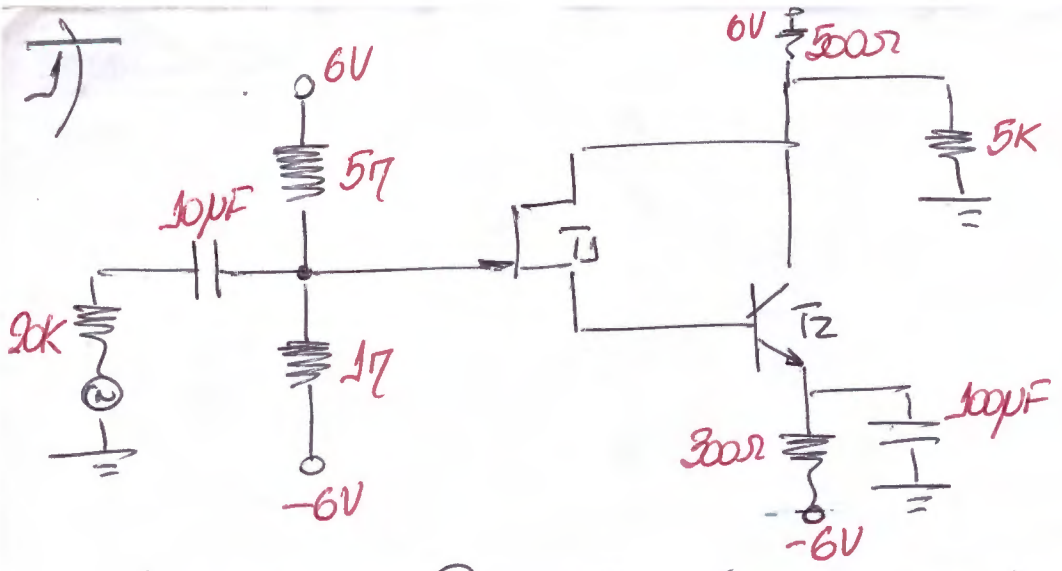
1)



$I_{DSS} = 8mA$
$V_P = -2V$
$\beta = 100$
$r_x \approx 0$
$C_{gs} = 6pF$
$C_{gd} = 2pF$
$C_\mu = 1pF$
$f_T = 300MHz$

a) ANALIZAR POR INSPECCIÓN CUÁL O CUALES PODRIAN SER LOS POLOS DOMINANTES PARA f_h. OBTENER f_h.

b) OBTENER f_l Y REALIZAR UN BODE DE AMPLITUD Y FASE APROXIMADOS PARA A_{vs} INDICANDO TODOS LOS PUNTOS RELEVANTES.

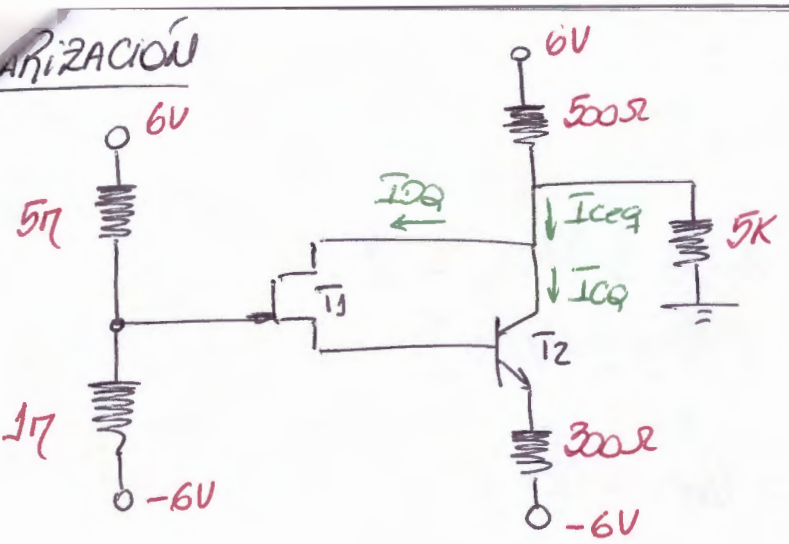
2) SE TIENE UN PAR DIFERENCIAL DE CANAL P (T1-T2) CON FUENTE ESPEJO SIMPLE COMO CARGA ACTIVA (T3-T4) Y FUENTE DE CORRIENTE CASCODE CON $R_{ref} = 12K$. ALIMENTACIÓN $\pm V_{DD} = 9V$
TODOS LOS TRANSISTORES SON DE CANAL INDUCIDO.

$|V_T| = 1V$; $|K'| = 250 \mu A/V^2$; $W/L = 1$; $\lambda = 0{,}01 V^{-1}$

a) HALLAR RRMC.

b) HALLAR A_{vc}, A_{vd} Y RRMC EN dB

ARIZACIÓN



$$I_{CEQ} = I_{CQ} + I_{DQ}$$

$$I_{DQ} = I_{BQ} = \frac{I_{CQ}}{\beta}$$

$$\Rightarrow I_{CEQ} = I_{CQ}\left[1 + 1/\beta\right]$$

$$\boxed{I_{CEQ} \approx I_{CQ}}$$

TENSIÓN DE SOURCE:

$$V_{SQ} = -6V + I_{CQ}\,300\Omega + 0{,}7V = -5{,}3V + I_{CQ}\,300\Omega$$

TENSIÓN DE GATE:

$$V_{GQ} = 12V\,\frac{1M}{1M+5M} - 6V = -4V \quad \Rightarrow V_{GSQ} = 1{,}3V - I_{CQ}\,300$$

CORRIENTE DE DRAIN.

$$I_{DQ} = \frac{I_{CQ}}{\beta} = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2$$

$$\frac{I_{CQ}}{\beta} = \frac{I_{DSS}}{V_P^2}\left(V_P - V_{GSQ}\right)^2 = \frac{I_{DSS}}{V_P^2}\left(V_P - 1{,}3V + I_{CQ}\,300\right)^2$$

$$5\,I_{CQ} = \left(-3{,}3V + I_{CQ}\,300\right)^2$$

$$5\,I_{CQ} = 10{,}89 + I_{CQ}^2\,90.000 - I_{CQ}\,1980$$

$$0 = I_{CQ}^2(90.000) + I_{CQ}(-1985) + (10{,}89)$$

$$\frac{1985 \pm 141}{180.000} \quad \rightarrow I_{CQ} = 11{,}8\,mA \Rightarrow V_{GSQ} = -2{,}24V \;\times$$

$$\rightarrow I_{CQ} = 10{,}24\,mA \Rightarrow V_{GSQ} = -1{,}77V \;\checkmark$$

$$\Rightarrow I_{CQ} = 10{,}24\,mA \;\wedge\; I_{DQ} \approx 0{,}1\,mA$$

VERIFICO QUE ESTÉN EN RAD:

$$V_{TH} = 6V\,\frac{5K}{5K + 500\Omega} = 5{,}45V \;;\; R_{TH} = 500\Omega \,//\, 5K = 455\Omega.$$

$\Rightarrow V_{CEQ} = 12V - I_{CQ}(R_{TH} + 300\Omega)$

$V_{CEQ} = 4,27V$ ✓

$\Rightarrow V_{DQ} = V_{CQ} = -6V + I_{CQ}\,300\Omega + V_{CEQ} = 1,34V$

$\Rightarrow V_{SQ} = -5,3V + I_{CQ}\,300\Omega = -2,23V$

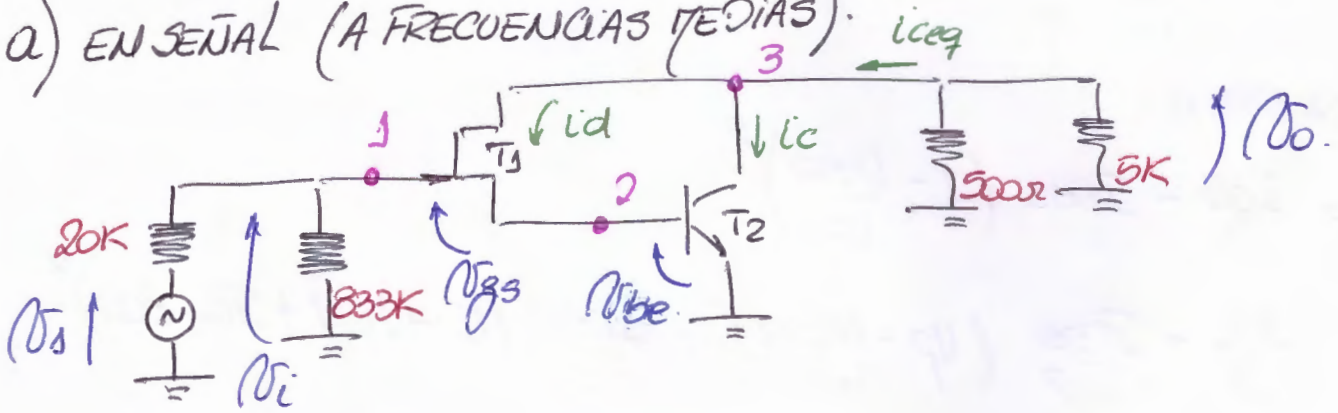
$\Rightarrow V_{DSQ} = 3,57V > V_{GSQ} - V_P$ ✓

$I_{CQ} = 10,24mA \Rightarrow g_{m2} = 410m\mho \Rightarrow r_{dTBJ} = 2,44\Omega$

$r_{\pi 2} = 244\Omega$; $C_\pi \cong 217pF$

$I_{DQ} = 0,1mA \Rightarrow g_{m1} = 0,88m\mho \Rightarrow r_{dFET} = 1136\Omega$

a) EN SEÑAL (A FRECUENCIAS MEDIAS).



3 NODOS A ANALIZAR.

<u>NODO 1</u>: $R_{eq} = 20K \parallel 833K$ ↑↑

CAPACIDADES → C_{gs}^* : SE REFLEJA MÁS CHICA ($C_{gs}^* < C_{gs}$)

→ C_{gd}^* : SE REFLEJA MÁS GRANDE ($C_{gd}^* > C_{gd}$).

$C_{eq} = C_{gs}^* + C_{gd}^*$ ~

NODO 2: $R_{eq} = r_\pi \,//\, r_{dFET}$ ↓↓

CAPACIDADES: → C_π: YA REFERIDA A MASA.

→ C_μ^*: SE REFLEJA MÁS GRANDE: $(C_\mu^* > C_\mu)$.

→ C_{gs}^*: SE REFLEJA IGUAL $(C_{gs}^* = C_{gs})$.

$$C_{eq} = C_\pi + C_\mu^* + C_{gs} \uparrow$$

NODO 3: $R_{eq} = 500\Omega \,//\, 5K$ ↓

CAPACIDADES: → C_μ^*: SE REFLEJA IGUAL $(C_\mu^* = C_\mu)$

→ C_{gd}^*: SE REFLEJA IGUAL $(C_{gd}^* = C_{gd})$.

$$\Rightarrow C_{eq} = C_\mu + C_{gd} \downarrow$$

Busco $f_h = \dfrac{1}{2\pi \tau_h}$; DONDE $\tau_h = R_{eq} C_{eq}$ ⇒ BUSCO LA CONSTANTE DE TIEMPO MÁS ALTA

→ DESCARTO EL NODO 3 $\begin{cases} R_{eq} \downarrow \\ C_{eq} \downarrow \end{cases}$

⇒ LOS NODOS DOMINANTES SERÁN 1 Y 2.

NODO 1: $R_{eq} \cong 20K$

$$C_{eq} = C_{gs}\left[1 - \frac{i_d r_\pi}{i_d r_\pi + \sigma_{gs}}\right] + C_{gd}\left[1 - \frac{-i_{ceq}(5K//500\Omega)}{i_d r_\pi + \sigma_{gs}}\right]$$

$$C_{eq} = \underbrace{C_{gs}\left[1 - \frac{r_\pi}{r_\pi + r_{dFET}}\right]}_{C_{gs}^* < C_{gs}} + \underbrace{C_{gd}\left[1 + \frac{(5K//500\Omega)}{r_d \tau_{BJ} + \frac{r_{dFET}}{\beta}}\right]}_{C_{gd}^* > C_{gd}}$$

$$C_{eq} = C_{gs}[1 - 0{,}18] + C_{gd}[1 + 33] \cong 73pF \Rightarrow \tau_1 = 1{,}46\mu s$$

NODO 2: $R_{eq} = 244\Omega \,//\, 1136\Omega \cong 200\Omega$.

$$C_{eq} = C_\pi + C_\mu\left[1 - \frac{-i_{ceq}(5K//500\Omega)}{v_{be}}\right] + C_{gs}\left[1 - \frac{20K}{20K + r_{gs}}\right]$$

$$C_{eq} = C_\pi + \underbrace{C_\mu\left[1 + g_{m2}(5K//500\Omega)\right]}_{C_\mu^* > C_\mu} + \underbrace{C_{gs}\left[1 - 0\right]}_{C_{gs}^* = C_{gs}}$$

$$C_{eq} = C_\pi + C_\mu\left[1 + 186\right] + C_{gs}.$$

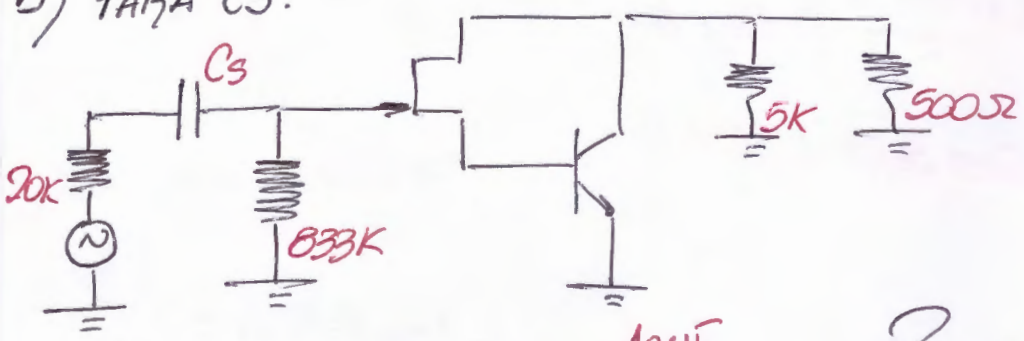
$$C_{eq} = 410pF$$

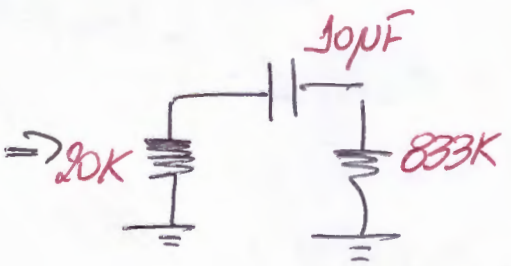
$$\Rightarrow \tau_2 = 0{,}082\,\mu s$$

$\tau_1 >> \tau_2 \Rightarrow$ EL NODO DOMINANTE ES EL 1

$$\Rightarrow \boxed{f_h = \frac{1}{2\pi\tau_1} = 109KHz.}$$

b) PARA C_s:





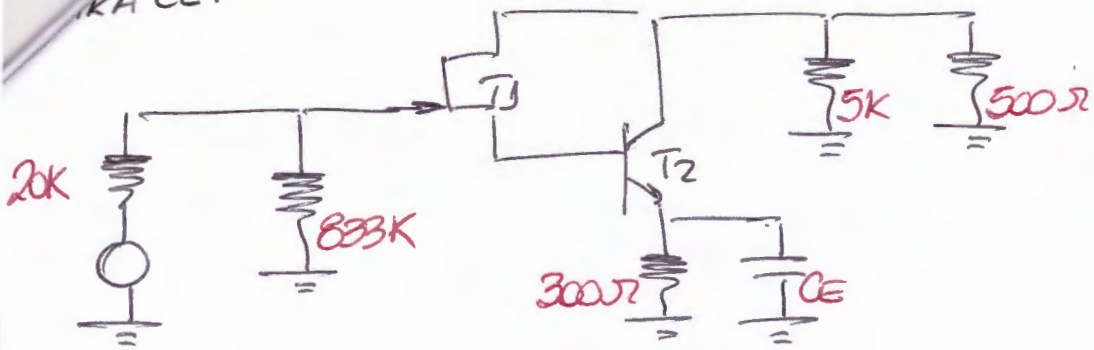
$R_{eq} = 20K + 833K = 853K$

$\Rightarrow \tau_{Cs} = 10\mu F\ 853K$

$\tau_{Cs} = 8{,}53s.$

$\hookrightarrow f_{Cs} = 0{,}019Hz.$

RA CE:



$$R^* = \frac{r_\pi + r_{dFET}}{\beta} = 13{,}8\,\Omega$$

$\Rightarrow$

$$\Rightarrow R_{eq} = 13{,}8\,\Omega \,//\, 300\,\Omega \approx 13{,}8$$

$$\Rightarrow \tau_{CE} = 13{,}8\,\Omega \; 100\,\mu F = 1{,}38\,ms$$

$$\hookrightarrow f_{CE} \cong 115\,Hz.$$

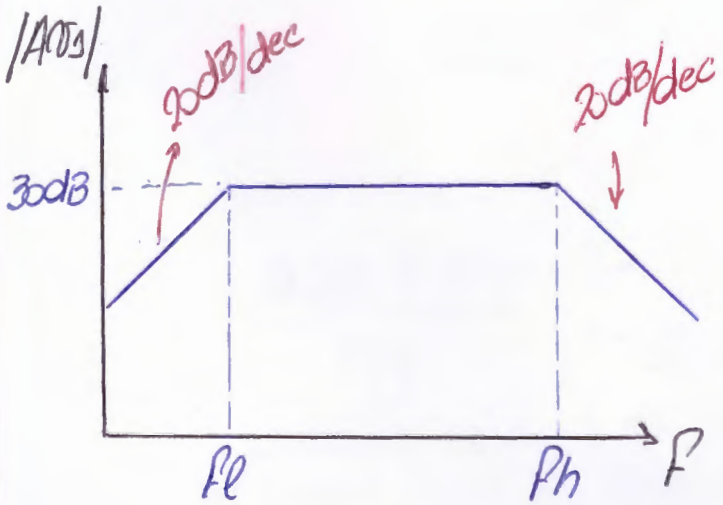
$$\Rightarrow \boxed{f_l = f_{CE} = 115\,Hz.}$$

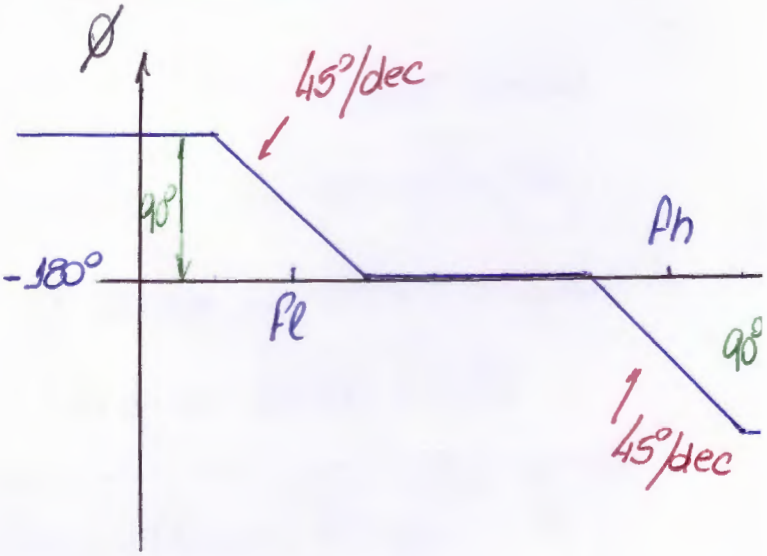
GANANCIA:

$$A_v = \frac{v_o}{v_i} = \frac{-i_{ceq}\,(5K\,//\,500\,\Omega)}{v_{be} + v_{gs}} = \frac{-(5K\,//\,500\,\Omega)}{r_{dTBJ} + \frac{r_{dFET}}{\beta}}$$

$$\Rightarrow \boxed{A_v \cong -33}$$

$$\Rightarrow A_{vs} = A_v \cdot \frac{833K}{833K + 20K} \Rightarrow \boxed{A_{vs} = -32{,}2.}$$

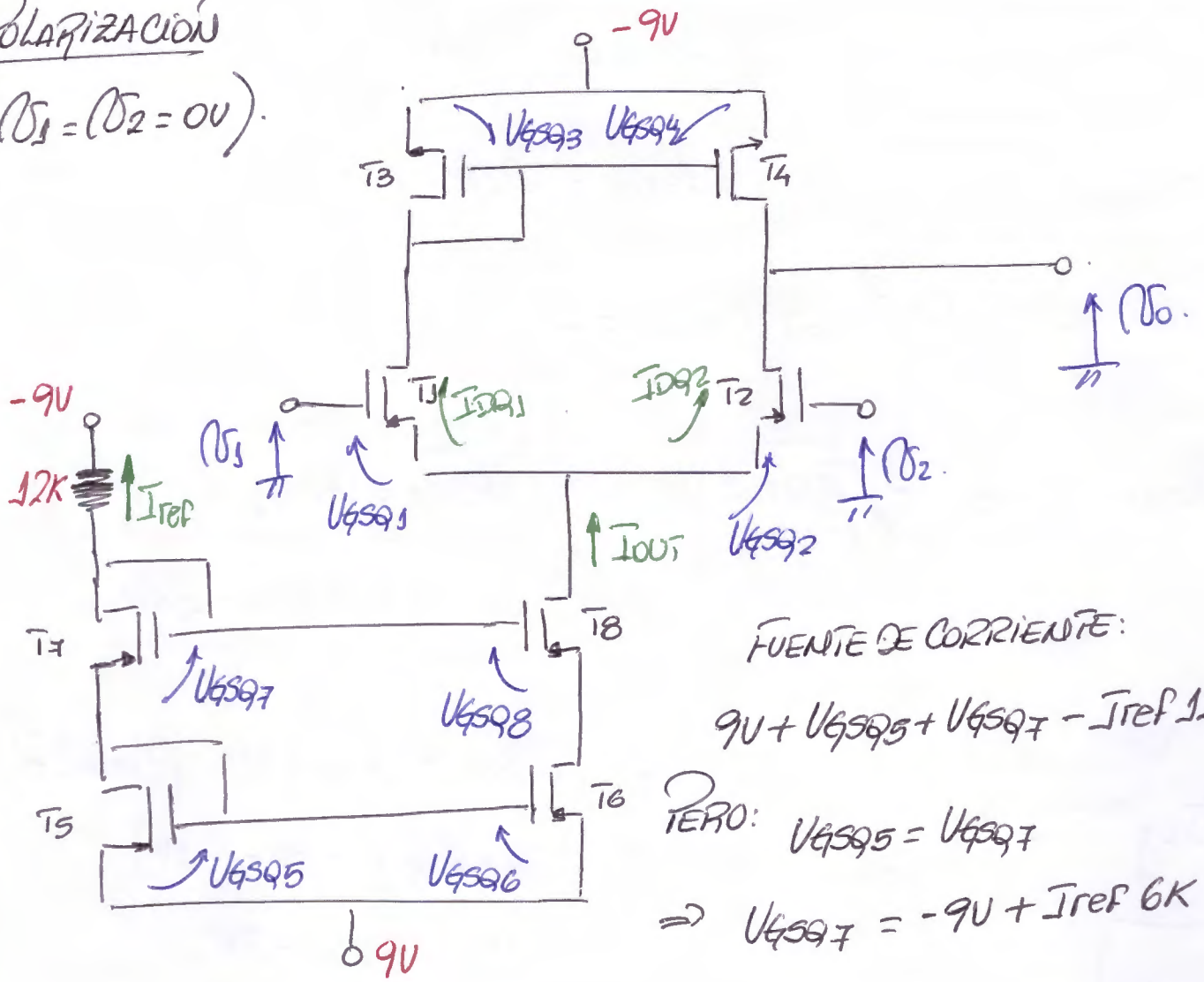




AR DIFERENCIAL CANAL P ⇒ FUENTE DE CORRIENTE CANAL P.
⇒ CARGA ACTIVA CANAL N

POLARIZACIÓN

$(V_1 = V_2 = 0V)$.



