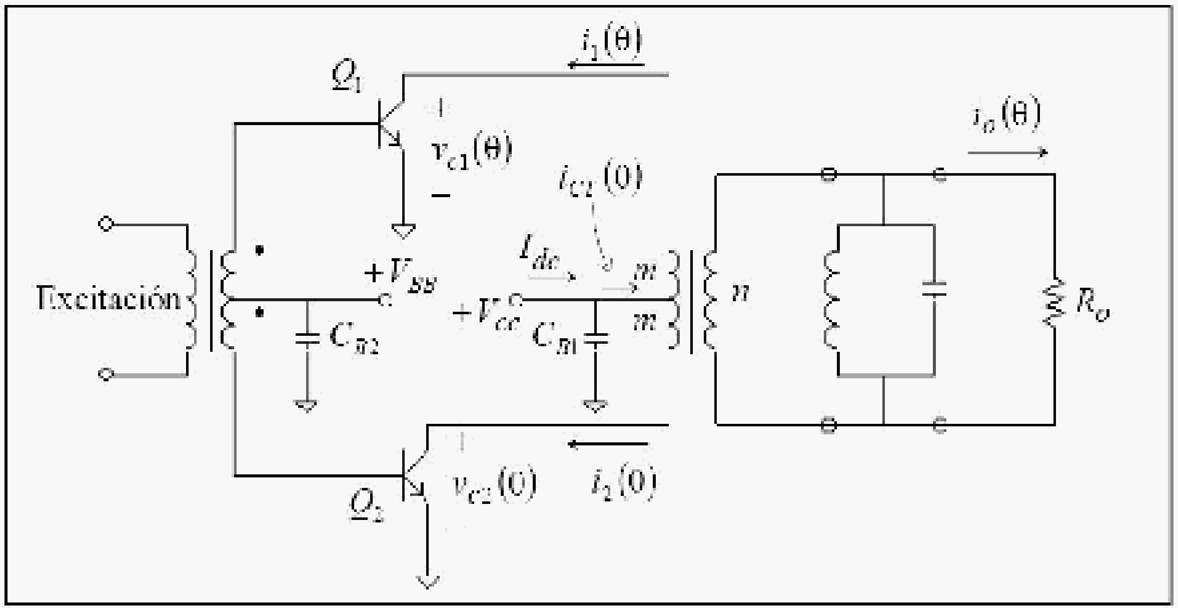
$$\boxed{I_{DC} = \frac{8\,V_{cc}}{R_o\,\pi^2}\,\frac{n^2}{m^2}}$$

$$\boxed{P_{DC} = V_{cc} I_{DC} = \frac{8}{R_o}\left(\frac{V_{cc}}{\pi}\,\frac{n}{m}\right)^2}$$

$$\boxed{\eta = \frac{P_o}{P_{DC}} = 100\%}$$

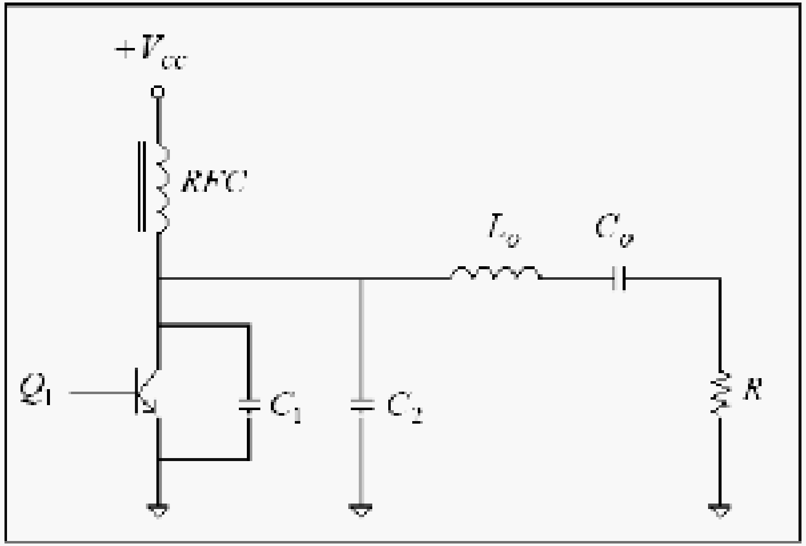


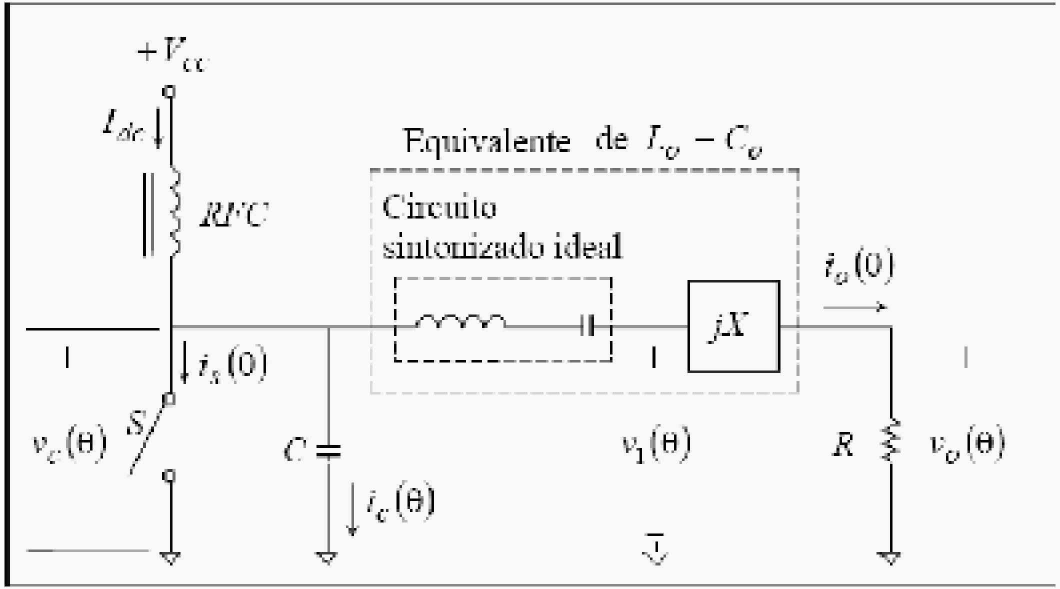
$i_1(\theta)$
Q_1
$v_{c1}(\theta)$
$i(\theta)$
$i_o(\theta)$
I_{dc}
RFC
m
m
n
Excitación
$+V_{cc}$
$v_{cr}(\theta)$
L_o
C_o
R_o
$v_o(\theta)$
Q_2
$v_{c2}(\theta)$
$i_2(\theta)$



$i_1(\theta)$
Q_1
$v_{c1}(\theta)$
$i_{C1}(\theta)$
$i_o(\theta)$
I_{dc}
$+V_{BB}$
m
m
n
Excitación
$+V_{cc}$
C_{B2}
C_{B1}
R_o
Q_2
$v_{c2}(\theta)$
$i_2(\theta)$

Amplificadores clase E





C: Capacitor en derivación
- C_1: Capacitor inherente al transistor
- C_2: Capacitor externo