FUENTE DE CORRIENTE:

$9V + V_{GSQ5} + V_{GSQ7} - I_{ref}\,12K = -9$

PERO: $V_{GSQ5} = V_{GSQ7}$

$\Rightarrow V_{GSQ7} = -9V + I_{ref}\,6K$

$$\Rightarrow I_{DQ7} = I_{DQ5} = I_{ref} = K'\frac{W}{L}\left(V_{GSQ7} - V_T\right)^2.$$

$$I_{ref} = K'\frac{W}{L}\left(-9V + I_{ref}6K - (-1V)\right)^2.$$

$$I_{ref} = K'\frac{W}{L}\left(-8V + I_{ref}\,6K\right)^2.$$

$$4000\,I_{ref} = 64 + I_{ref}^2\,367 - I_{ref}\,96000.$$

$$0 = I_{ref}^2(367) + I_{ref}(-100K) + (64)$$

$$\frac{100K \pm 28K}{734}$$

$\nearrow I_{ref} = 1{,}78\,mA \Rightarrow V_{GSQ7} = 1{,}68V$ ✗

$\searrow I_{ref} = 1\,mA \Rightarrow V_{GSQ7} = -3V$ ✓

$\Rightarrow \boxed{I_{ref} = 1\,mA}$ $\boxed{V_{GSQ5} = V_{GSQ6} = V_{GSQ7} = V_{GSQ8} = -3V}$

$\Rightarrow \boxed{I_{OUT} = 1mA} \Rightarrow \boxed{I_{DQ1} = I_{DQ2} = \frac{I_{OUT}}{2} = 0{,}5mA}$

$\boxed{gm_{5A8} = 1m} \quad \boxed{gm_{1A4} = 0{,}7m}$

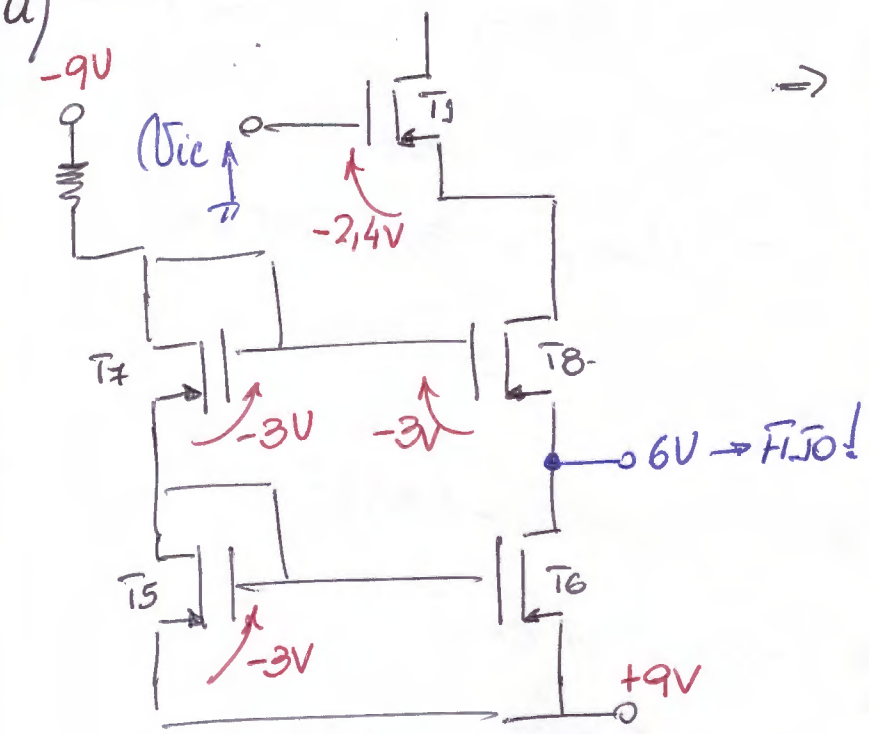
$\boxed{r_{ds5A8} = 100K} \quad \boxed{r_{ds1A4} = 200K}$

$R_{OUT} = gm_8 \, r_{ds8}^2 \Rightarrow \boxed{R_{OUT} = 10M\Omega}$

$V_{GSQ1} = V_{GSQ2} = -\sqrt{\frac{I_{DQ1}}{K'W/L}} - V_T \Rightarrow \boxed{V_{GSQ1} = V_{GSQ2} = -2{,}4V}$

$\boxed{V_{GSQ3} = V_{GSQ4} = 2{,}4V}$

a)



$\Rightarrow V_{DS8} < V_{GS8} - V_T$ (CANAL P)

$V_{D8} - V_{S8} < -3V - (-1V)$

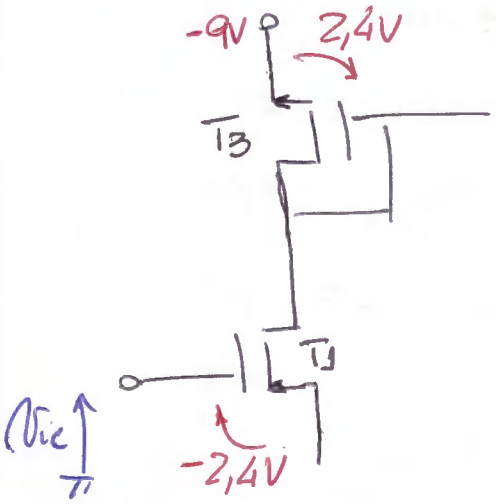
$V_{D8} - 6V < -2V$

$V_{D8} < 4V$

$V_{ic} - (-2{,}4V) < 4V$

$V_{ic} + 2{,}4V < 4V$

$\Rightarrow \boxed{V_{ic} < 1{,}6V}$



$\Rightarrow V_{DS1} < V_{GS1} - V_T$ (CANAL P)

$V_{D1} - V_{S1} < -2{,}4V - (-1V)$

$-9V + 2{,}4V - V_{S1} < -1{,}4V$

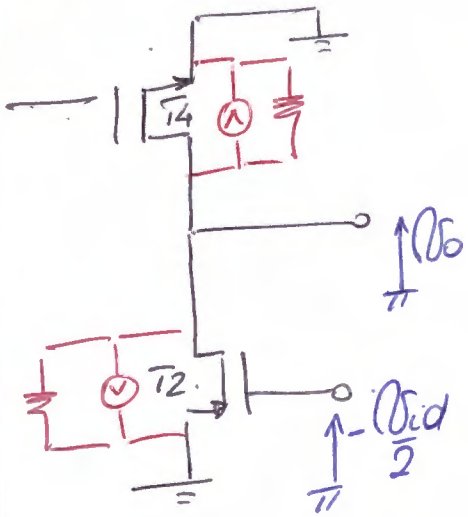
$-6{,}6V - V_{S1} < -1{,}4V$

$V_{S1} > -5{,}2V$

$V_{ic} - (-2{,}4V) > -5{,}2V \Rightarrow \boxed{V_{ic} > -7{,}6V}$

$\Rightarrow$ RTMC: $\underbrace{-7{,}6V}_{T_1 \text{ EN ZONA ÓHMICA}} < v_{ic} < \underbrace{1{,}6V}_{T_0 \text{ EN ZONA ÓHMICA}}$

b) ENTRADA DIFERENCIAL PURA: $(v_{ic}=0)$



SUMO CORRIENTES:

$$0 = \frac{v_o}{r_{ds2}//r_{ds4}} + g_{m2} v_{gs2} + g_{m4} v_{gs4}$$

$$0 = \frac{v_o}{r_{ds2}//r_{ds4}} + g_{m2}\left(-\frac{v_{id}}{2}\right) + g_{m4} v_{gs3}$$

$$0 = \frac{v_o}{r_{ds2}//r_{ds4}} + g_{m2}\left(-\frac{v_{id}}{2}\right) + g_{m4}\left(-i_{d1} r_{d3}\right)$$

$$0 = \frac{v_o}{r_{ds2}//r_{ds4}} + g_{m2}\left(-\frac{v_{id}}{2}\right) - i_{d1}$$

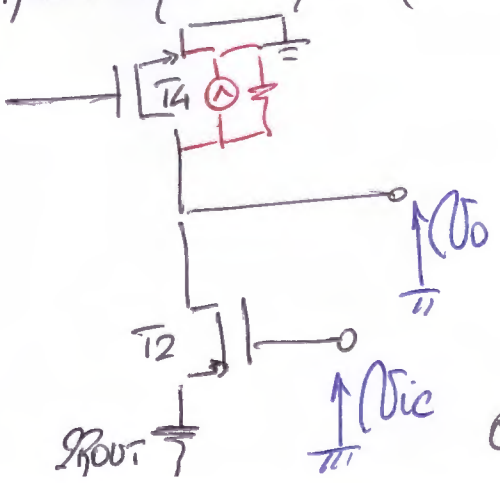
$$0 = \frac{v_o}{r_{ds2}//r_{ds4}} - g_{m2}\frac{v_{id}}{2} - g_{m1}\frac{v_{id}}{2}$$

$$0 = \frac{v_o}{r_{ds2}//r_{ds4}} - g_{m1,2} v_{id}$$

$$\Rightarrow A_{vd} = \frac{v_o}{v_{id}} = g_{m1,2}\left(r_{ds2}//r_{ds4}\right) = g_{m1,2}\frac{r_{ds2}}{2}$$

$$\Rightarrow \boxed{A_{vd} = 70}$$

ENTRADA COMÚN PURA: $(v_{id}=0)$



$$0 = \frac{v_o}{r_{ds4}} + g_{m4} v_{gs4} + \frac{v_{ic}}{2R_{OUT}}$$

$$0 = \frac{v_o}{r_{ds4}} + g_{m4} v_{gs3} + \frac{v_{ic}}{2R_{OUT}}$$

$$0 = \frac{v_o}{r_{ds4}} + g_{m4}\left(-i_{d1}\left(r_{d3}//r_{ds3}\right)\right) + \frac{v_{ic}}{2R_{O}}$$

$$0 = \frac{v_o}{r_{ds4}} - i_{d1} g_{m4}\frac{r_{d3}\cdot r_{ds3}}{r_{d3}+r_{ds3}} + \frac{v_{ic}}{2R_{OUT}}$$

$$0 = \frac{v_o}{r_{ds4}} - i_{d1}\frac{r_{ds3}}{r_{d3}+r_{ds3}} + \frac{v_{ic}}{2R_{out}}$$

$$0 = \frac{v_o}{r_{ds4}} - \frac{v_{ic}}{2R_{out}}\frac{r_{ds3}}{r_{d3}+r_{ds3}} + \frac{v_{ic}}{2R_{out}}$$

$$0 = \frac{v_o}{r_{ds4}} + \frac{v_{ic}}{2R_{out}}\left[1 - \frac{r_{ds3}}{r_{d3}+r_{ds3}}\right]$$

$$0 = \frac{v_o}{r_{ds4}} + \frac{v_{ic}}{2R_{out}}\frac{r_{d3}}{r_{d3}+r_{ds3}}$$

$$0 = \frac{v_o}{r_{ds4}} + \frac{v_{ic}}{2R_{out}}\frac{r_{d3}}{r_{ds3}}$$

$$\Rightarrow A_{vc} = \frac{v_o}{v_{ic}} = \frac{-r_{d3}}{2R_{out}}$$

$$\Rightarrow \boxed{A_{vc} = 71{,}4\mu}$$

$$\Rightarrow RRMC = 20\log\left|\frac{A_{vd}}{A_{vc}}\right| = 20\log(980.000)$$

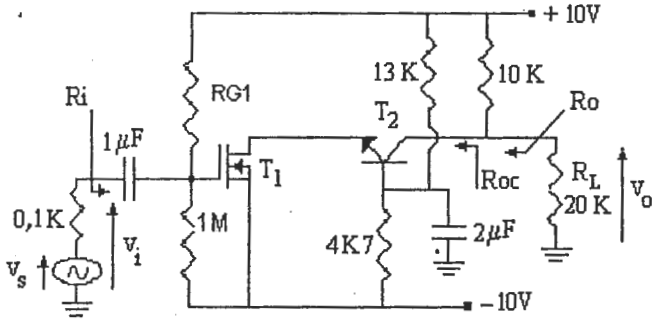
$$\Rightarrow \boxed{RRMC = 120\,dB.}$$

P/ Fotocopiar

66.08 - Circuitos Electrónicos I — Evaluación integradora 2/2012 – 22/02/13

APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
			M	T	N			

1.- k= 1 mA/V^2 ; V_T = 1 V ; $\lambda \cong 0{,}01\ V^{-1}$; Cgs = 4 pF ; Cgd = 0,5 pF
β = 200 ; $V_A \to \infty$; r_x = 100 Ω ; f_T = 300 MHz; C_μ = 0,5 pF.

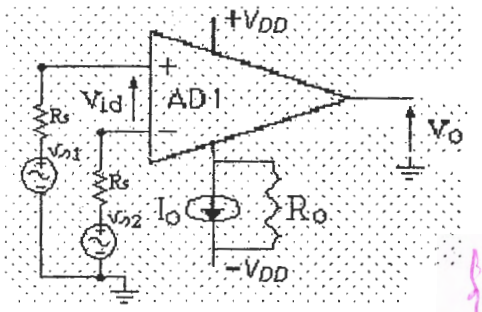


a) Obtener los puntos de reposo de los transistores, hallando R_{G1} de modo que la tensión de reposo sobre la carga R_L sea V_{OQ} = 0V.

b) ***Otener por inspección*** la amplificación de tensión total Av = v_O/v_i y $Av_s = v_O/v_S$.

c) Obtener f_l aproximada y ***justificar*** cuál es el nodo que resultará necesario calcular para obtener un valor aproximado de f_h para Av_S. Calcular su valor.

2.- AD1: par acoplado por source de NMOSFET inducidos (T_1 -T_2), con una fuente espejo PMOSFET como carga (T_3 -T_4).



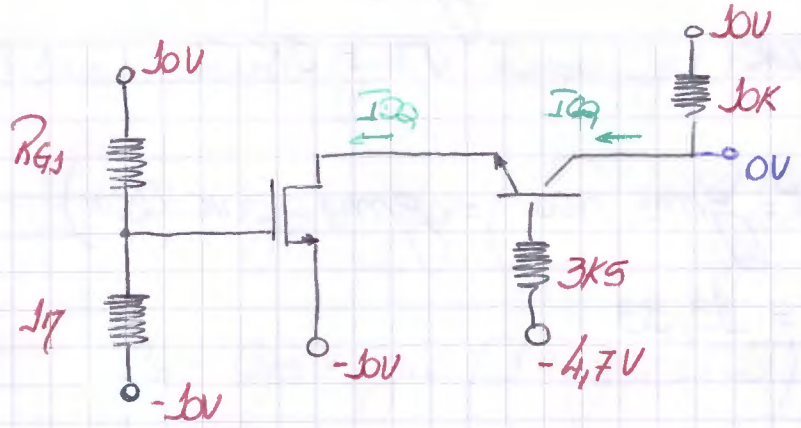
Se admiten transistores con características nominalmente similares (T_1 = T_2 y T_3 = T_4). ***Definir y hallar la expresión*** de la tensión de offset, V_{off}, del circuito para los siguientes casos:

a) $100.|W_2 - W_1| / W_1 = \delta$, donde $0 < \delta < 2\%$.
b) $100.|W_4 - W_3| / W_3 = \delta$, donde $0 < \delta < 2\%$.
c) $100.|V_{T2} - V_{T1}| / V_{T1} = \delta$, donde $0 < \delta < 2\%$.

Justificar por qué en señal los desapareamientos afectan en forma importante a Av_c y no a Av_d.

Preg.

1)



$\beta = 200$

$r_x = 100\Omega$

$V_A \to \infty$

$K = 1mA/V^2$

$V_T = 1V$

$\lambda = 0{,}01\ V^{-1}$

$$I_{CQ} = \frac{10V}{10K} = 1mA = I_{DQ}$$

$$I_{DQ} = K\left(V_{GSQ} - V_T\right)^2 \Rightarrow V_{GSQ} = 2V$$

$$V_{GSQ} = V_{GQ} - V_{SQ} = V_{GQ} - (-10V) = 2V$$

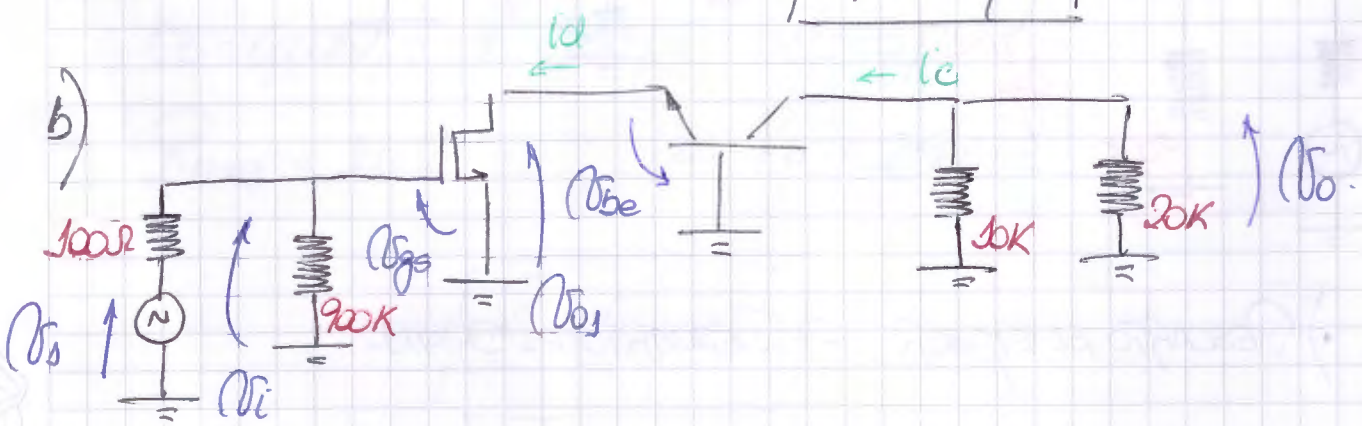
$$\Rightarrow V_{GQ} = -8V$$

$$V_{GQ} = 20V \frac{17}{17 + R_{G1}} - 10V = -8V$$

$$20V\ 17 = 2V\left(17 + R_{G1}\right)$$

$$\Rightarrow \boxed{R_{G1} = 97}$$

b)



PARÁMETROS

$g_{m1} = 2m$ $\qquad$ $g_{m2} = 4m$

$r_{ds} = 100K$ $\qquad$ $r_\pi = 5K$

PARA UN CASCODE:

$$A_v = g_{m1} R_{ca} = g_{m1} (10K \parallel 20K)$$

$$A_v = 13,33$$

PARA A_{vs} NECESITO R_i:

$$R_i = R_{ig} \parallel 900K \quad ; \quad R_{ig} = r_{gs}$$

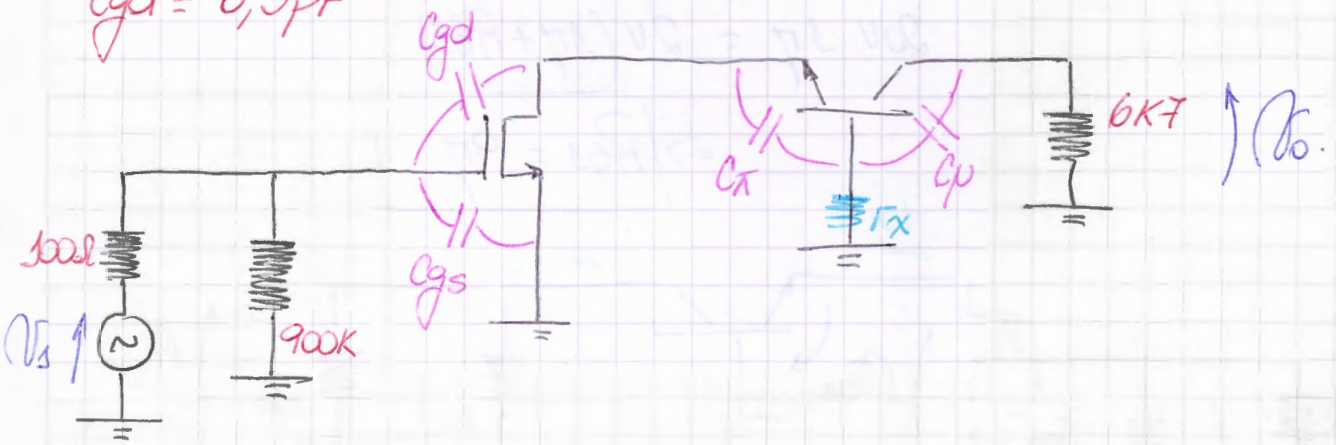
$$R_{ig} \gg 900K \Rightarrow R_i \cong 900K$$

$$\Rightarrow \quad A_{vs} = A_v \frac{R_i}{R_i + R_s} = 13,32$$

c) $f_T = 300\,MHz \Rightarrow C_\pi = 20,7pF$

$C_\mu = 0,5pF$ $\qquad$ $C_{gs} = 4pF$

$C_{gd} = 0,5pF$



•) GATE: TENGO C_{gs} Y TENGO C_{gd} REFLEJADO

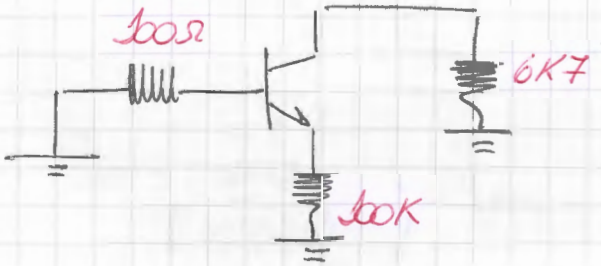
$$C_G = C_{gs} + C_{gd}\left(1 - \frac{-i_d\, r_{d2}}{v_{gs}}\right)$$

$$C_G = C_{gs} + C_{gd}\left(1 + g_{m1}\, r_{d2}\right) = 4{,}5\,pF$$

$$R_{Geq} = 100\,\Omega \quad \Rightarrow \quad f_h = 353\,MHz$$

•) COLECTOR: TENGO SOLO C_μ $\Rightarrow$ $\left.\begin{array}{l} C_{Ceq} = C_\mu = 0{,}5\,pF \\ R_{Ceq} = 6K7 \end{array}\right\} f_h = 47$

•) BASE:



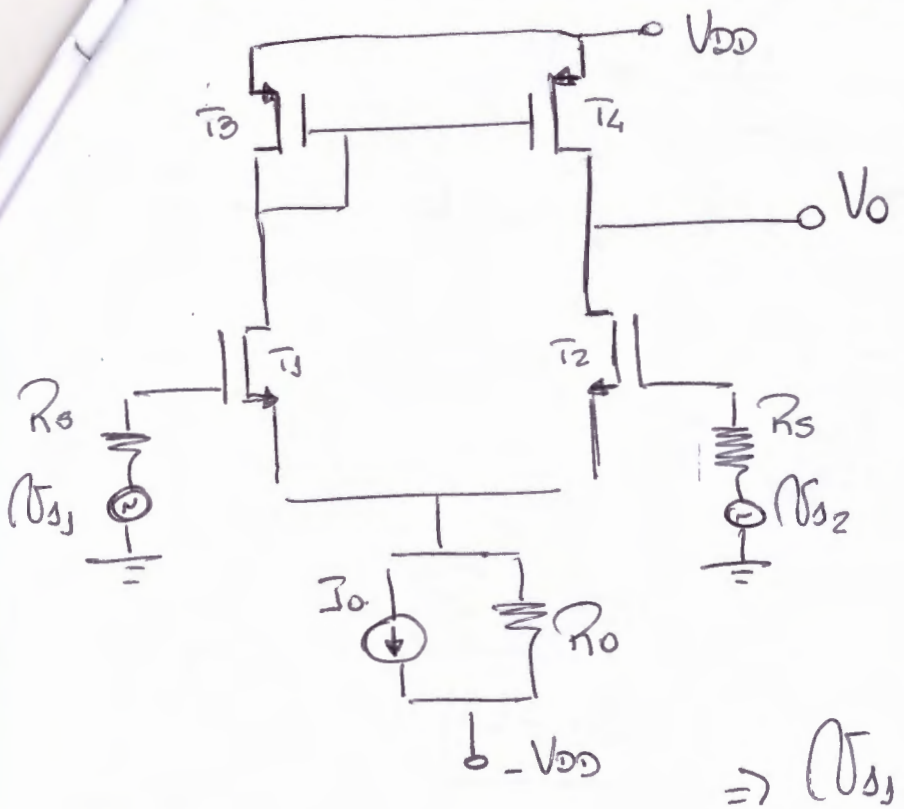
$$C_b = C_\pi\left(1 - \frac{v_e}{v_{bp}}\right) + C_\mu\left(1 - \frac{v_c}{v_{bp}}\right)$$

$$C_b = C_\pi\left(1 - \frac{100K}{100K + 25}\right) + C_\mu\left(1 - \frac{-6K7}{100K + 25}\right)$$

$$C_b = 0{,}0052\,pF + 0{,}53\,pF = 0{,}5352\,pF$$

$$R_{beq} = 100\,\Omega \quad \Rightarrow \quad f_h = 2{,}9\,GHz$$

$$\Rightarrow \boxed{f_h = 47\,MHz}$$



22/02/201

$$\begin{cases} T_1 = T_2 \\ T_3 = T_4 \end{cases}$$

TENSIÓN DE OFFSET.

$$V_{s1} - \cancel{V_{Rs}} - V_{gs1} + V_{gs2} + \cancel{V_{Rs}} - V_{s2} = 0$$

$$\Rightarrow V_{s1} - V_{s2} = V_{off} = V_{gs1} - V_{gs2}$$

$$\Rightarrow V_{off} = V_{gs1} - V_{gs2} \; ; \quad I_d = K\left(V_{gs} - V_T\right)^2$$

$$\hookrightarrow V_{gs} = V_T + \sqrt{\frac{I_d}{K}} \; ; \quad K = K'\frac{W}{L}$$

$$\Downarrow$$

$$V_{off} = V_{T1} + \sqrt{\frac{I_{d1}}{K'W_1/L}} - V_{T2} - \sqrt{\frac{I_{d2}}{K'W_2/L}} \; ; \quad V_{T1} = V_{T2}$$

$$V_{off} = \sqrt{\frac{I_{d1}}{K'W_1/L}} - \sqrt{\frac{I_{d2}}{K'W_2/L}} \; ; \quad I_{d1} = I_{d2} = I_d \rightarrow$$ ¿PUEDO DECIR ESTO?

$$V_{off} = \sqrt{\frac{I_d}{K'/L}}\left\{\sqrt{\frac{1}{W_1}} - \sqrt{\frac{1}{W_2}}\right\} \; ; \quad \frac{|W_2 - W_1|}{W_1} = \delta$$

$$V_{off} = \sqrt{\frac{I_d}{K'W_1/L}}\left\{1 - \frac{1}{\sqrt{W_2/W_1}}\right\} \qquad \frac{W_2}{W_1} - 1 = \delta$$

$$\hookrightarrow \frac{W_2}{W_1} = 1 + \delta$$

$$V_{off} = \sqrt{\frac{I_d}{K'W_1/L}}\left\{1 - \frac{1}{\sqrt{1+\delta}}\right\} \; ; \quad \sqrt{1+x} \approx 1 + x/2$$

$$V_{off} = \sqrt{\frac{I_d}{K'W_1/L}}\left\{1 - \frac{1}{1+\delta/2}\right\} = A\left\{\frac{1+\delta/2 - 1}{1+\delta/2}\right\} = A\left\{\frac{\delta/2}{1+\delta/2}\right\}$$

$$v_{off} = A\left\{\frac{\delta/2}{1+\delta/2}\right\} = A\,\frac{\delta}{2+\delta}$$

$$1 - \frac{1}{1+\delta/2} = 1 - \frac{2}{2+\delta}$$

$$= \frac{2+\delta-2}{2+\delta} = \frac{\delta}{2+\delta}$$

$$= \boxed{2 \gg \delta}$$

$$\Downarrow \delta/2$$

$2 \gg \delta$

$$\boxed{v_{off} = A\,\frac{\delta}{2}}$$

a) $$\boxed{v_{off} = \sqrt{\frac{I_d}{K'W_1/L}}\,\frac{\delta}{2}}$$

b) $$v_{off} = v_{gs_1} - v_{gs_2} = V_{T1} + \sqrt{\frac{I_{d1}}{K'W_1/L}} - V_{T2} - \sqrt{\frac{I_{d2}}{K'W_2/L}}$$

$$V_{T1} = V_{T2} \Rightarrow v_{off} = \sqrt{\frac{I_{d1}}{K'W_1/L}} - \sqrt{\frac{I_{d2}}{K'W_2/L}}$$

PERO $I_{d1} = I_{d3}$, $I_{d2} = I_{d4}$

$$v_{off} = \sqrt{\frac{K'_3W_3/L_3}{K'_1W_1/L_1}}\,(v_{gs3} - V_{T3}) - \sqrt{\frac{K'_4W_4/L_4}{K'_2W_2/L_2}}\,(v_{gs4} - V_{T4})$$

$$I_{d1} = I_{d3}$$

$$K'_1\frac{W_1}{L_1}(v_{gs1} - V_{T1})^2 = K'_3\frac{W_3}{L_3}(v_{gs3} - V_{T3})^2$$

b) $V_{off} = V_{gs_1} - V_{gs_2}$ $\quad \cancel{V_{gs_1} =}$

$I_{d_1} = I_{d3}$

$$K_1' \frac{W_1}{L_1} (V_{gs_1} - V_{T_1})^2 = K_3' \frac{W_3}{L_3} (V_{gs_3} - V_{T3})^2$$

$$(V_{gs_1} - V_{T_1})^2 = \frac{K_3' W_3/L_3}{K_1' W_1/L_1} (V_{gs_3} - V_{T3})^2 .$$

$$V_{gs_1} = V_{T_1} + (V_{gs_3} - V_{T3}) \sqrt{\frac{K_3' W_3/L_3}{K_1' W_1/L_1}}$$

$$V_{gs_2} = V_{T2} + (V_{gs_4} - V_{T4}) \sqrt{\frac{K_4' W_4/L_4}{K_2' W_2/L_2}}$$

$$V_{off} = \cancel{V_{T_1}} + (V_{gs_3} - V_{T3}) \sqrt{\frac{K_3' W_3/L_3}{K_1' W_1/L_1}} - \cancel{V_{T2}} - (V_{gs_4} - V_{T4}) \sqrt{\frac{K_4' W_4/L_4}{K_2' W_2/L_2}}$$

$$V_{off} = (V_{gs_3} - V_{T3}) \sqrt{\frac{K_3' W_3/L_3}{K_1' W_1/L_1}} - (V_{gs_4} - V_{T4}) \sqrt{\frac{K_4' W_4/L_4}{K_2' W_2/L_2}}$$

$$T_1 = T_2 \Rightarrow \begin{cases} K_1' = K_2' \\ L_1 = L_2 \\ W_1 = W_2 \end{cases}$$

$$V_{off} = \frac{1}{\sqrt{K_1' W_1/L_1}} \left\{ (V_{gs_3} - V_{T3}) \sqrt{K_3' W_3/L_3} - (V_{gs_4} - V_{T4}) \sqrt{K_4' W_4/L_4} \right\} .$$

$$\left.\begin{matrix} K_3' = K_4' \\ L_3 = L_4 \end{matrix}\right\} \quad V_{off} = \sqrt{\frac{K_3'/L_3}{K_1' W_1/L_1}} \left\{ (V_{gs_3} - V_{T3}) \sqrt{W_3} - (V_{gs_4} - V_{T4}) \sqrt{W_4} \right.$$

↳ $\boxed{\text{Y AHORA ?}}$ ⊛

$$V_{off} = V_{gs1} - V_{gs2}$$

$$V_{off} = V_{T1} + \sqrt{\frac{I_{d1}}{K_1' W_1/L_1}} - V_{T2} - \sqrt{\frac{I_{d2}}{K_2' W_2/L_2}}$$

$I_{d1} = I_{d2} = I_d \rightarrow ??$

$$V_{off} = V_{T1} - V_{T2} \quad ; \quad \frac{|V_{T1} - V_{T2}|}{V_{T1}} = \delta$$

$$\boxed{V_{off} = V_{T1}\,\delta}$$

b) $$V_{off} = \sqrt{\frac{K_3/L_3}{K_1 W_1/L_1}} \left\{ (V_{gs3} - V_{T3})\sqrt{W_3} - (V_{gs4} - V_{T4})\sqrt{W_4} \right\}$$

$$V_{off} = \sqrt{\frac{W_3 K_3/L_3}{K_1 W_1/L_1}} \left\{ V_{gs3} - V_{T3} - (V_{gs4} - V_{T4})\sqrt{W_4/W_3} \right\}$$

$$V_{off} = \sqrt{\frac{W_3 K_3/L_3}{K_1 W_1/L_1}} \left\{ V_{gs3} - V_{T3} - (V_{gs4} - V_{T4})\sqrt{1+\delta} \right\}$$

$$V_{off} = \sqrt{\frac{K_3 W_3/L_3}{K_1 W_1/L_1}} \left\{ V_{gs3} - V_{T3} - (V_{gs4} - V_{T4})\left(1 + \frac{\delta}{2}\right) \right\}$$

$$V_{off} = \sqrt{\frac{K_3 W_3/L_3}{K_1 W_1/L_1}} \left\{ -\frac{\delta}{2}(V_{gs4} - V_{T4}) \right\} \quad ; \quad (V_{gs4} - V_{T4}) = \sqrt{\frac{I_{d4}}{K_4 W_4/L_4}}$$

$$V_{off} = \sqrt{\frac{K_3 W_3/L_3}{K_1 W_1/L_1}} \left(-\frac{\delta}{2}\right)\sqrt{\frac{I_{d4}}{K_4 W_4/L_4}} = -\frac{\delta}{2}\sqrt{\frac{\cancel{K_3} W_3/\cancel{L_3}}{K_1 W_1/L_1} \frac{I_{d4}}{\cancel{K_4} W_4/\cancel{L_4}}}$$

si $W_4/W_3 = 1+\delta \Rightarrow W_3/W_4 = \frac{1}{1+\delta} \approx 1$?

$$V_{off} = -\sqrt{\frac{I_{d4}}{K_1 W_1/L_1}}\,\delta/2 = -\sqrt{\frac{I_{d1}}{K_1 W_1/L_1}}\,\delta/2 \quad ; \quad I_{d4} = I_{d2} \; ; \; I_{d2} = I_{d4} \; ?$$

$$\Rightarrow V_{off\,a)} = V_{off\,b)}$$

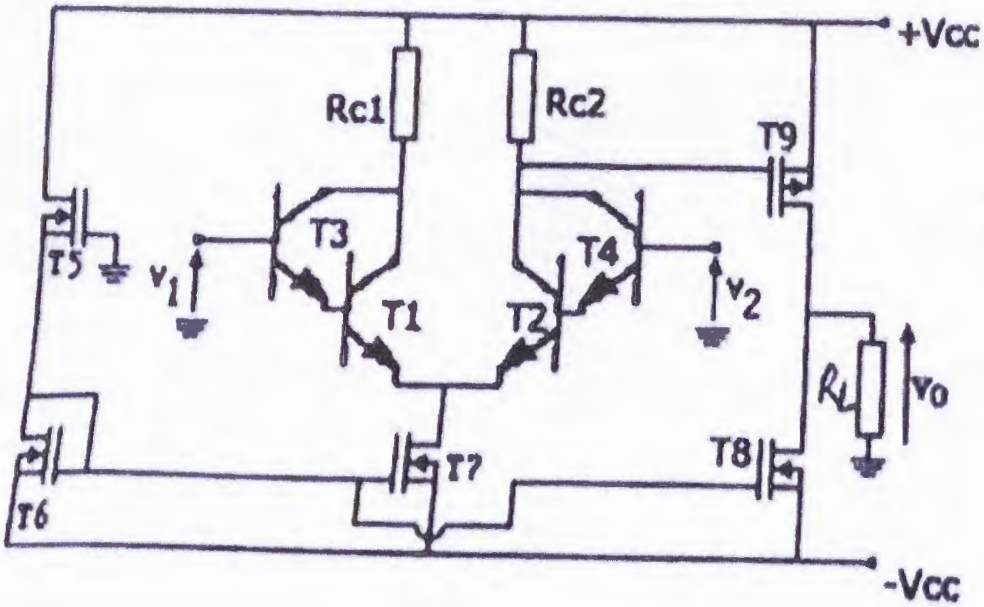
66.08 - 86.06 Eval. Integradora - 2/2016 - 2da fecha 21/12/16

APELLIDO	NOMBRE	PADRON	TURNO		Nº de HOJAS	Corrección
Rivas	Santiago	93947	(T)	N		

1.- Vcc = 6V ; Rc1 = Rc2 = 30K ; R_L = 10K

β = 100 ; r_x = 100 Ω ; V_A = 100V ; f_T = 200 MHz ; C_μ = 1 pF

MOSFETs inducidos:
V_T = ±2V ; k'=1mA/V² ; λ=0,01V⁻¹ ; $(W/L)_{5,6,8}$=1 ; $(W/L)_7$=0,2 ; Cgs=5 pF ; Cgd=1 pF



Hallar:

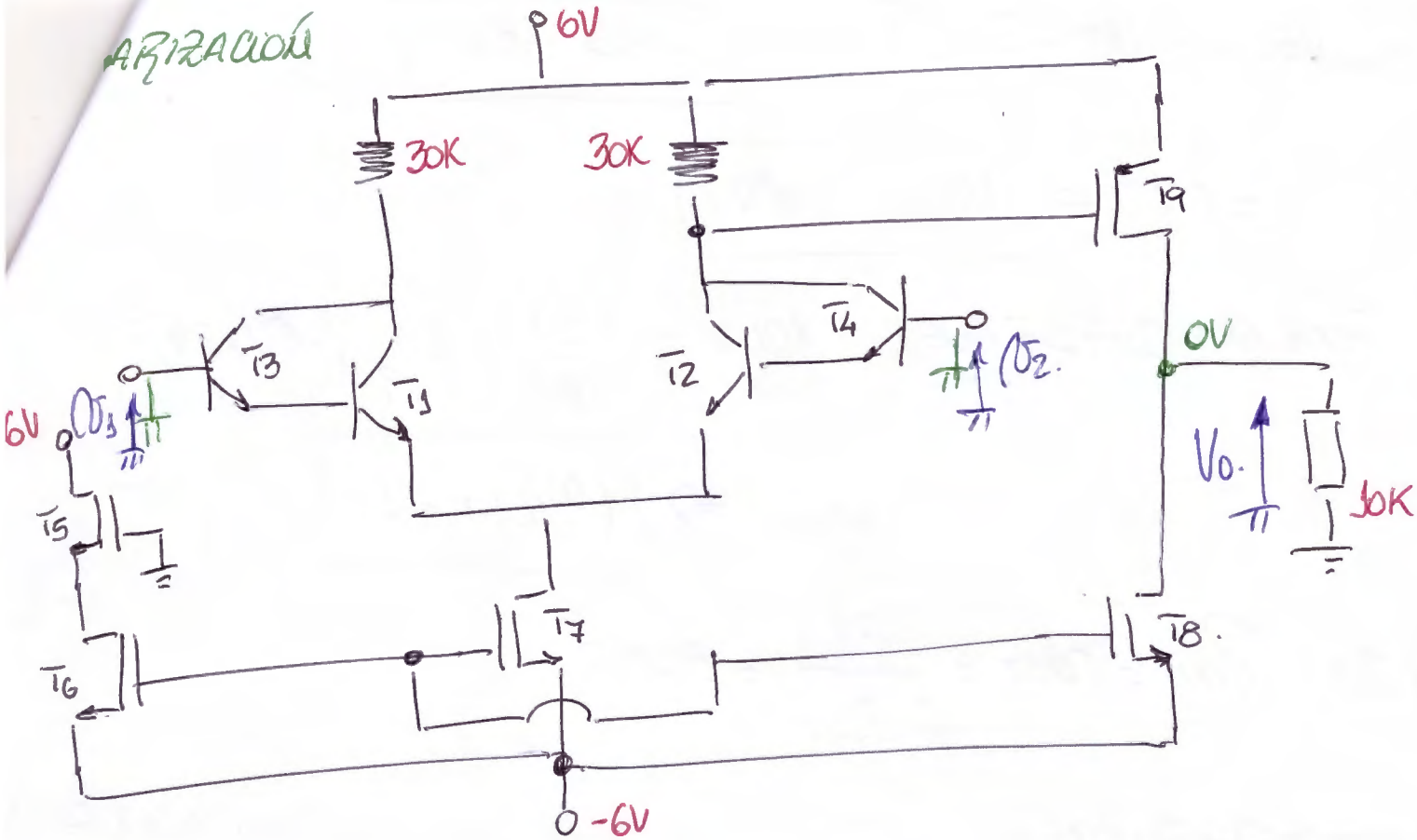
a) El valor de $(W/L)_9$ para V_{OQ} = 0V.

b) Rid, Ric y la RRMC en dB.

c) La f_h aproximada. PAJA

d) Cómo se modifica la RRMC si se reemplazan Rc1 y Rc2 por una fuente espejo simple PMOSFET (inducidos) T10-T11.
¿Qué relación W/L deberán tener para mantener V_{OQ} = 0V?

ARIZACIÓN



a) Busco $(W/L)_9$ / $V_{oQ} = 0V$

si $V_{oQ} = 0V \Rightarrow I_{DQ9} = I_{DQ8}$

RAMA REFERENCIA:

$-6V + V_{GSQ6} + V_{GSQ5} = 0$; $\left.\begin{array}{l} I_{DQ5} = I_{DQ6} \\ K'_5 = K'_6 \\ (W/L)_5 = (W/L)_6 \end{array}\right\} V_{GSQ5} = V_{GSQ6}$

$\hookrightarrow \boxed{V_{GSQ6} = 3V}$

$\Rightarrow \boxed{I_{DQ5} = I_{DQ6} = 1mA}$ $\boxed{I_{DQ7} = \frac{I_{DQ5}(W/L)_7}{(W/L)_5} = 0,2mA}$

$\Rightarrow \boxed{I_{DQ8} = \frac{I_{DQ5}(W/L)_8}{(W/L)_5} = 1mA}$

$\boxed{I_{CQ1} = I_{CQ2} = \frac{I_{DQ7}}{2} = 0,1mA}$

$\Rightarrow V_{GQ9} = V_{CC} - I_{CQ2} R_{C2} \Rightarrow \boxed{V_{GQ9} = 3V}$

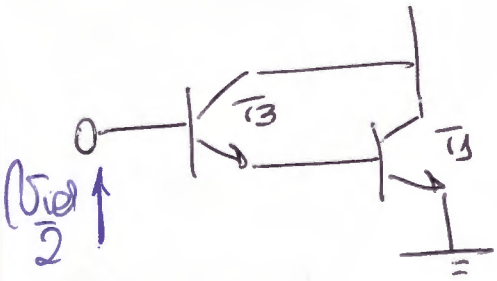
Y: $V_{SQ9} = 6V \Rightarrow \boxed{V_{GSQ9} = -3V}$

SE TIENE QUE CUMPLIR QUE: $1mA = \frac{1mA}{V^2} \left(\frac{W}{L}\right)_9 (-3V+2V)^2$.

$\Rightarrow \boxed{(W/L)_9 = 1}$

b) SEA: $R_{OUT} = r_{dS7} = \frac{1}{\lambda I_{DQ7}} = 500K\Omega$.

ENTRADA DIFERENCIAL:



BUSCO PRIMERO UN TRANSISTOR EQUIVALENTE

$\{ r_\pi^* = r_{\pi 3} + \beta (r_x + r_{\pi 1}) \}$.

$\{ \beta^* = \beta \cdot \beta = \beta^2 \}$.

$g_m^* r_\pi^* = \beta^*$

$\hookrightarrow g_m^* = \frac{\beta^*}{r_\pi^*} = \frac{\beta^2}{r_{\pi 3} + \beta (r_x + r_{\pi 1})}$

$\{ g_m^* = \frac{\beta}{r_{d3} + (r_x + r_{\pi 1})} \}$

PARÁMETROS:

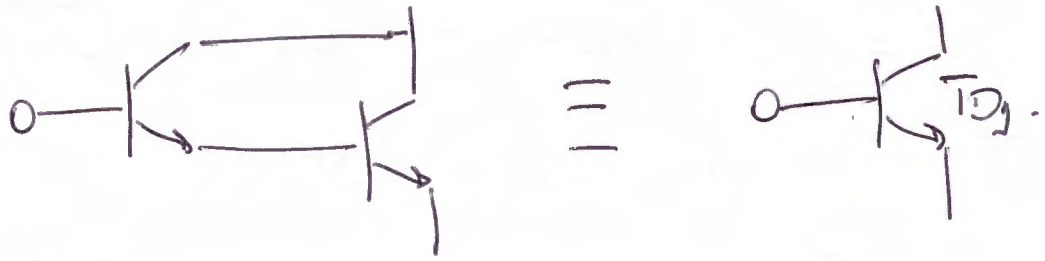
$g_{m1} = 4m \Rightarrow r_{\pi 1} = 25K$

$I_{CQ3} = \frac{I_{CQ1}}{\beta} = 1\mu A$

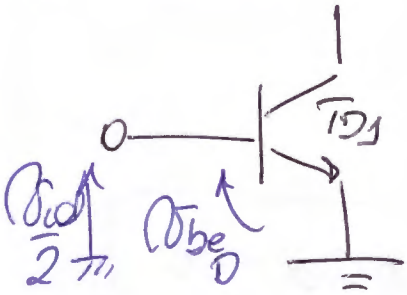
$\hookrightarrow g_{m3} = 40\mu \Rightarrow r_{\pi 3} = 2{,}5M$

$\Rightarrow \begin{cases} r_\pi^* \cong 5M\Omega. \\ \beta^* = 10.000 \\ g_m^* = 2m. \end{cases}$

• PODRÍA HACER DESPRECIANDO r_x $(r_x << r_\pi)$.



ENTONCES:

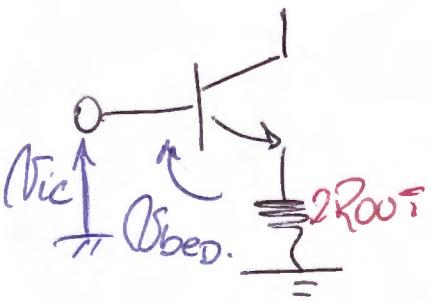


$$\frac{V_{id}}{2} = V_{be_D} = i_b r_\pi^*$$

$$\Rightarrow R_{id} = \frac{V_{id}}{i_b} = 2 r_\pi^*$$

$$\boxed{R_{id} \cong 10 M\Omega}$$

ENTRADA COMÚN:



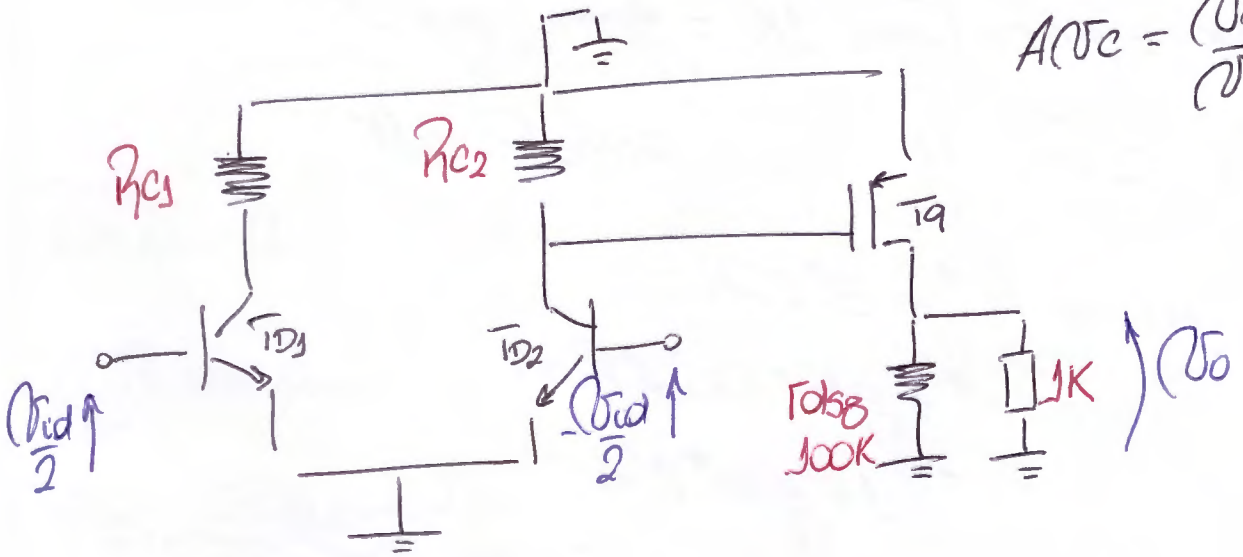
$$V_{ic} = i_b\left(r_\pi^* + \beta^* 2R_{out}\right).$$

$$\Rightarrow R_{ic} = \frac{V_{ic}}{i_b} = r_\pi^* + \beta^* 2R_{out}.$$

$$\boxed{R_{ic} \approx 10 \times 10^9 \Omega}$$

SE DEFINE: $RRMC = \left|\frac{A_{Vd}}{A_{Vc}}\right|$ DONDE: $A_{Vd} = \frac{V_o}{V_{id}}\Big|_{V_{ic}=0}$.

$$A_{Vc} = \frac{V_o}{V_{ic}}\Big|_{V_{id}=0}.$$



$$v_o = i_{d9}\, 1K = g_{m9}\, v_{gs9}\, 1K = g_{m9}\left(v_{g9} - \cancel{v_{s9}}^{\,0}\right) 1K$$

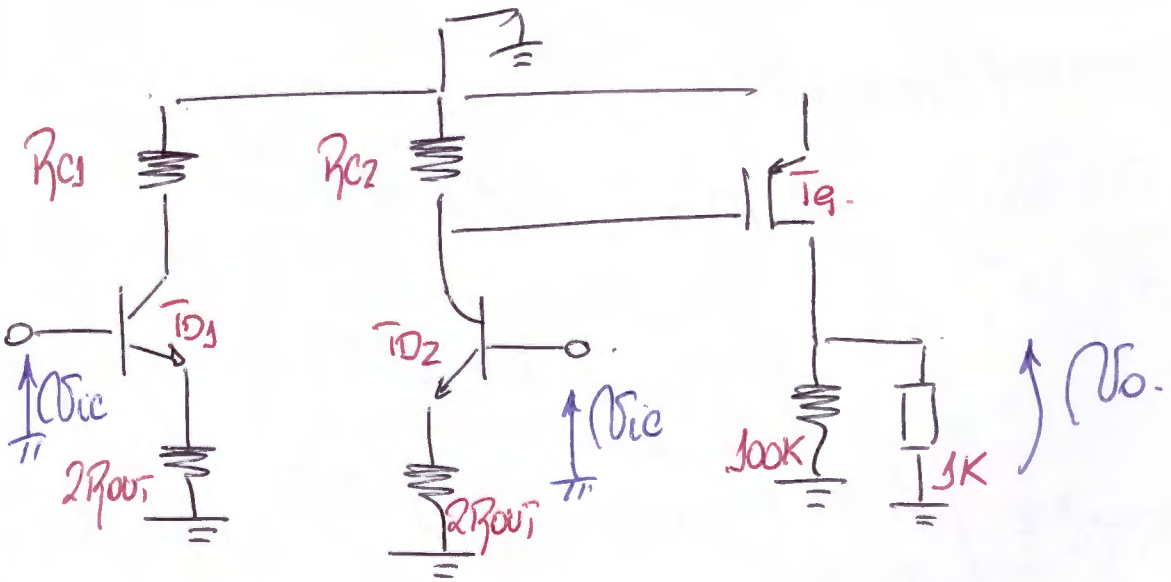
$$v_o = g_{m9}\, v_{g9}\, 1K = g_{m9}\cdot(-i_{c2} R_{c2})\, 1K$$

$$v_o = -i_{c2}\, g_{m9}\, R_{c2}\, 1K \qquad ; g_{m9} = 2mA/V$$

$$v_o = -g_m^{*}\, v_{be_D}\, g_{m9}\, R_{c2}\, 1K$$

$$v_o = -g_m^{*}\left(-\frac{v_{id}}{2}\right) g_{m9}\, R_{c2}\, 1K$$

$$\Rightarrow A_{vd} = \frac{v_o}{v_{id}} = \frac{g_m^{*}\, g_{m9}\, R_{c2}\, 1K}{2} \Rightarrow \boxed{A_{vd} = 60.}$$



$$v_o = i_{d9}\, 1K = g_{m9}\, v_{gs9}\, 1K = g_{m9}\, v_{g9}\, 1K$$

$$v_o = g_{m9}\,(-i_{c2} R_{c2})\, 1K = -i_{c2}\, g_{m9}\, R_{c2}\, 1K$$

AHORA BIEN:

$$R_{ic} = r_\pi^{*} + \beta^{*}\, 2R_{out}$$

$$R_{ic} = r_\pi^{*} + g_m^{*}\, r_\pi^{*}\, 2R_{out}$$

$$R_{ic} = r_\pi^{*}\,(1 + g_m^{*}\, 2R_{out})$$

↳ SE PUEDE DECIR QUE v_{ic} CAE PRACTICAMENTE EN "$2R_{out}$"

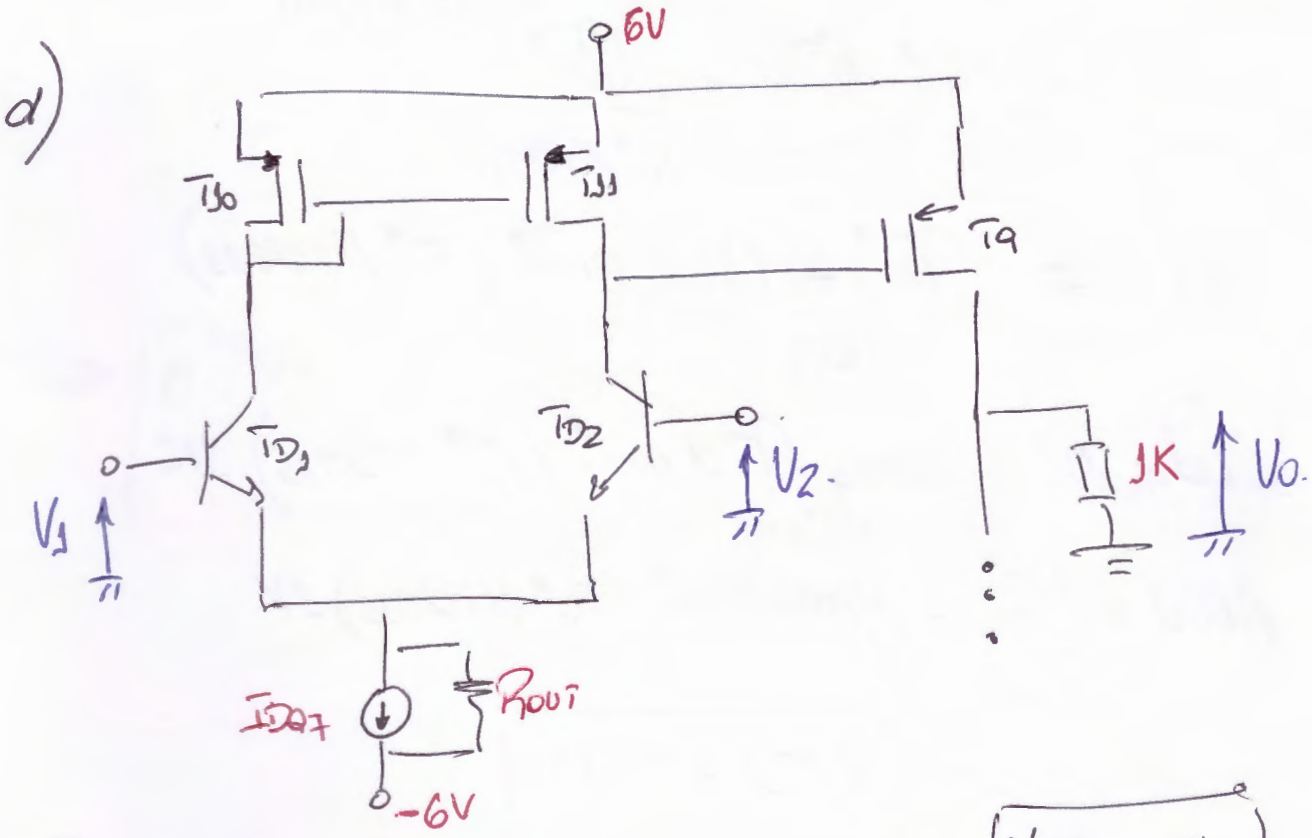
$$i_{d2} \approx \frac{v_{ic}}{2R_{out}} \Rightarrow v_o = -\frac{v_{ic}}{2R_{out}} g_{m9} R_{C2} \| 1K$$

$$A_{vc} = \frac{v_o}{v_{ic}} = \frac{-g_{m9} R_{C2} \| 1K}{2R_{out}}$$

$$\boxed{A_{vc} = -0{,}06}$$

$$\Rightarrow \boxed{RRMC = \left|\frac{60}{-0{,}06}\right| = 1000}, \text{ EN DB: } \boxed{RRMC = 60dB}$$

d)



PARA QUE $V_{oQ} = 0V \Rightarrow V_{GSQ_9} = -3V$ CON $\boxed{V_{GQ9} = 3V}$

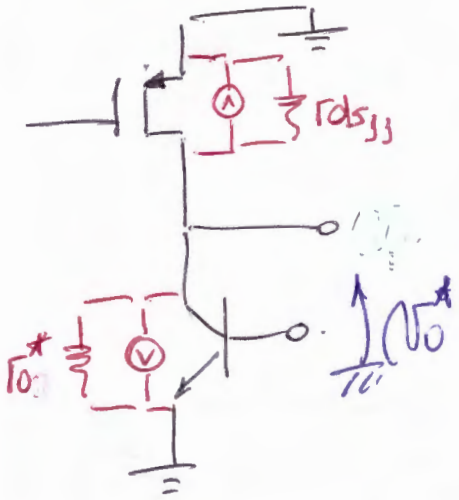
$\Rightarrow$ BUSCO QUE: $6V + V_{GSQ10} = 3V \Rightarrow \boxed{V_{GSQ10} = -3V}$

LUEGO: $I_{DQ10} = I_{CQ1} = 0{,}1mA$.

$$\Rightarrow 0{,}1mA = 1mA \left(\frac{W}{L}\right)_{10} (-3V+2V)^2$$

$$\Rightarrow \boxed{(W/L)_{10} = 0{,}1}$$

MODO DIFERENCIAL:



$$g_{m_{11}} v_{gs_{11}} + g_m^* v_{be_{D_2}} + \frac{v_o^*}{r_o^* // r_{ds_{11}}} = 0$$

$$g_{m_{11}} (-i_{d_{10}} r_{d_{10}}) + g_m^* v_{be_{D_2}} + \frac{v_o^*}{r_o^* // r_{ds_{11}}} = 0$$

$$-i_{d_{10}} + g_m^* v_{be_{D_2}} + \frac{v_o^*}{r_o^* // r_{ds_{11}}} = 0.$$

$$-g_m^* v_{be_{D_1}} + g_m^* v_{be_{D_2}} + \frac{v_o^*}{r_o^* // r_{ds_1}} = 0$$

$r_{o_2} = 1M\Omega$.

$r_o^* = \frac{2}{3} r_{o_2} = 667K\Omega$

$$g_m^* (v_{be_{D_2}} - v_{be_{D_1}}) + \frac{v_o^*}{r_o^* // r_{ds_{11}}} = 0.$$

$$-g_m^* v_{id} + \frac{v_o^*}{r_o^* // r_{ds_{11}}} = 0.$$

$r_{ds_{11}} = 1M\Omega$.

$$\Rightarrow v_o^* = v_{id}\, g_m^* (r_o^* // r_{ds_{11}})$$

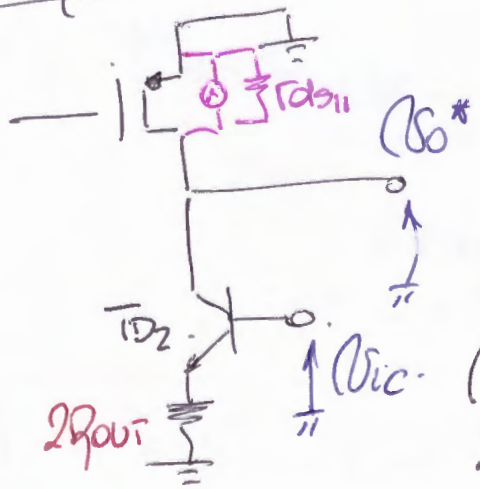
ENTONCES.

$$v_o = i_{d_9} 1K = g_{m_9} v_{id}\, g_m^* (r_o^* // r_{ds_{11}}) 1K$$

$$\Rightarrow A_{vd} = \frac{v_o}{v_{id}} = g_{m_9} g_m^* (r_o^* // r_{ds_{11}}) 1K.$$

$$\Rightarrow \boxed{A_{vd} = 1600.}$$

MODO COMÚN:



$$\frac{v_{ic}}{2R_{OUT}} + g_{m_{11}} v_{gs_{11}} + \frac{v_o^*}{r_{ds_{11}}} = 0.$$

$$\frac{v_{ic}}{2R_{OUT}} + g_{m_1} (-i_{c_1} (r_{d_{10}} // r_{ds_{10}})) + \frac{v_o^*}{r_{ds_{11}}} = 0$$

$$\frac{v_{ic}}{2R_{OUT}} \left[1 - g_{m_1} (r_{d_{10}} // r_{ds_{10}}) \right] + \frac{v_o^*}{r_{ds_{11}}} = 0$$

$$\frac{v_{ic}}{2R_{out}}\left[1 - g_{m_{11}}\frac{r_{d_{10}}\, r_{ds_{10}}}{r_{d_{10}} + r_{ds_{10}}}\right] + \frac{v_o^*}{r_{ds_{11}}} = 0.$$

$$\frac{v_{ic}}{2R_{out}}\left[1 - \frac{r_{ds_{10}}}{r_{d_{10}} + r_{ds_{10}}}\right] + \frac{v_o^*}{r_{ds_{11}}} = 0.$$

$$\frac{v_{ic}}{2R_{out}}\left[\frac{r_{d_{10}}}{r_{d_{10}} + r_{ds_{10}}}\right] + \frac{v_o^*}{r_{ds_{11}}} = 0$$

$$\frac{v_{ic}}{2R_{out}}\,\frac{r_{d_{10}}}{r_{ds_{10}}} + \frac{v_o}{r_{ds_{11}}} = 0. \; ; \; g_{m_{10}} = 0{,}2\,m.$$

$\hookrightarrow r_{d_{10}} = 5K.$

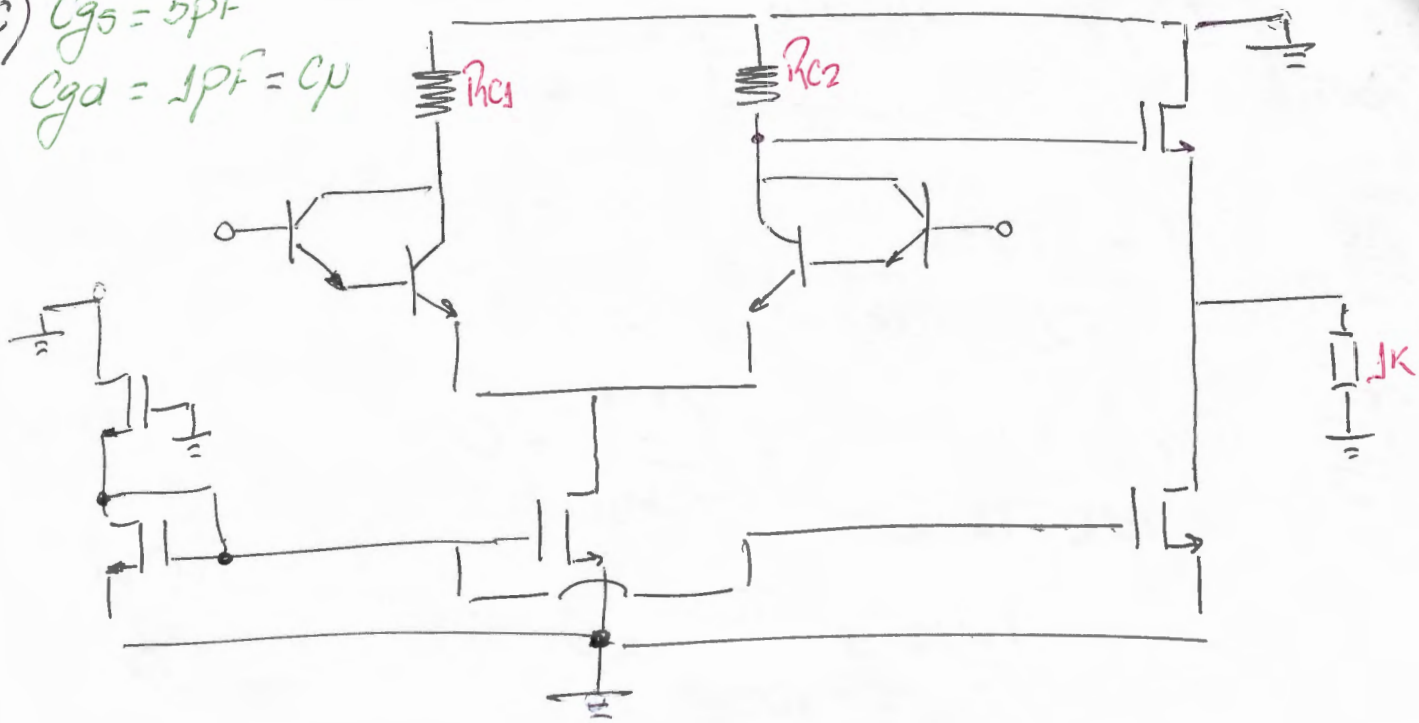
$$\Rightarrow A_{vc} = \frac{v_o}{v_{ic}} = -\frac{r_{d_{10}}}{2R_{out}} \Rightarrow \boxed{A_{vc} = -5\,m}$$

$$\Rightarrow \boxed{RRMC = \left|\frac{A_{vd}}{A_{vc}}\right| = \left|\frac{1600}{-5\,m}\right| = 320.000 \cong 110\,dB.}$$

$\hookrightarrow$ COMO ERA DE ESPERARSE, $\uparrow$ RRMC.

c) $C_{gs} = 5pF$

$C_{gd} = 1pF = C_\mu$

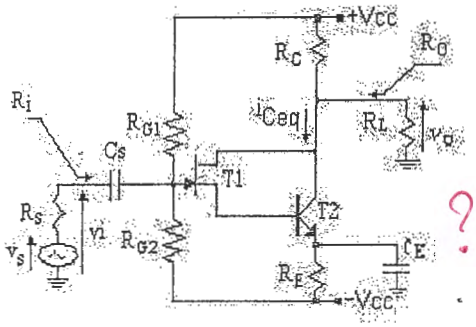


Para Estudiar

66.08 – 86.06 Evaluación integradora 2014/2- cuarta fecha - 18/02/15

APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
			M	T	N			

1.- Admitiendo que ambos transistores (de bajo nivel de potencia) se encuentran en modo activo, se conocen todos sus parámetros (de valores típicos), los valores de los resistores y capacitores y V_{CC}:

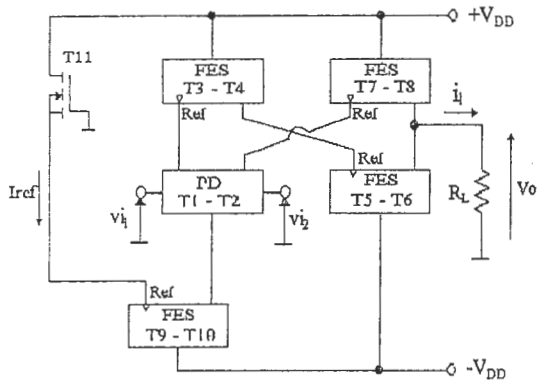


a) Si V_{CC} es del orden de 10 V, R_C y R_L de algunos KΩ y R_E de cientos de Ω, ¿podría estimarse un valor ***aproximado*** de V_{GSQ} sin cálculo previo?. ***Justificar***. Si V_{OQ} = 0V, justificar qué relación deberían tener entre sí los resistores del divisor de gate para funcionamiento en modo activo (cuál es mayor)

b) Hallar la expresión por inspección, justificando el procedimiento de la relación de pequeña señal $i_{ceq}/v_i|_{Vce(eq)=0}$ a frecuencias medias.

c) Explicar por qué el uso del modelo equivalente del darlington no resulta válido para el cálculo de la respuesta en alta frecuencia de este circuito. Justificar por qué sí resulta válido para el cálculo de la respuesta en baja frecuencia.

2 - a) Para $v_{i1} = v_{i2} = 0$, hallar todas las tensiones y corrientes de reposo del circuito, incluyendo I_{LQ}. Despreciar la corrección de I_{DQ} por el λ.



b) Hallar las expresiones y valor de:

$Gm_d = i_l / v_{id} |_{vo=0}$

$Gm_c = i_l / v_{ic} |_{vo=0}$.

Definir y hallar la expresión de la R_o vista por la carga. Obtener su valor. Definir y obtener $Av_d = v_o/v_{id}$.

c) Definir y hallar el rango de tensión de modo común.

FES: Fuente Espejo Simple – **PD:** Par Diferencial. Todos los MOSFET son inducidos (canal **N** ó **P** según corresponda)

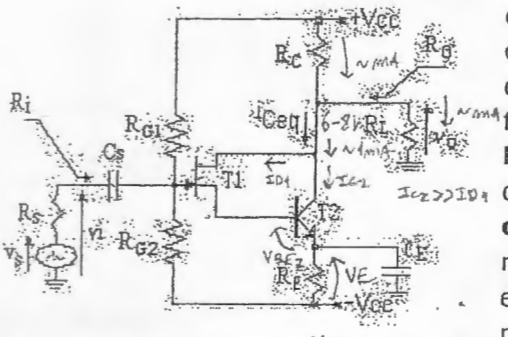
$\pm V_{DD}$= ±6V, $|V_T|$= 2V; $|K'|$= 100μA/V²; W/L= 2; λ= 0,01 1/V; γ ≅ 0 ; R_L = 10KΩ.

↳ IDEM 29/02/2016

66.08 – 86.06 Evaluación integradora [redacted] 3er fecha 2017/15

APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
			M	T	N			

1.- Admitiendo que ambos transistores (de bajo nivel de potencia) se encuentran en modo activo, se conocen todos sus parámetros (de valores típicos), los valores de los resistores y capacitores y V_{CC}:



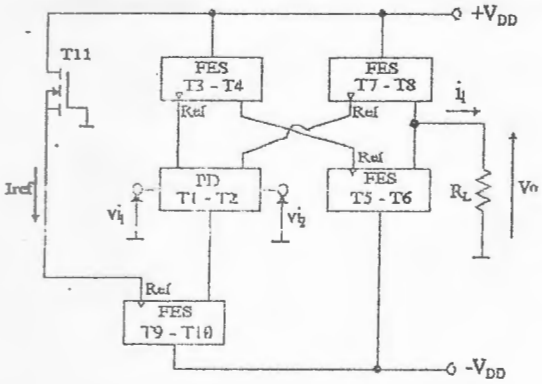
$V_{S2} = -8{,}8V\ ,\ -9{,}1V$ $\quad$ $V_E \sim -9{,}5V, -9{,}8V$

a) Si V_{CC} es del orden de 10 V, R_C y R_L de algunos KΩ y R_E de cientos de Ω, ¿podría estimarse un valor ***aproximado*** de V_{GSQ} sin cálculo previo?. ***Justificar***. Si V_{DQ} = 0V, justificar qué relación deberían tener entre sí los resistores del divisor de gate para funcionamiento en modo activo (cuál es mayor)

b) Hallar la expresión por inspección, justificando el procedimiento de la relación de pequeña señal $i_{ceq}/v_i|_{Vce(eq)=0}$ a frecuencias medias.

c) Explicar por qué el uso del modelo equivalente del darlington no resulta válido para el cálculo de la respuesta en alta frecuencia de este circuito. Justificar por qué sí resulta válido para el cálculo de la respuesta en baja frecuencia.

2 - a) Para $v_{i1} = v_{i2} = 0$, hallar todas las tensiones y corrientes de reposo del circuito, incluyendo I_{LQ}. Despreciar la corrección de I_{DQ} por el λ.



b) Hallar las expresiones y valor de:

$Gm_d = i_l/v_{id}\ |_{vo=0}$

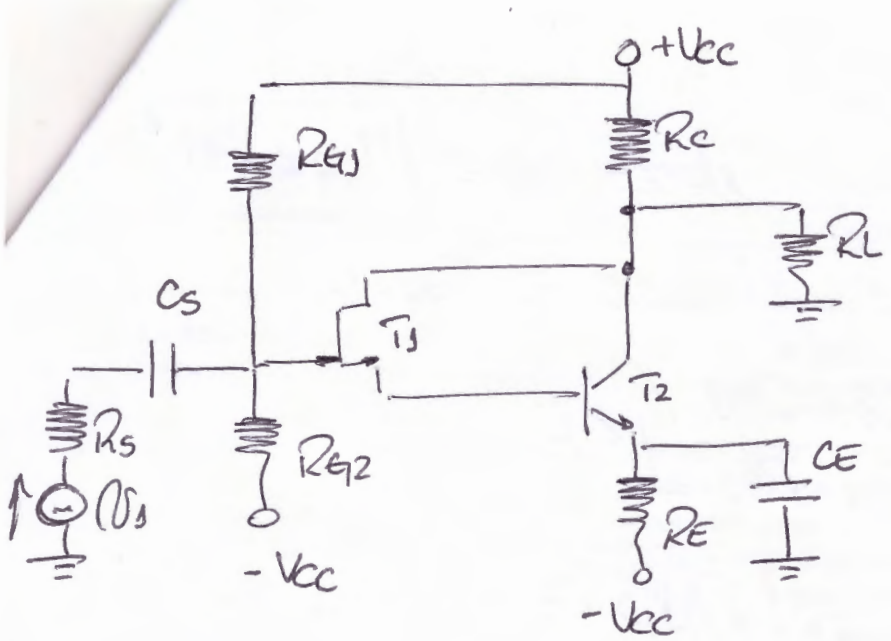
$Gm_c = i_l/v_{ic}\ |_{vo=0}$.

Definir y hallar la expresión de la R_o vista por la carga. Obtener su valor. Definir y obtener $Av_d = v_o/v_{id}$.

c) Definir y hallar el rango de tensión de modo común.

FES: Fuente Espejo Simple – **PD:** Par Diferencial. Todos los MOSFET son inducidos (canal **N** ó **P** según corresponda)

$\pm V_{DD} = \pm 6V$, $|V_T| = 2V$; $|K'| = 100\mu A/V^2$; $W/L = 2$; $\lambda = 0{,}01\ 1/V$; $\gamma \cong 0$; $R_L = 10K\Omega$.

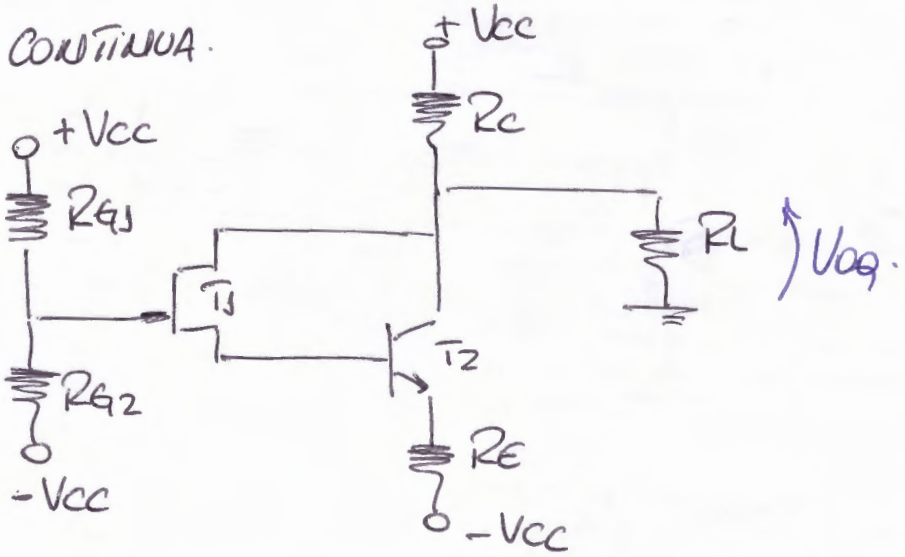


$V_{CC} \sim 30V$

$\left.\begin{matrix} R_C \\ R_L \end{matrix}\right\} K\Omega$

$R_E \rightarrow \Omega$

a) EN CONTINUA.



Si $V_{DQ} = 0V \Rightarrow I_{TOT} = \dfrac{V_{CC}}{R_C} \sim 3mA$

LUEGO: $I_{TOT} = I_{CQ} + I_{DQ} = I_{CQ} + \dfrac{I_{CQ}}{\beta}$

DESPRECIANDO I_{DQ}:

$$I_{CQ} \cong I_{TOT}$$

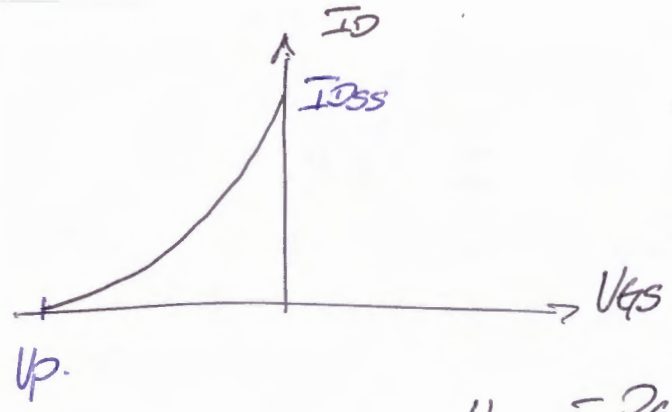
$$\Rightarrow V_{EQ} = -V_{CC} + I_{CQ} R_E < 0$$

$$V_{SQ} = V_{EQ} + 0{,}7V < 0$$

PARA QUE EL JFET ESTE EN MODO ACTIVO: $\boxed{V_P < V_{GSQ} < 0}$

$$V_{GQ} = \frac{2V_{CC} \cdot R_{G2}}{R_{G1}+R_{G2}} - V_{CC} = V_{CC}\left[\frac{2R_{G2}}{R_{G1}+R_{G2}} - 1\right]$$

$$V_{GQ} = V_{CC}\left[\frac{R_{G2}-R_{G1}}{R_{G1}+R_{G2}}\right]$$



$\Rightarrow V_{GSQ} = V_{GQ} - V_{SQ}$.

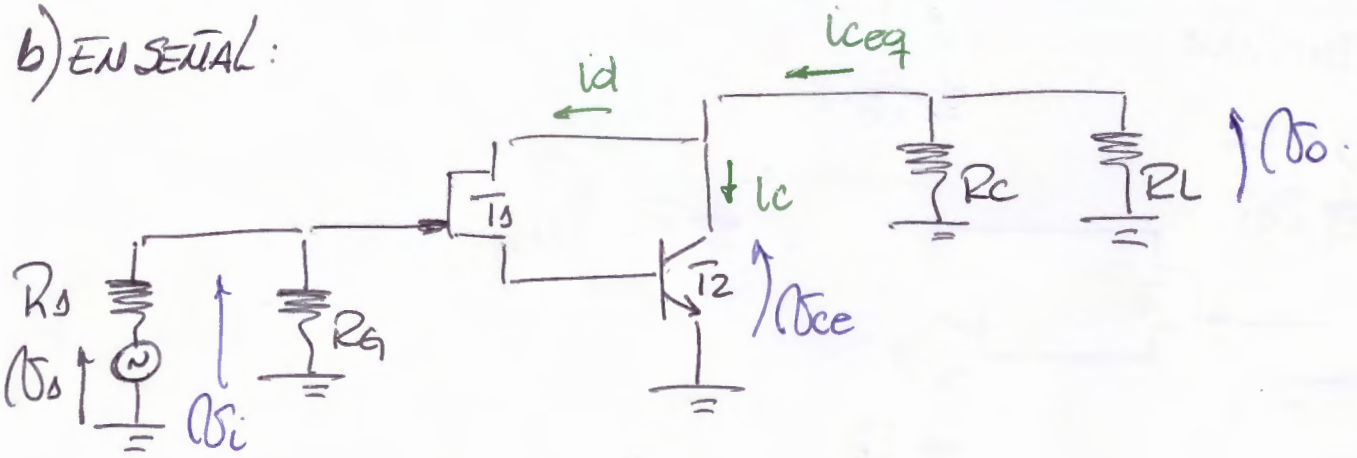
NECESITO QUE $\boxed{V_{GQ} < V_{SQ}}$.

$V_{SQ} < 0 \Rightarrow V_{GQ} < 0$

$$\Rightarrow V_{CC}\left[\frac{R_{G2}-R_{G1}}{R_{G1}+R_{G2}}\right] < 0.$$

$$\Rightarrow \boxed{R_{G1} > R_{G2}.}$$

b) EN SEÑAL:



BUSCO: $$g_m^* = \frac{i_{ceq}}{v_i}\Big|_{v_{ce}=0}.$$

AHORA BIEN $v_{ce} = -v_o = 0$.

$$\Rightarrow \left\{ i_{ceq} = i_d + i_c = i_d + \beta i_d = i_d(1+\beta) \approx \beta i_d \right\}$$

$$i_d = g_{m_{FET}} v_{gs} = g_{m_{FET}}(v_i - v_{be})$$

OTRO CAMINO:

$$v_i = i_g r_{gs} + i_d r_\pi = \frac{i_d}{\beta_{FET}} r_{gs} + i_d r_\pi$$

$$\left\{ v_i = i_d\left[r_{d_{FET}} + r_\pi\right] \right\}$$

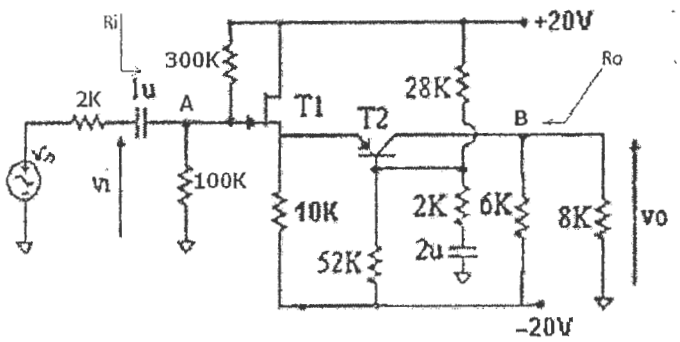
$$\Rightarrow \frac{i_{ceq}}{v_i} = \frac{\beta i_d}{i_d\left[r_{dFET} + r_\pi\right]} \Rightarrow \boxed{g_m^* = \frac{\beta}{r_{dFET} + r_\pi}}$$

66.08 - 86.06 Evaluación integradora 2015/2- quinta fecha - 29/02/16

APELLIDO	NOMBRE	PADRON	TURNO		Nº de hojas	Corrección	
			T	N			

1.- $\beta = 200$; $V_A \to \infty$; $r_x = 100\Omega$; $I_{DSS} = 12mA$; $V_P = -6V$; r_{gs} y $r_{ds} \to \infty$. $f_T = 200MHz$ $C_\mu = 1pF$ $C_{gs} = 5pF$ $C_{gd} = 1p$

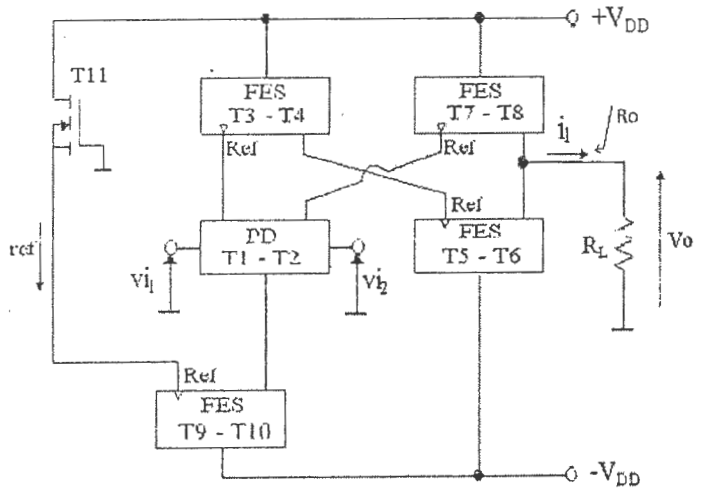
a) Obtener los puntos de reposo de los transistores, indicando las tensiones de sus terminales contra común.



b) Dibujar el circuito de señal sin reemplazar los transistores por su modelo circuital. Obtener *por inspección Ri, Ro*, $Av = v_o/v_i$ y $Av_s = v_o/v_s$.

c) Obtener el valor de la f_l aproximada. Analizar *cualitativamente* cuál podría considerarse el nodo dominante que determine el valor de f_h. Obtener f_h.

d) Se realimenta el circuito conectando una $R = 1M\Omega$ entre A y B. ¿Qué se muestrea y qué suma? ¿La realimentación es positiva o negativa?. *Justificar.*



2 - a) Para $v_{i1} = v_{i2} = 0$, hallar todas las tensiones y corrientes de reposo del circuito. Despreciar la corrección de I_{DQ} por el λ.

b) Hallar las expresiones y valor de:

$Gm_d = i_l / v_{id} \,|_{vo=0}$

$Gm_c = i_l / v_{ic} \,|_{vo=0}$.

Definir y hallar los valores de R_{id}, R_{ic} y R_o. Obtener $Av_d = v_o/v_{id}$ y $Av_c = v_o/v_{ic}$.

c) Analizar cualitativamente cómo se modifican todos los valores calculados si se reemplaza T9-T10 por una fuente Widlar con $R_E = 100\Omega$.

FES: Fuente Espejo Simple – **PD:** Par Diferencial. Todos TBJs (NPN ó PNP, según corresponda)

$\pm V_{DD} = \pm 6V$; $R_L = 1K\Omega$; $\beta = 100$; $V_A = 100V$; $V_T = 2V$; $K' = 100\mu A/V^2$; $W/L = 2$; $\lambda = 0{,}01\ V^{-1}$

1) EN CONTINUA:

$\beta = 200$; $V_A \to \infty$; $r_x = 100\Omega$

$I_{DSS} = 12mA$

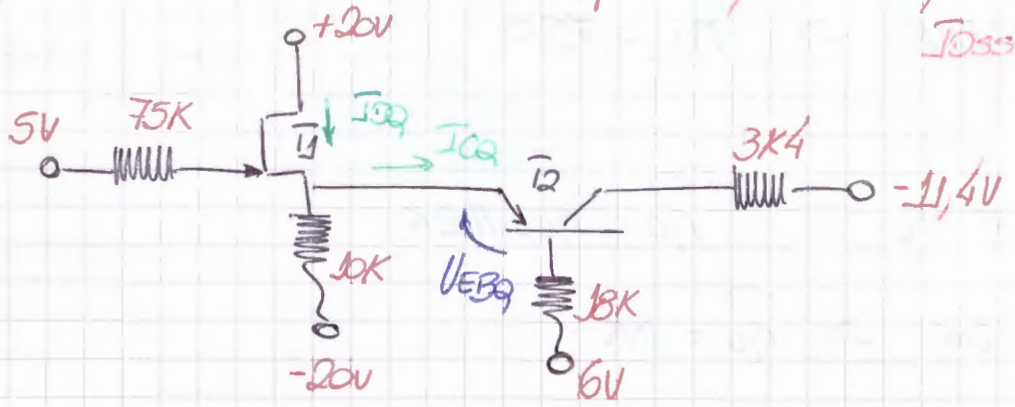
$V_P = -6V$

$f_T = 200MHz$

$C_\mu = 1pF$

$C_{gs} = 5pF$

$C_{gd} = 1pF$



DESPRECIO CAÍDA EN BASE:

$$\Rightarrow V_{BQ} = V_{BB} = 6V$$

$$\hookrightarrow V_{EQ} = V_{BQ} + 0{,}7V = 6{,}7V$$

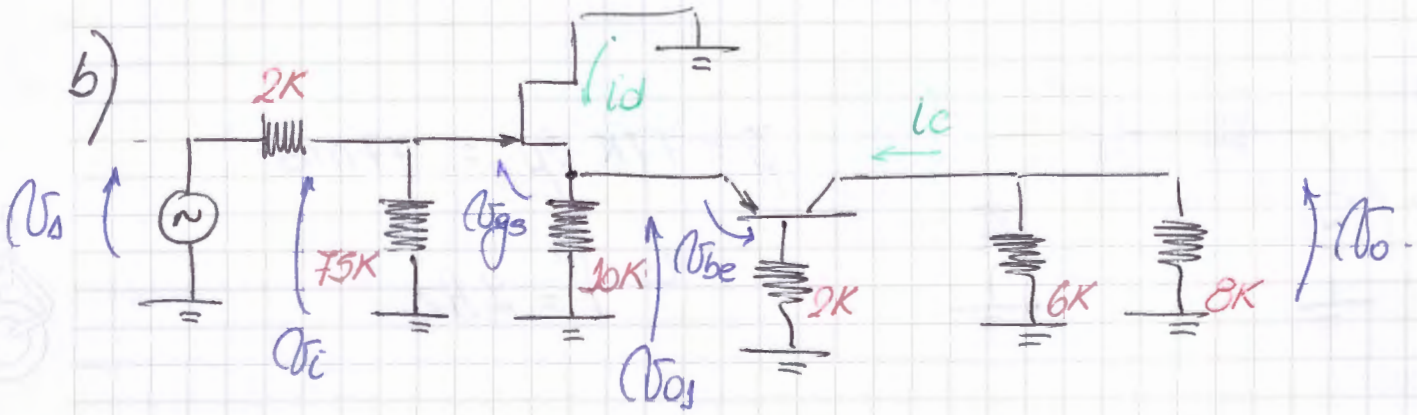
$$I_{10K} = I_{DQ} - I_{CQ} = \frac{6{,}7V - (-20V)}{10K} = 2{,}67mA$$

$$V_{GQ} = 5V \wedge V_{SQ} = V_{EQ} = 6{,}7V \Rightarrow V_{GSQ} = -1{,}7V$$

$$I_{DQ} = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2 = 6{,}16mA$$

$$\Rightarrow I_{CQ} = 3{,}49mA$$

b)



$\underline{R_i}$

$$R_{ig} = r_{gs} \quad ; \quad R_i = R_{ig} \,//\, 75K$$

$$R_{ig} \gg 75K \Rightarrow R_i = 75K$$

$\underline{R_o}$

$$R_{oc} \propto r_o \quad ; \quad R_o = R_{oc} \,//\, 6K$$

$$R_{oc} \gg 6K \Rightarrow R_o = 6K$$

PARÂMETROS. $g_{m1} \cong 10m$ $\qquad g_{m2} = 14m$

$r_\pi = 1K4$

$\underline{A_v}$:

$$A_{v1} = \frac{v_{o1}}{v_i} = \frac{i_d\left(10K \,//\, \frac{r_\pi + 2K}{\beta}\right)}{i_d\left(10K \,//\, \frac{r_\pi + 2K}{\beta}\right) + v_{gs}} = \frac{17}{17 + 100} = 0{,}15$$

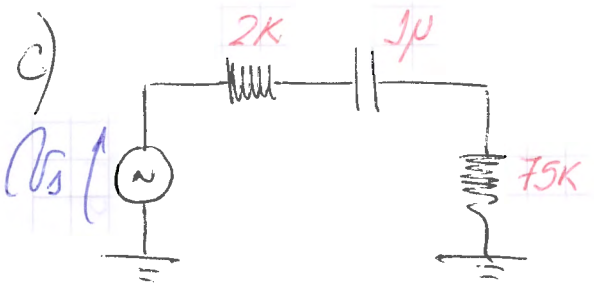
$$A_{v2} = \frac{v_o}{v_{o1}} = \frac{-i_c\,(6K \,//\, 8K)}{-i_b 2K - v_{be}} = \frac{3K4}{10 + 7} = 200$$

$$\Rightarrow A_v = 30$$

$\underline{A_{vs}}$

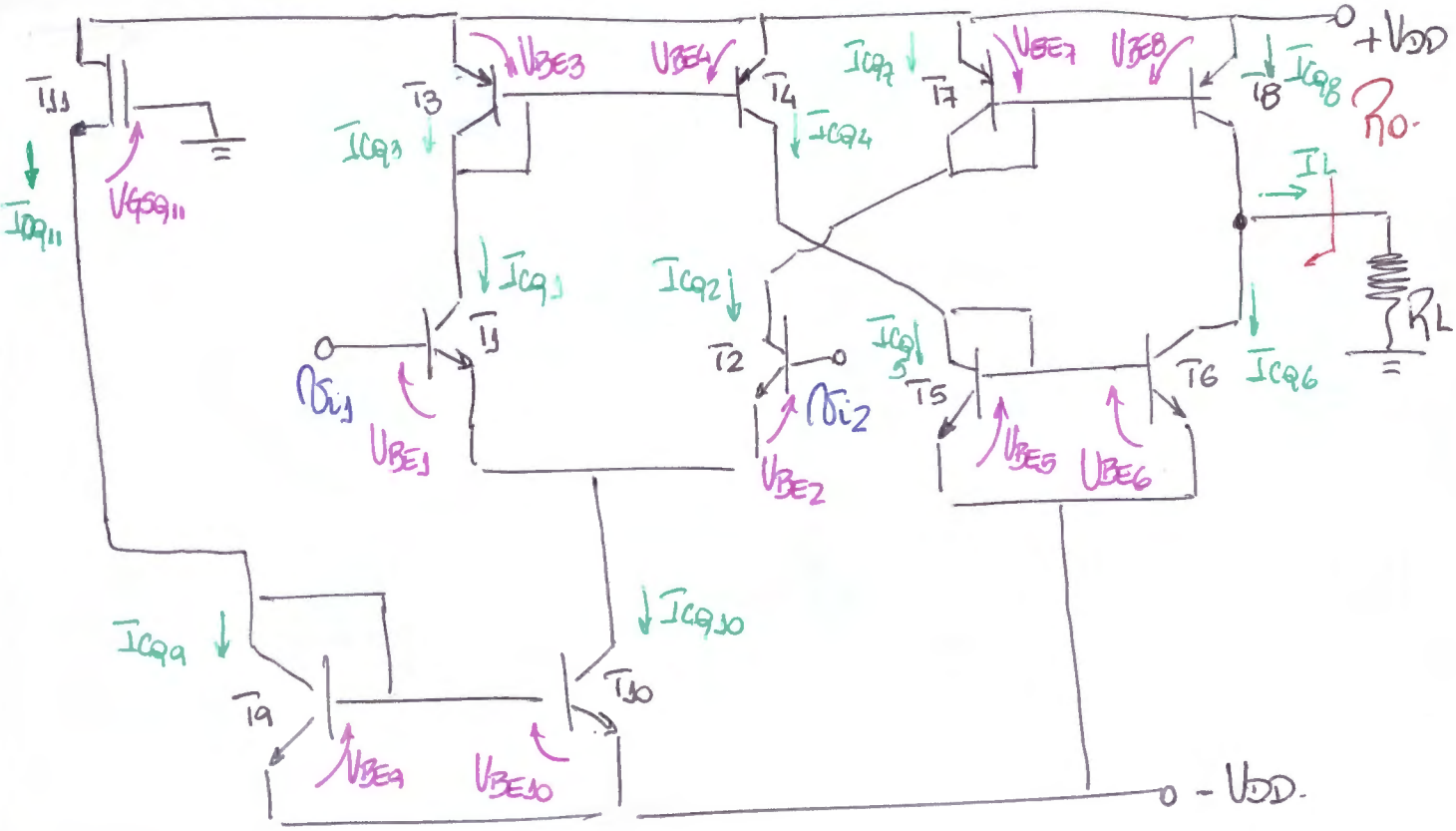
$$A_{vs} = A_v \frac{R_i}{R_i + R_s} = 29{,}2$$

c)



$$\tau = 77K \; 1\mu = 77ms$$

$$\hookrightarrow f = 2\,Hz$$



a) $R_{i1} = R_{i2} = 0.$

$$-V_{DD} + V_{BEQ} + V_{GSQ11} = 0.$$

$$-6V + 0{,}7V + V_{GSQ11} = 0.$$

$$\hookrightarrow \boxed{V_{GSQ11} = 5{,}3V}$$

$$I_{DQ11} = K' \frac{W}{L} (V_{GSQ11} - V_T)^2$$

$$\boxed{I_{DQ11} \cong 2{,}2mA}$$

$$\boxed{I_{CQ9} = I_{CQ10} = I_{DQ11} = 2{,}2mA}$$

$$\boxed{I_{CQ1} = I_{CQ2} = \frac{I_{CQ10}}{2} = 1{,}1mA}$$

$$\boxed{I_{CQ3} = I_{CQ1} = 1{,}1mA.}$$

$$\boxed{I_{CQ7} = I_{CQ2} = 1{,}1mA}$$

$$\boxed{I_{CQ4} = I_{CQ3} = 1{,}1mA}$$

$$\boxed{I_{CQ5} = I_{CQ4} = 1{,}1mA}$$

$$\boxed{I_{CQ6} = I_{CQ5} = 1{,}1mA}$$

$$\boxed{I_{CQ8} = I_{CQ7} = 1{,}1mA}$$

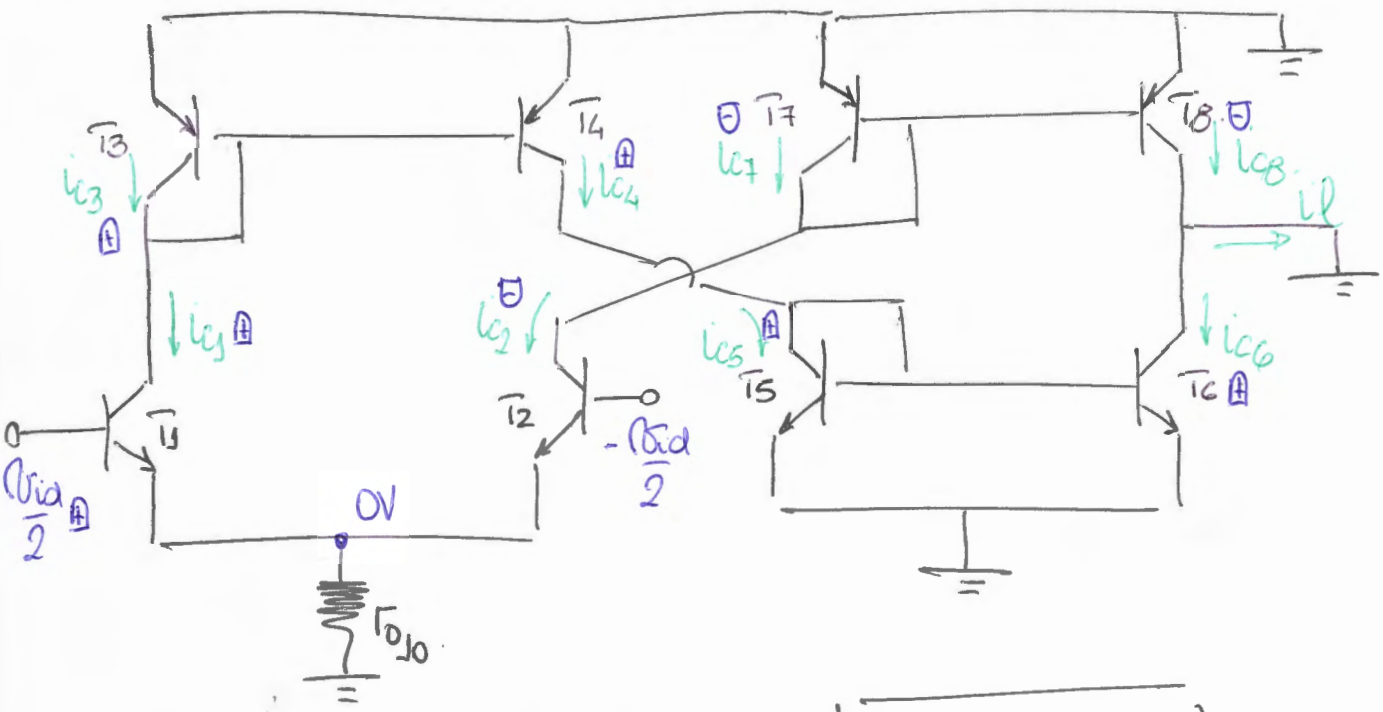
DADO QUE $I_{CQ8} = I_{CQ6}$

$$\hookrightarrow \boxed{I_{LQ} = 0.}$$

$$\boxed{V_{oQ} = 0V}$$

b) PARA ENTRADA DIFERENCIAL PURA: $G_{md} = \left.\dfrac{i_l}{v_{id}}\right|_{v_o=0}$.

EN SEÑAL



$$i_{c8} = i_l + i_{c6} \Rightarrow \boxed{i_l = i_{c8} - i_{c6}}$$

DEFINO: $K_{ES} = \dfrac{\beta}{\beta+2}$ $\Rightarrow$ •) $i_{c1} = g_{m1}\dfrac{v_{id}}{2}$

$i_{c3} = i_{c1}$

$i_{c4} = i_{c3} K_{ES}$

$i_{c5} = i_{c4} = i_{c3} K_{ES}$

$i_{c6} = i_{c5} K_{ES} = i_{c3} K_{ES}^2 = i_{c1} K_{ES}^2$

•) $i_{c2} = g_{m2}\left(-\dfrac{v_{id}}{2}\right)$

$i_{c7} = i_{c2}$

$i_{c8} = i_{c7} K_{ES} = i_{c2} K_{ES}$

$\Downarrow$

$$i_l = i_{c2} K_{ES} - i_{c1} K_{ES}^2 = \left\{ g_{m2}\left(-\frac{v_{id}}{2}\right) - g_{m1}\frac{v_{id}}{2} K_{ES} \right\} K_{ES}$$

$$i_l = K_{ES}\frac{v_{id}}{2}\left\{ -g_{m2} - g_{m1} K_{ES} \right\}.$$

$$\frac{i_l}{v_{id}} = \frac{K_{ES}}{2}\left\{ -g_{m2} - g_{m1} K_{ES} \right\} \; ; \quad g_{m1} = g_{m2} = g_m.$$

$$\Rightarrow G_{md} = -\frac{K_{ES}}{2} g_m \{1 + K_{ES}\} \quad ; \quad K_{ES} = 0{,}98$$

$$G_{md} = -\frac{g_m}{2}\{1 + K_{ES}\} \Rightarrow G_{md} \approx -g_m$$

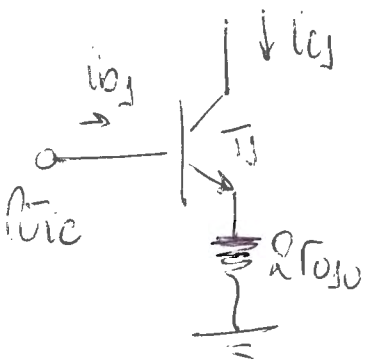
PARÁMETROS:

$$g_m = \frac{1{,}1\,mA}{U_{TA}} = 44\,\frac{mA}{V} \quad ; \quad r_\pi = 2K3 \,,\; r_{o10} = 45K$$

$$r_{o1aB} = 90K$$

$$\Rightarrow \boxed{G_{md} \simeq -44\,\frac{mA}{V}}$$

PARA ENTRADA COMÚN PURA:



$$i_{b1} = \frac{v_{ic}}{R_{ic}} = \frac{v_{ic}}{r_{\pi 1} + \beta\, 2 r_{o10}}$$

$$i_{b1} = \frac{v_{ic}}{r_{\pi 1} + r_{\pi 1} g_{m1} 2 r_{o10}}$$

$$i_{b1} = \frac{v_{ic}}{r_{\pi 1}[1 + 2 g_{m1} r_{o10}]} \simeq \frac{v_{ic}}{2 r_{\pi 1} g_{m1} r_{o10}}$$

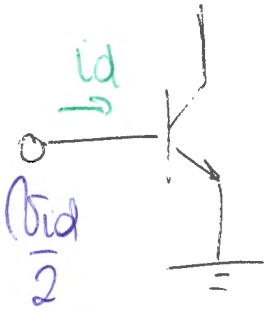
$$i_{b1} = \frac{v_{ic}}{2\beta r_{o10}} \Rightarrow i_{c1} = \beta\, i_{b1}$$

$$\boxed{i_{c1} = i_{c2} = \frac{v_{ic}}{2 r_{o10}}}$$

$$\Rightarrow \frac{i_l}{v_{ic}} = G_{mc} = \frac{i_{c8} - i_{c6}}{v_{ic}} = \frac{i_{c2} K_{ES} - i_{c1} K_{ES}^2}{v_{ic}}$$

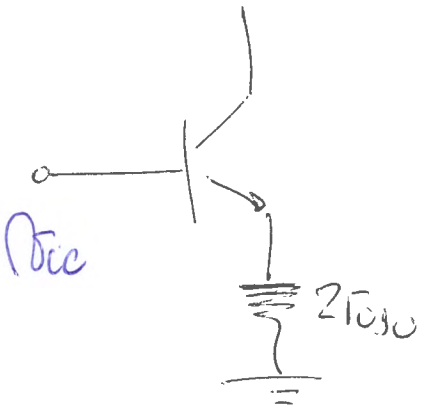
$$G_{mc} = \frac{K_{ES}}{2 r_{o10}}[1 - K_{ES}] = \frac{1}{2 r_{o10}}[1 - K_{ES}]$$

$$\Rightarrow \boxed{G_{mc} = 0{,}2\ \mu A/V}$$



$$R_{id} = \frac{v_{id}}{i_d} \quad ; \quad i_d\, r_\pi = \frac{v_{id}}{2}$$

$$\boxed{R_{id} = 2 r_\pi = 4K6}$$

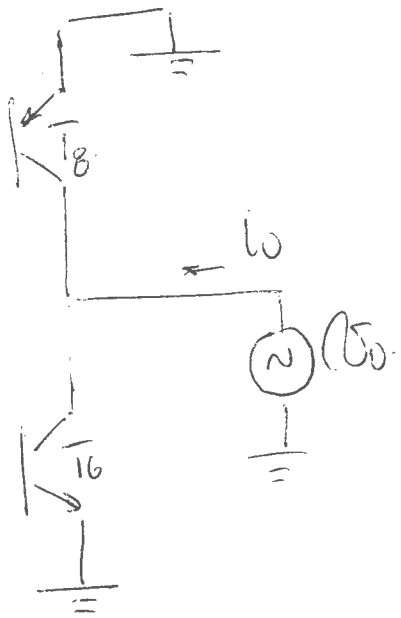


$$R_{ic} = r_\pi + \beta\, 2 r_{o30}$$

$$\boxed{R_{ic} = 9M\Omega}$$

PARA R_o

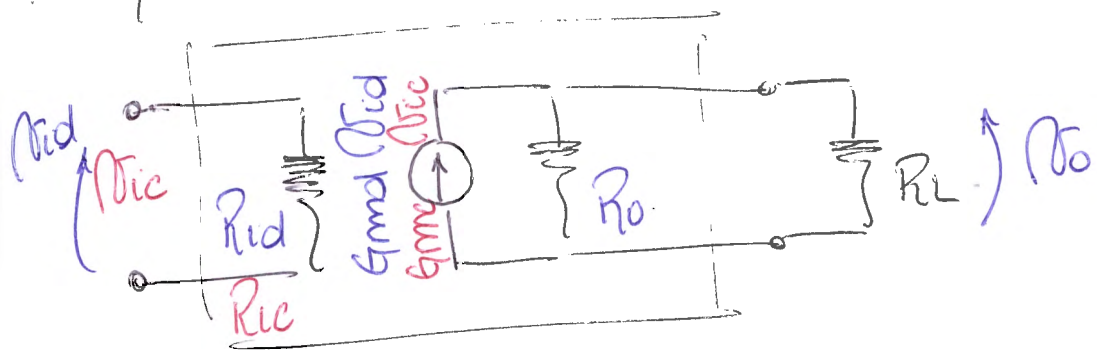
$$R_o = \frac{v_o}{i_o}\Big|_{v_{i1,2}=0}$$



$$\Rightarrow R_o = r_{o8} \,//\, r_{o6} = \frac{90K}{2}$$

$$\boxed{R_o = 45K}$$

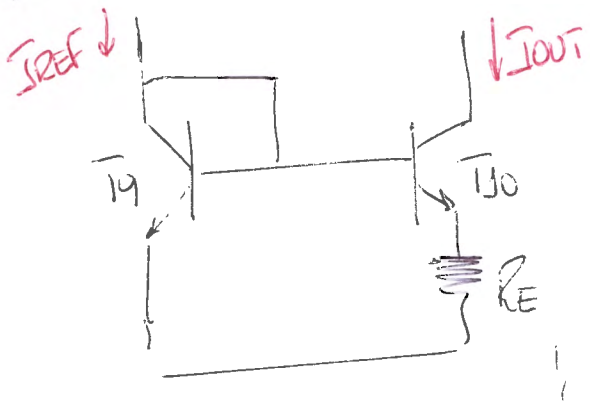
DIFERENCIAL ||| COMÚN |||



$$\Rightarrow A_{vd} = \frac{v_o}{v_{id}} = g_{md}\,(R_o // R_L)$$

$$\Rightarrow A_{vc} = \frac{v_o}{v_{ic}} = g_{mc}\,(R_o // R_L).$$

c) FUENTE WIDLAR



$$V_{BEq} = V_{BE_{10}} + I_{OUT} R_E$$

$$I_C = I_S\, e^{V_{BE}/V_{TH}}$$

$$V_{BE} = V_{TH} \ln\left(\frac{I_C}{I_S}\right)$$

$$V_{TH} \ln\left(\frac{I_{REF}}{I_S}\right) = V_{TH} \ln\left(\frac{I_{OUT}}{I_S}\right) + I_{OUT} R_E$$

$$V_{TH} \ln\left(I_{REF}/I_{OUT}\right) = + I_{OUT} R_E$$

↳ *) PUEDO TRABAJAR CON CORRIENTES MÁS PEQUEÑAS!

$$R_{OUT} = r_{o_{10}}\left[1 + \frac{\beta R_E}{R_E + r_{\pi_{10}} + r_{d9}}\right]$$

$I_{REF} >> I_{OUT}$

$g_{m9} >> g_{m10}$

$g_{m10} \downarrow\downarrow \Rightarrow r_{\pi_{10}} \uparrow\uparrow$

$$\hookrightarrow R_{OUT} = r_{o_{10}}\left[1 + \frac{\beta R_E}{r_{\pi_{10}}}\right] \Rightarrow R_{OUT} = r_{o_{10}}\left[1 + g_{m_{10}} R_E\right]$$

$\Rightarrow$ LA RESISTENCIA DE SALIDA AUMENTÓ

- $G_{md} = \cancel{\text{cte}} \downarrow$
- $G_{mc} \downarrow\downarrow$

$$RRMC = \left| \frac{A_{vd}}{A_{vc}} \right| = \left| \frac{G_{md}(R_o // R_L)}{G_{mc}(R_o // R_L)} \right|$$

$$RRMC = \left| \frac{G_{md}}{G_{mc}} \right|$$

$\hookrightarrow$ $RRMC \uparrow\uparrow$

- p/ Fotocopiar -

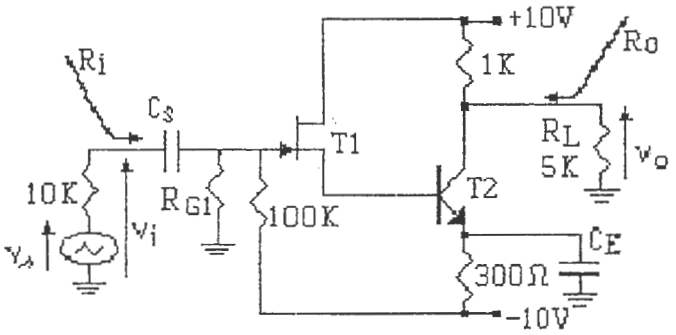
66.08 - Circuitos Electrónicos I — Evaluación integradora 2/11 - quinta fecha 29/02/11

APELLIDO	NOMBRE	PADRON	TURNO			Corrección	
			M	T	N		

1.- Dada la siguiente configuración, donde se tienen transistores con características:
$\beta = 50$; $V_A \to \infty$; $r_x = 100\Omega$; $C_\mu = 0{,}3$ pF, $f_T = 300$ MHz
$V_P = -1{,}5V$; $I_{DSS} = 4$ mA ; $r_{gs} = r_{ds} \to \infty$; $C_{gs} = 3$pF ; $C_{gd} = 0{,}5$ pF
$C_S = 10\ \mu F$; $C_E = 100\ \mu F$

Preguntar

a) Hallar el valor de R_{G1} de modo tal de obtener una $V_{OQ} = 0V$.



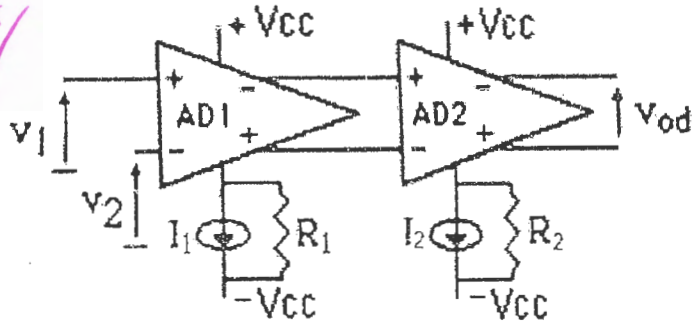
b) Dibujar el circuito de señal para frecuencias medias. Hallar las expresiones justificando ***por inspección*** y el valor de: R_i, R_o y A_v totales. Hallar A_{vs}.

c) Hallar el valor garantizable de f_h para A_{vs} (si se desprecia la influencia de uno o más nodos, se deberá justificar).

d) ¿Se modifican en forma importante los valores de reposo, A_v y/o f_h si se desconecta el drain de $+V_{CC}$ y se lo conecta al colector de T_2?. Justificar ***cualitativamente***.

2.- Se tiene el circuito de la figura formado por dos pares NMOSFET de canal inducido T_1-T_2 y T_3-T_4, acoplados por source, polarizados mediante fuentes de alimentación $\pm V_{CC}$ y fuentes de corriente I_1–R_1 e I_2-R_2 (admitir R_1 y R_2 >> r_{ds} de los NMOSFET). Se admiten en principio transistores con características similares (k', V_T, W, L y λ) e igual carga resistiva R_D, tal que $I_1.R_D$ e $I_2.R_D < V_{CC}$ en ambos pares. ¿Qué significado tiene esta última condición?.

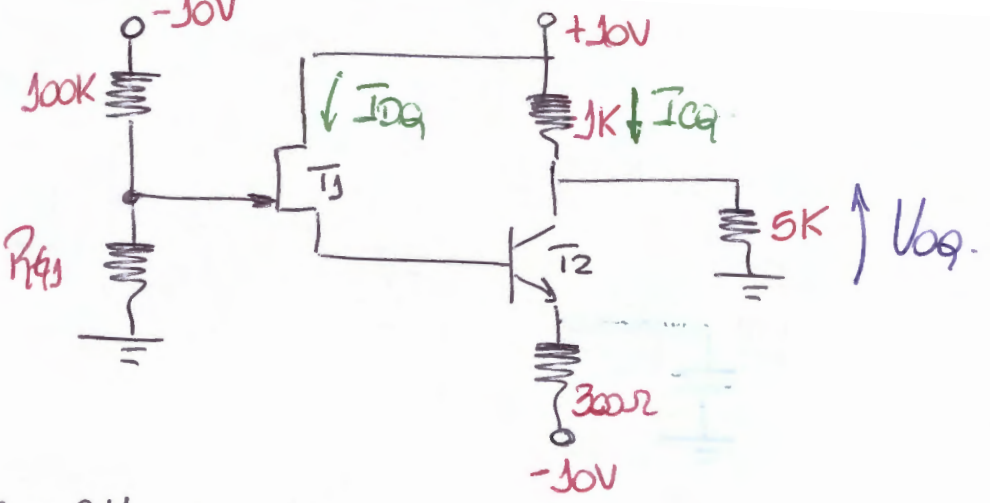
FALTA



a) Dibujar el circuito correspondiente de acuerdo con las características descriptas. ***Definir y hallar la expresión*** de la tensión de offset V_{off} del circuito si existe un desapareamiento en AD1: $(W_2 - W_1)/W_1=\delta$ donde $|\delta|<0{,}02$. Expresarla en función de δ. ¿Por qué es necesario ajustar el offset antes de calcular las amplificaciones de señal?.

b) Analizar ***cualitativamente*** si un desapareamiento en la 2da etapa, AD2: $(W_4 - W_3)/W_3=\delta$, de igual magnitud al analizado en a), afectará del mismo modo en el valor de V_{off}. ***Justificar***.

1) a)



Si $V_{oQ} = 0V \Rightarrow I_{CQ} = \frac{10V}{1K} = 10mA$

LUEGO: $I_{DQ} = I_{BQ} = \frac{I_{CQ}}{\beta} \Rightarrow I_{DQ} = 0{,}2mA = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2$

$\hookrightarrow V_{GSQ} = V_P - \sqrt{\frac{0{,}2mA}{I_{DSS}}}\, V_P$

$V_{GSQ} = -1{,}16V$

AHORA BIEN: $V_{GSQ} = V_{GQ} - V_{SQ}$

$\hookrightarrow$ •) $V_{SQ} = -10V + I_{CQ}\, 300\Omega + 0{,}7V = -6{,}3V$

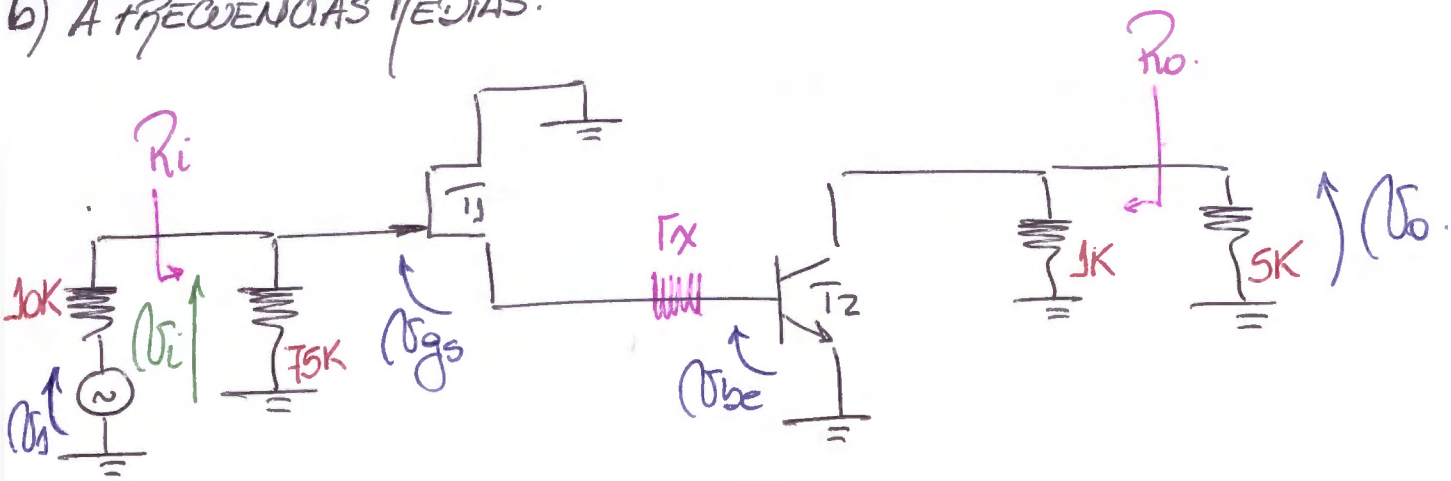
$\hookrightarrow$ •) $V_{GQ} = -10V \frac{R_{G1}}{R_{G1} + 100K}$

$\Rightarrow -\frac{10V\, R_{G1}}{R_{G1} + 100K} - (-6{,}3V) = -1{,}16V$

$\frac{R_{G1}}{R_{G1} + 100K} = 0{,}746$

$\hookrightarrow \boxed{R_{G1} = 294K}$

b) A FREQUENCIAS MEDIAS:



$\underline{Ri}$: $Ri = 75K \,//\, Rig$ DONDE $Rig = rgs \to \infty$.

$\Rightarrow \boxed{Ri = 75K}$

PARÁMETROS:

$gm_1 = 1{,}8\,m$

$gm_2 = 400\,m = 0{,}4$

$r_\pi = 125\,\Omega$

$r_o = V_A / I_{CQ} \to \infty$

$\underline{Ro}$: $\boxed{Ro = 1K}$

$\underline{Av}$: $$Av_1 = \frac{Vbe}{Vi} = \frac{id(r_\pi + rx)}{id(r_\pi + rx) + Vgs} = \frac{r_\pi + rx}{r_\pi + rx + rd_1} \cong 0{,}29$$

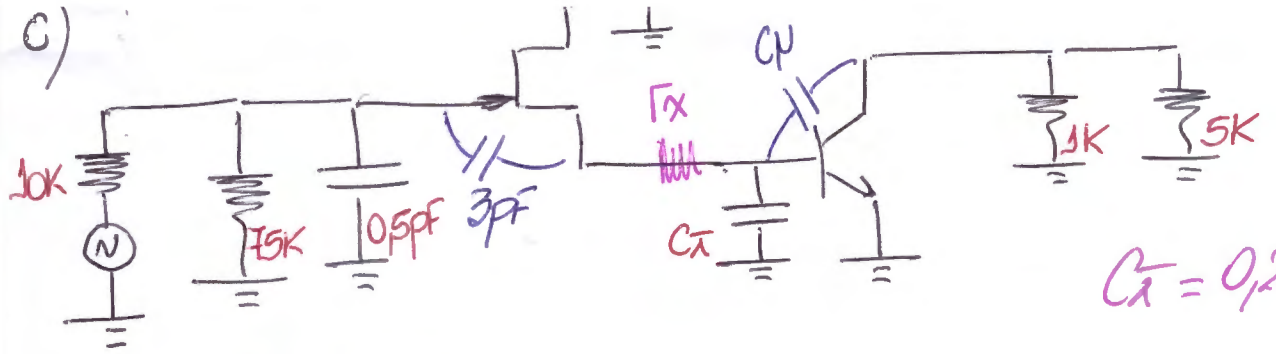
$$Av_2 = \frac{Vo}{Vbe} = \frac{-ic(1K//5K)}{Vbe + ib\,rx} = -\frac{(1K//5K)}{rd_2 + rx/\beta} \cong -185$$

$\Rightarrow Av = Av_1 \cdot Av_2$

$\boxed{Av \cong -53{,}7}$

$$Avs = \frac{Vo}{Vs} \cdot \frac{Vi}{Vi} = \frac{Vo}{Vi} \cdot \frac{Vi}{Vs} = Av \frac{Ri}{Ri + 10K} \Rightarrow \boxed{Avs = -47{,}4}$$

c)



$C_\pi = 0{,}21\,nF$

TENGO QUE REFLEJAR C_μ:

$$C_{\mu b} = C_\mu \left(1 - \frac{v_c}{v_{bp}}\right) = C_\mu \left(1 - \frac{v_o}{v_{be}}\right)$$

$$C_{\mu b} = C_\mu \left(1 + g_{m2}(1K \| 5K)\right) = C_\mu\, 333 = 0{,}1\,nF$$

$$\Rightarrow \quad C_b = C_\pi + C_{\mu b} = 0{,}31\,nF$$

[DEBERÍA SER A_{v2}?
$C_{\mu b} = (1 - A_{v2})\, C_\mu$
$C_{\mu b} \doteq 186\, C_\mu$]

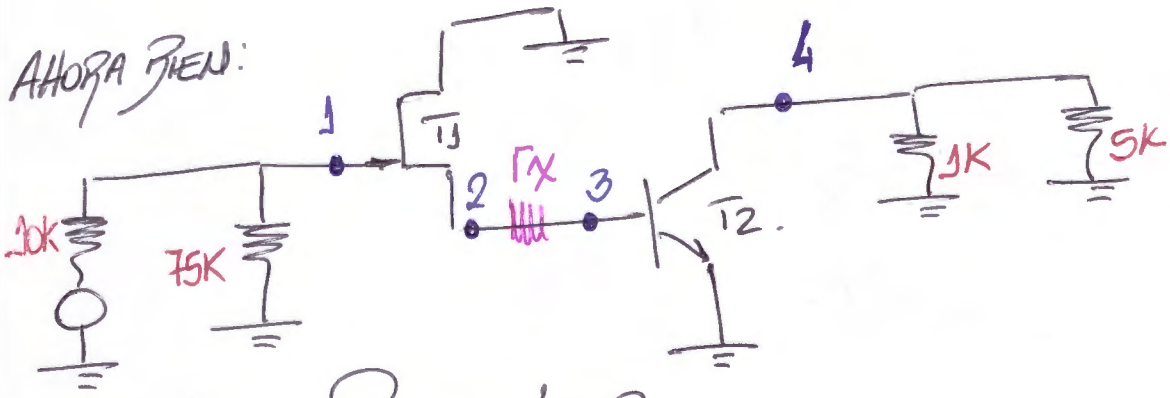
ANÁLISIS CUALITATIVO:

BUSCO LA FRECUENCIA DE CORTE SUPERIOR MÁS CHICA.

$$f_h = \frac{1}{2\pi \tau} \quad \Rightarrow \text{BUSCO EL } \tau \text{ MÁS GRANDE.}$$

DONDE: $\tau = RC$

AHORA BIEN:



$C_{gs} = 3\,pF$
$C_{gd} = 0{,}5\,pF$
$C_\mu = 0{,}3\,pF$
$C_\pi = 0{,}21\,pF$

TENGO 4 NODOS PARA ANALIZAR.

1) VEO UNA RESISTENCIA EQUIVALENTE $R_{eq} \cong 9K$.
CAPACIDADES TENGO A C_{gd} Y C_{gs} QUE SE REFLEJA MÁS CHICA (C_{gs}^*)

$$\rightarrow C_{eq} = C_{gd} + C_{gs}^* \; ; \; C_{gs}^* < C_{gs}$$

2) VEO UNA RESISTENCIA EQUIVALENTE MUY PEQUEÑA

$$R_{eq} = r_x + r_\pi = 225\Omega$$

VEO UNA CAPACIDAD EQUIVALENTE $C_{gs}^{**} < C_{gs}$?

3) $R_{eq} = (r_{d1} + r_x) \parallel r_\pi \cong 105\,\Omega$.

$C_{eq} = C_\pi + C_{\mu b}$ DONDE $C_{\mu b} > C_\mu$

4) $R_{eq} = 1K \parallel 5K \cong 833\,\Omega$.

$C_{eq} = C_\mu$

~~⇒ QUIEN DEFINE f_h ES EL NODO~~

3) $C_{eq} = C_\pi + C_\mu (1 - A_{v2})$

$C_{eq} = 0{,}27\,nF$.
$R_{eq} = 105\,\Omega$ } $\tau \cong 28\,ns$.

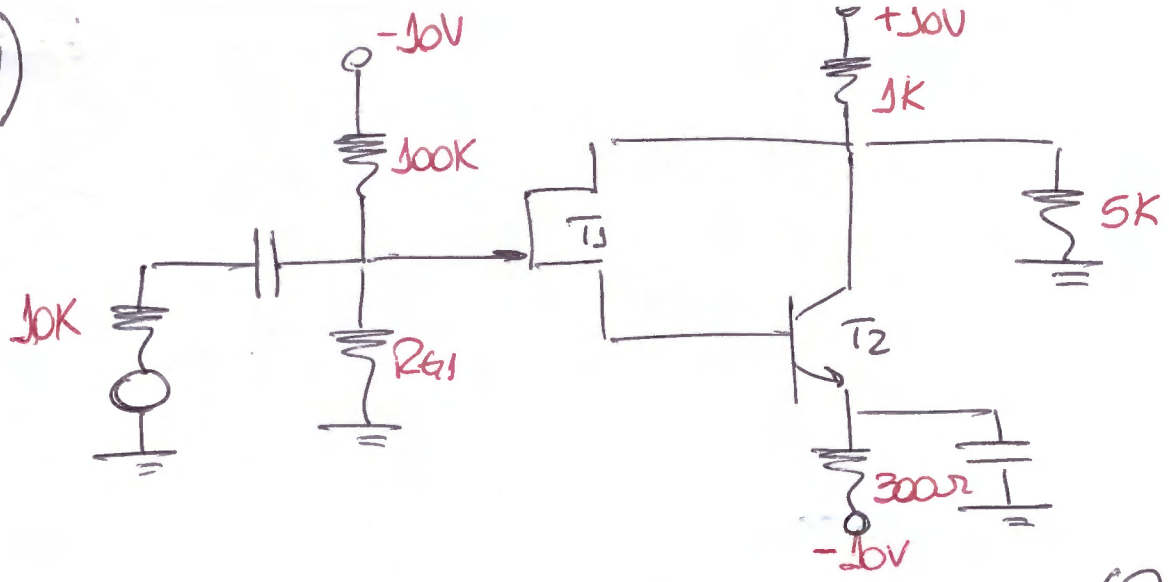
1) $C_{eq} = C_{gd} + C_{gs}(1 - 0{,}18)$.

$C_{eq} \cong 3pF$.
$R_{eq} = 9K$ } $\tau \approx 27\,ns$.

$\Rightarrow \tau = 28\,ns + 27\,ns = 55\,ns$.

↳ $\boxed{f_h \cong 3\,MHz}$.

d)



LOS TRANSISTORES QUEDAN EN CONFIGURACIÓN IGBT (DARLINGTON HIBRIDO).

⇒ PARA POLARIZACIÓN NO VARÍA POR LA RELACIÓN DE CORRIENTES.

$I_{TOT} = I_{CQ} + I_{DQ}$; PERO $I_{DQ} = \frac{I_{CQ}}{\beta}$

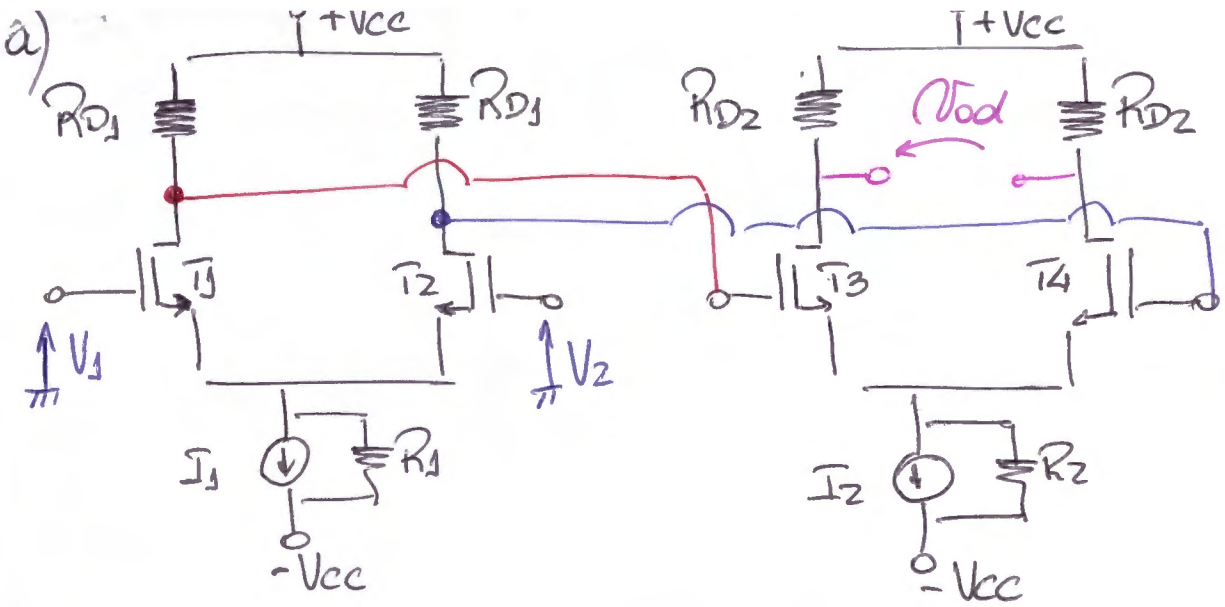
⇒ $I_{DQ} << I_{CQ}$.

PARA ESTE CASO R_i Y R_o SON LA MISMAS !!!

⇒ AV NO CAMBIA !

LA RESPUESTA EN FRECUENCIA SI VARÍA PUÉS EN EL NODO 1 YA NO TENEMOS C_{gd}, SINO QUE C_{gd} AMPLIFICADO !

a)



SE DEFINE:

$$v_{od} = A_{vdd(2)} v_{id(2)} + A_{vdc(2)} v_{ic(2)}$$

BUSCO QUE:

$$v_{id(1)} = v_{OFF} \Rightarrow v_{od} = 0.$$

AHORA BIEN EN AD2 NO HAY DESAPAREAMIENTO $\Rightarrow A_{vdc(2)} = 0.$

$$v_{od} = A_{vdd(2)} v_{id(2)}$$

DONDE $v_{id(2)} = v_{od(1)} = A_{vdd(1)} v_{id(1)} + \underbrace{A_{vdc(1)}}_{\neq 0 \rightarrow \text{HAY DESAPAREAMIENTO}} v_{ic(1)}$

$$\Rightarrow v_{od} = A_{vdd(2)} \left[A_{vdd(1)} v_{id(1)} + A_{vdc(1)} v_{ic(1)} \right]$$

BUSCO $v_{od} = 0 \Rightarrow v_{id(2)} = v_{od(1)} = 0$ SIENDO $v_{id} = v_{OFF}$

$$\Rightarrow v_{OFF} = v_{id} = v_{gs1} - v_{gs2} \quad ; \quad I_D = K' \frac{W}{L} (v_{gs} - V_T)^2.$$

$$v_{gs} = \sqrt{\frac{I_D}{K'W/L}} + V_T$$

$$v_{OFF} = \sqrt{\frac{I_{DQ1}}{K_1' W_1/L_1}} + V_T - \sqrt{\frac{I_{DQ2}}{K_2' W_2/L_2}} - V_T$$

AL APLICAR $v_{OFF} \Rightarrow I_{DQ1} = I_{DQ2} = \frac{I_1}{2}$

$$v_{OFF} = \sqrt{\frac{I_{DQ1}}{K_1' W_1/L_1}} - \sqrt{\frac{I_{DQ2}}{K_2' W_2/L_2}} \; ;$$

$$V_{OFF} = \sqrt{\frac{I_{DQ1}}{K'/L_1}} \left\{ \frac{1}{\sqrt{W_1}} - \frac{1}{\sqrt{W_2}} \right\} = \sqrt{\frac{I_{DQ1}}{K' W_1/L_1}} \left\{ 1 - \frac{1}{\sqrt{W_2/W_1}} \right\}$$

$$V_{OFF} = \sqrt{\frac{I_{DQ1}}{K' W_1/L_1}} \left\{ 1 - \frac{1}{\sqrt{W_2/W_1}} \right\} \quad ; \quad \frac{W_2 - W_1}{W_1} = \delta \qquad \frac{W_2}{W_1} = 1+\delta$$

$$V_{OFF} = \sqrt{\frac{I_{DQ1}}{K' W_1/L_1}} \left\{ 1 - \frac{1}{\sqrt{1+\delta}} \right\}$$

$$V_{OFF} = \sqrt{\frac{I_{DQ1}}{K' W_1/L_1}} \left\{ 1 - \frac{1}{1+\delta/2} \right\} = \sqrt{\frac{I_{DQ1}}{K' W_1/L_1}} \left\{ \frac{\delta/2}{1+\delta/2} \right\}$$

$$\boxed{V_{OFF} = \sqrt{\frac{I_{DQ1}}{K' W_1/L_1}} \; \frac{\delta}{2}}$$

b) $V_{od} = A_{vdd(2)} V_{id(2)} + \underbrace{A_{vdc(2)}}_{\neq 0 \rightarrow \text{HAY DESAPAREAMIENTO}} V_{ic(2)}$

$V_{id(2)} = V_{od(1)} = A_{vdd(1)} V_{id(1)} + \underbrace{A_{vdc(1)}}_{=0 \rightarrow \text{NO HAY DESAPAREAMIENTO}} V_{ic(1)}$

$V_{id(2)} = V_{od(1)} = A_{vdd(1)} V_{id(1)}$; $V_{id(1)} = V_{id}$

$V_{ic(2)} = A_{vcc(1)} V_{ic(1)} + \underbrace{A_{vcd(1)}}_{=0} V_{id(1)}$

$V_{ic(2)} = A_{vcc(1)} V_{ic}$

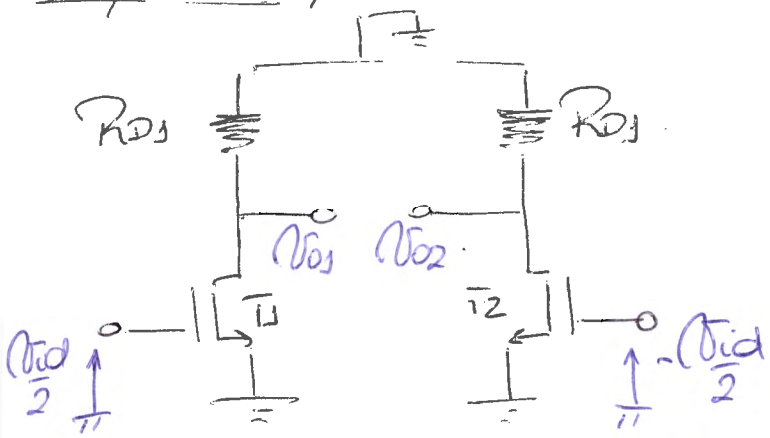
$\Rightarrow V_{od} = A_{vdd(2)} A_{vdd(1)} V_{id} + A_{vdc(2)} A_{vcc(1)} V_{ic}$

Busco $V_{od} = 0 \Rightarrow V_{id(2)} = V_{od(1)} = V_{OFF_2} = A_{vdd(1)} V_{id}$

$\Rightarrow V_{OFF} = \frac{V_{OFF2}}{A_{vdd(1)}}$; $V_{OFF} = \sqrt{\frac{I_{DQ3}}{K' W_3/L_3}} \frac{\delta}{2}$; $I_{DQ3} = \frac{I_2}{2}$

$$A_{vdd(1)} = \frac{v_{od(1)}}{v_{id}}$$

ENTRADA DIFERENCIAL PURA



$$v_{o1} = -i_{d1} R_{D1} = -g_{m1} v_{gs1} R_{D1} = -g_{m1} \frac{v_{id}}{2} R_{D1}$$

$$v_{o2} = -i_{d2} R_{D1} = -g_{m2} v_{gs2} R_{D2} = g_{m2} \frac{v_{id}}{2} R_{D1}$$

$$v_{od(1)} = v_{o1} - v_{o2} = -g_{m1} \frac{v_{id}}{2} R_{D1} - g_{m2} \frac{v_{id}}{2} R_{D1}$$

$$v_{od(1)} = -\frac{v_{id}}{2} R_{D1} (g_{m1} + g_{m2})$$

$$T_1 \equiv T_2 \wedge I_{DQ1} = I_{DQ2} \Rightarrow g_{m1} = g_{m2} = g_{mAD1}$$

$$\Rightarrow \frac{v_{od(1)}}{v_{id}} = -g_{mAD1} R_{D1} = A_{vdd(1)}$$

$$\Rightarrow \boxed{v_{OFF} = \sqrt{\frac{I_{DQ3}}{K' W_3/L_3}} \frac{\delta}{2 g_{mAD1} R_{D1}}}$$

CASO a) Busco: $V_{id} = V_{OFF}$ / $V_{od} = 0$.

DESAPAREAMIENTO EN AD1

Si $V_{id} = V_{OFF} \Rightarrow V_{od(1)} = 0 = V_{id(2)}$

Si $V_{id(2)} = 0 \Rightarrow V_{od} = 0$.

CASO b)

DESAPAREAMIENTO EN AD2.

$\Rightarrow V_{od} = 0 \Rightarrow V_{id(2)} = V_{OFF_2} = V_{od(1)}$

$V_{od(1)} = A_{Vdd(1)} V_{id} = V_{OFF_2}$.

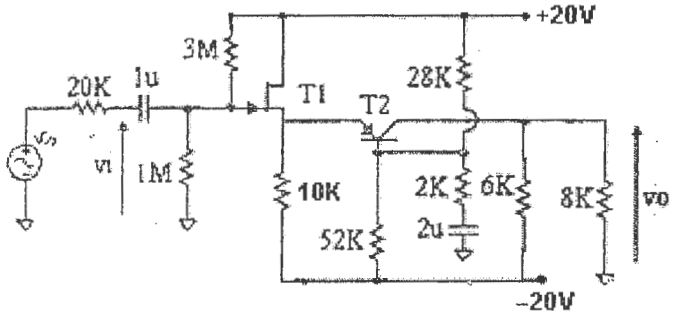
$$\Rightarrow V_{id} = V_{OFF} = \frac{V_{OFF_2}}{A_{Vdd(1)}}$$

7 Fotocopiar

66.08 - 86.06 Evaluación integradora 2014/2- quinta fecha - 25/02/15

APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
			M	T	N			

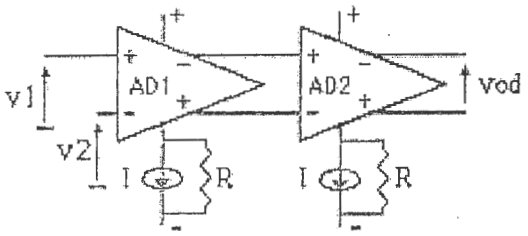
1.- $\beta = 200$; $V_A \to \infty$; $r_x = 100\Omega$; $I_{DSS} = 12mA$; $V_P = -6V$; r_{gs} y $r_{ds} \to \infty$.



a) Obtener los puntos de reposo de los transistores, indicando las tensiones de los tres terminales de cada uno contra común (V_Q).

b) Dibujar el circuito de señal sin reemplazar los transistores por su modelo circuital. Definir, obtener *por inspección* las resistencias de entrada, de salida y de carga de cada etapa; la amplificación de tensión de cada una y la total $Av = v_o/v_i$. Obtener $Av_s = v_o/v_s$.

c) Obtener por inspección el valor de la frecuencia de corte inferior aproximada. Analizar *cualitativamente* cuál podría considerarse del nodo dominante que determine el valor de f_h.



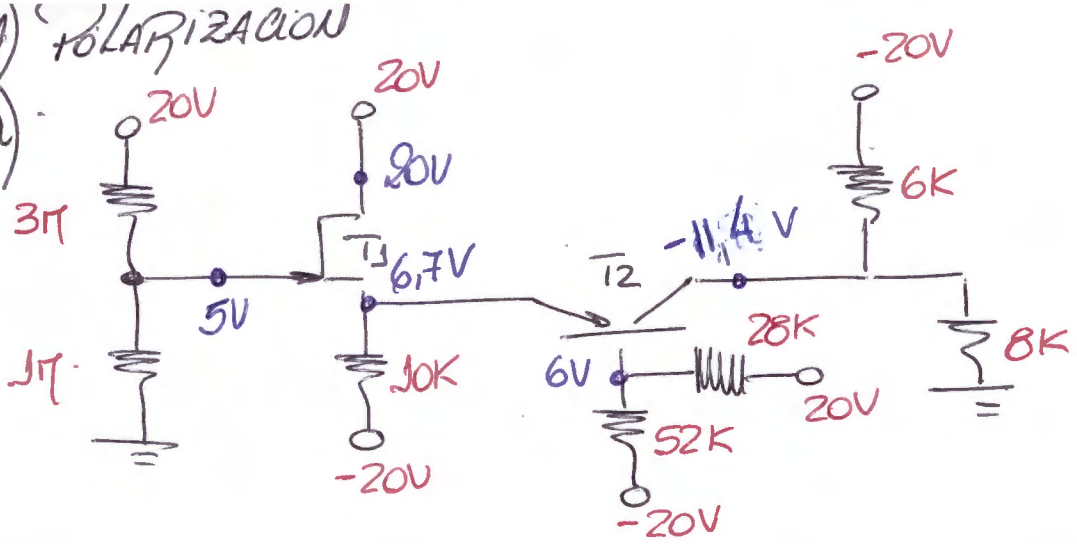
2.- Se tiene el circuito de la figura formado por dos pares NMOSFET T_1-T_2 , T_3-T_4, acoplados por source, polarizados mediante fuente de alimentación $\pm V_{DD}$ y una fuente de corriente I - R. Se admiten en principio transistores cuasi-apareados, con carga $R_{D\ (AD1)}$ y $R_{D\ (AD2)}$, admitiéndose para ambos pares: $I.R_D < V_{DD}$. *¿Qué significa esta condición?*

a) Dibujar el circuito correspondiente de acuerdo con los signos de los terminales inversor y no inversor. Si en el AD1, existe un desapareamiento tal que $100(R_{D2} - R_{D1}) / R_{D1} = \alpha$, donde $|\alpha| < 3\%$, obtener las expresiones de $Av_d = (v_{od} / v_{id})|_{vic = 0}$ y $Av_c = (v_{od} / v_{ic})|_{vid = 0}$ totales y de su cociente para la salida v_{od} indicada, en función de α. *¿Por qué estas expresiones son válidas sólo si se ajusta previamente la tensión de offset?*.

b) Repetir a) si en el AD2, $100(R_{D4} - R_{D3}) / R_{D3} = \alpha$. Analizar cualitativamente a cuál de los dos juegos de expresiones obtenidas se acercarán más los valores de la RRMC si existieran ambos desapareamientos a la vez. *(Considerar valores típicos si fuese necesario).*

1) POLARIZACION

a)



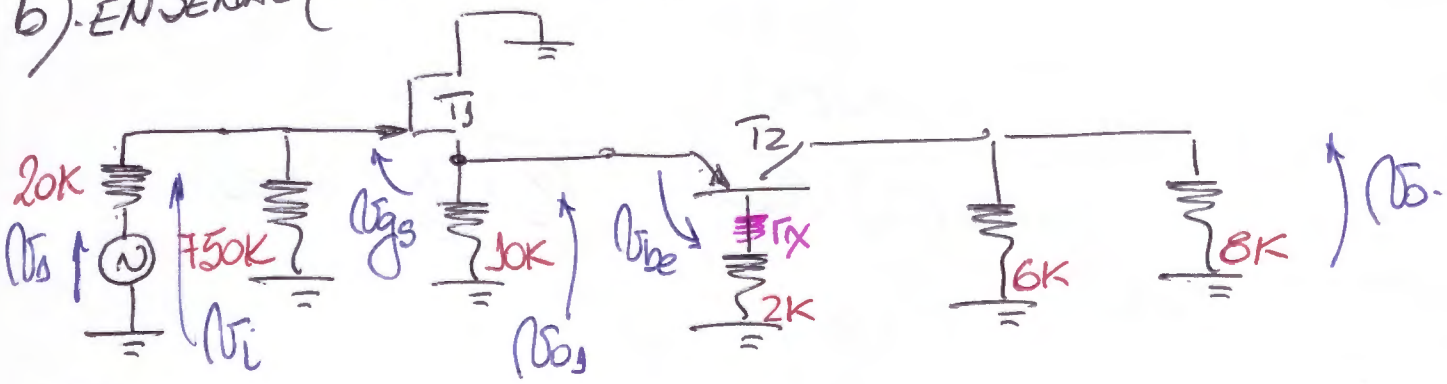
$$V_{GQ} = \frac{20V \cdot 1M}{1M+3M} = 5V \quad ; \quad V_{BQ} = \frac{40V \cdot 52K}{52K+28K} - 20V = 6V$$

$$\Rightarrow V_{SQ} = V_{EQ} = V_{BQ} + 0{,}7V = 6{,}7V \quad \Rightarrow V_{GSQ} = -1{,}7V$$

$$\Rightarrow I_{10K} = \frac{6{,}7V - (-20V)}{10K} = 2{,}67\,mA$$

- $I_{DQ} = I_{CQ} + I_{10K} = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2 = 6{,}16\,mA$
- $I_{CQ} = 6{,}16\,mA - 2{,}67\,mA = 3{,}49\,mA$

b) EN SEÑAL (A FRECUENCIAS MEDIAS)



PARÁMETROS: $g_{m1} = 17{,}2\,m$ $\qquad g_{m2} = 139{,}6\,m \approx 140\,m$

$r_{ds} \to \infty$ $\qquad r_\pi \cong 1K4$

$r_o \to \infty$

•) $R_i = 750K // R_{ig}$; $R_{ig} = r_{gs} \to \infty$.

$$\Rightarrow \boxed{R_i = 750K}$$

•) DESDE EL COLECTOR DE T2 VEO UNA RESISTENCIA DEL ORDEN DE βr_0

$$\Rightarrow \boxed{R_o = 6K}$$

•) DEFINO COMO CARGA A AQUELLA RESISTENCIA SOBRE LA CUAL TOMO LA TENSIÓN DE SALIDA:

$$\Rightarrow \boxed{R_L = 8K}$$

•) $$A_{v1} = \frac{v_{o1}}{v_i} = \frac{i_d\left[10K // \left(\frac{r_\pi + r_x + 2K}{\beta}\right)\right]}{i_d\left[10K // \frac{r_\pi + r_x + 2K}{\beta}\right] + v_{gs}}$$

$$\boxed{A_{v1} = \frac{17{,}5\Omega}{17{,}5\Omega + 58\Omega} \cong 0{,}23.}$$

•) $$A_{v2} = \frac{v_o}{v_{o1}} = \frac{-i_c(6K // 8K)}{-i_b(r_\pi + 2K) - v_{be}} = \frac{3K4}{\frac{r_\pi}{\beta} + \frac{2K}{\beta} + r_0(1+\beta)}$$

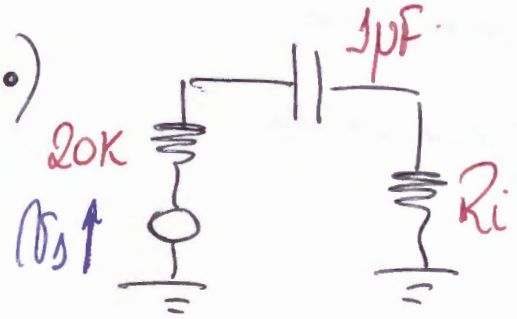
$$\boxed{A_{v2} = \frac{3K4}{10 + 7{,}14} \cong 198.}$$

•) $$A_{v_{TOT}} = A_{v1} \cdot A_{v2} \Rightarrow \boxed{A_{v_{TOT}} = 45{,}6.}$$

•) $$A_{vs} = A_v \frac{R_i}{R_i + 20K} \Rightarrow \boxed{A_{vs} = 44{,}4}$$

c) PARA BAJAS FRECUENCIAS.

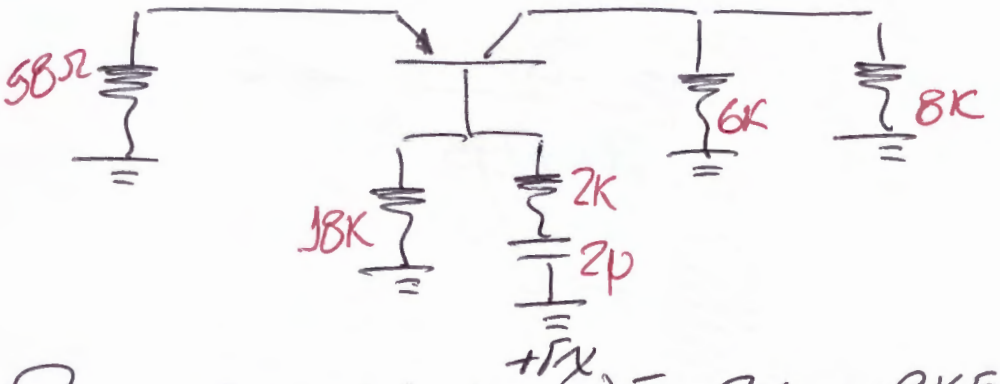
•)



$\Rightarrow R_{eq} = R_i \parallel 20K \approx 20K$

$\Rightarrow \tau = 20ms \Rightarrow f_1 \approx 8Hz.$

•)

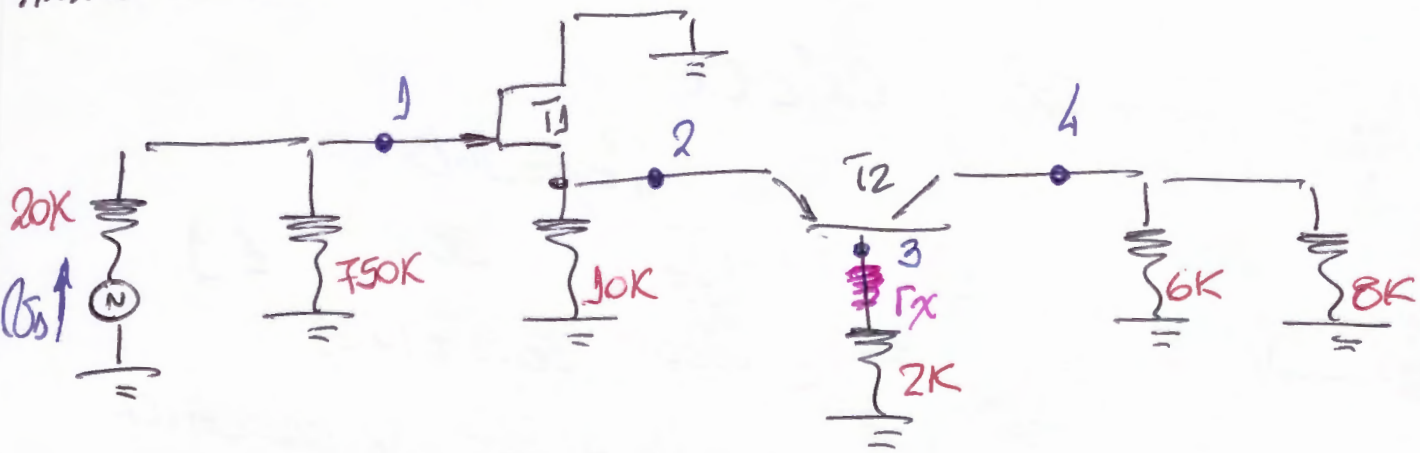


$\Rightarrow R_{eq} = [18K \parallel (r_\pi + \beta 58)] + 2K = 9K5$

$\Rightarrow \tau = 19ms \Rightarrow f_2 \approx 8,4Hz.$

$$\Rightarrow \boxed{f_\ell = f_1 + f_2 \approx 16Hz}$$

ALTAS FRECUENCIAS:



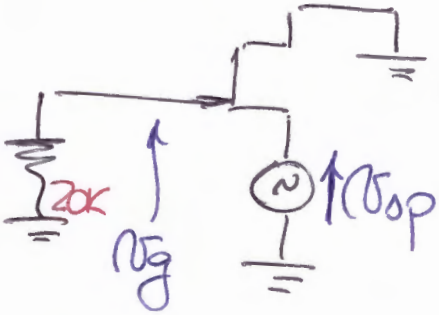
1) $R_{eq} = 20K$

C_{gd} SE REFLEJA IGUAL POR ESTAR REFERIDA A MASA

C_{gs} SE REFLEJA MÁS CHICA POR SER UN DRAIN-COMÚN

$$C_{eq} = C_{gd} + C_{gs}^{*} \quad ; \quad C_{gs}^{*} < C_{gs}.$$

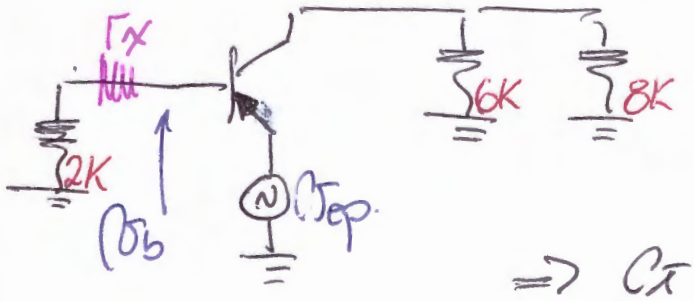
2) $$R_{eq} = r_{d_{FET}} \,//\, \frac{r_\pi + r_x + 2K}{\beta} \cong 13\Omega$$



$$v_g = v_{op} \frac{20K}{20K + r_{gs}} \rightarrow 0.$$

$$\Rightarrow \frac{v_g}{v_{op}} \rightarrow 0.$$

$\Rightarrow$ C_{gs} SE REFLEJA IGUAL.



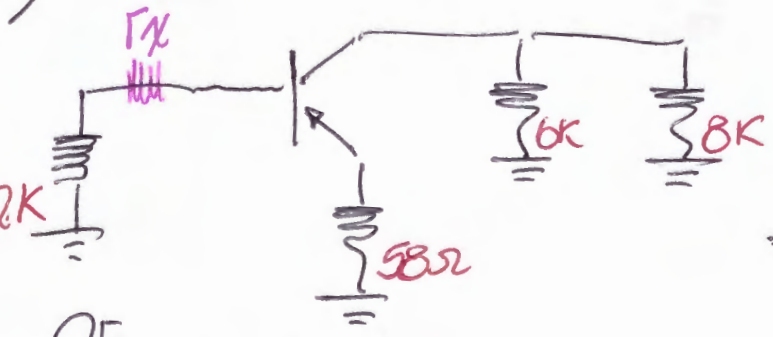
$$\frac{v_b}{v_{ep}} = \frac{r_x + 2K}{r_x + 2K + r_\pi} < 1.$$

$\Rightarrow$ C_π SE REFLEJA MÁS CHICA.

$$C_{eq} = C_{gs} + C_\pi^{*} \quad ; \quad C_\pi^{*} < C_\pi$$

3)

$R_{eq} \cong 1K8.$



$$\frac{v_e}{v_{bp}} = \frac{58\Omega}{58\Omega + r_{d_{TBJ}}} < 1.$$

$\Rightarrow$ C_π SE REFLEJA MÁS CHICA

$$\frac{v_c}{v_{bp}} = \frac{-3K4}{\ldots + r_{d_{TBJ}}}$$

$\Rightarrow$ C_μ SE REFLEJA MÁS GRANDE

4) $R_{eq} = R_0 // 8K = 6K // 8K = 3K4$

C_μ SE REFLEJA IGUAL $\Rightarrow C_{eq} = C_\mu$

BUSCO AQUEL QUE TENGA $\uparrow Z_0 \Rightarrow \downarrow f$

1) $R_{eq} \uparrow$; $C_{eq} \sim$

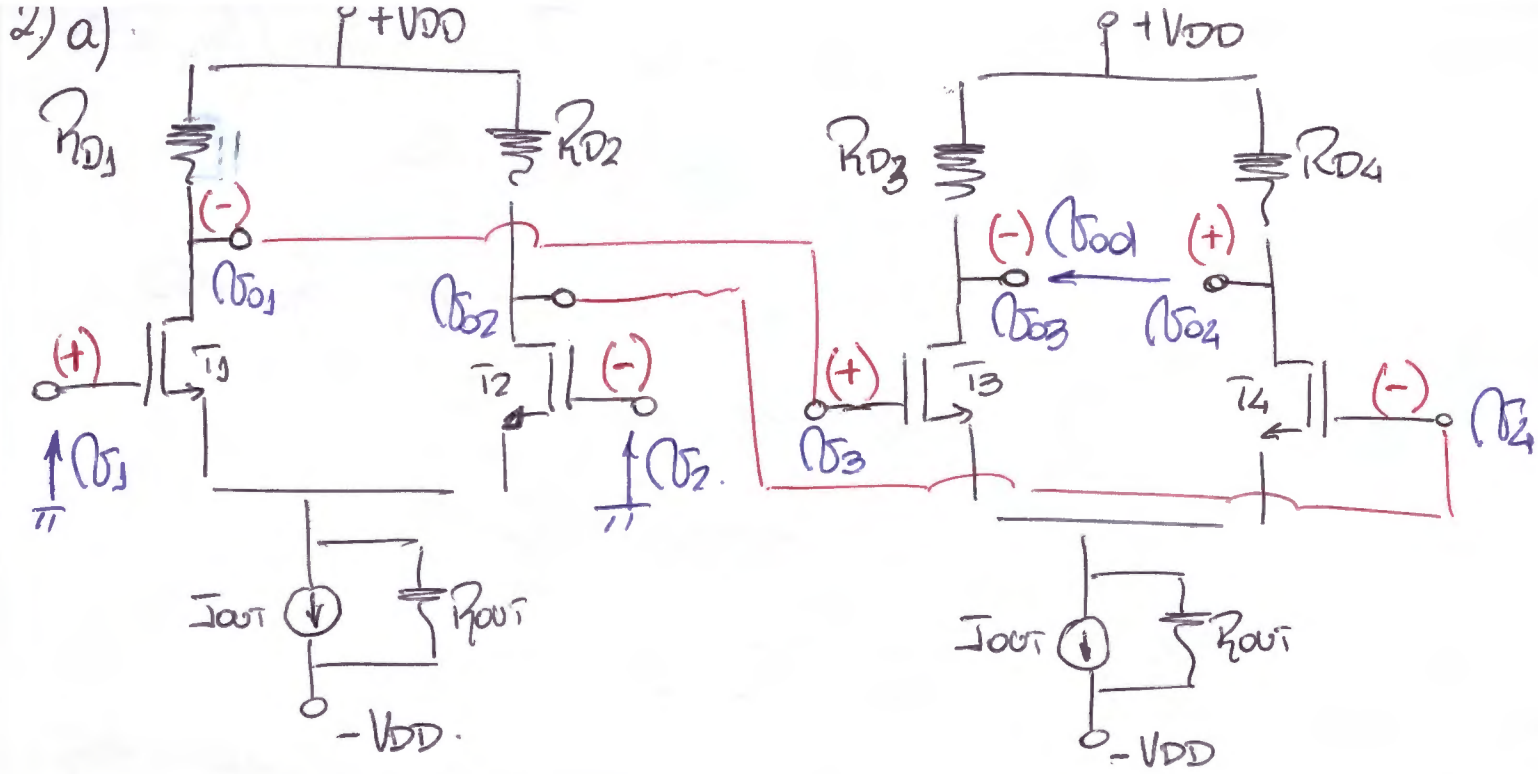
2) $R_{eq} \downarrow$; $C_{eq} \sim$

3) $R_{eq} \sim$; $C_{eq} \uparrow$

4) $R_{eq} \sim$; $C_{eq} \downarrow$

LOS NODOS DOMINANTES PODRÍAN SER EL 1 O EL 3

2) a)



Busco: $A_{Vd} = \frac{V_{od}}{V_{id}} \Big|_{V_{ic}=0}$; $A_{Vc} = \frac{V_{od}}{V_{ic}} \Big|_{V_{id}=0}$.

Ahora bien:

$$V_{od} = A_{Vdd(2)} V_{id(2)} + A_{Vdc(2)} V_{ic(2)}.$$

Pero en AO2 no hay desapareamiento $\Rightarrow A_{Vdc(2)} = 0$.

$$\Rightarrow V_{od} = A_{Vdd(2)} V_{id(2)} \quad (1); \quad V_{id(2)} = V_3 - V_4.$$

$$V_{id(2)} = V_{o1} - V_{o2}.$$

$$V_{id(2)} = V_{od(1)}$$

y donde:

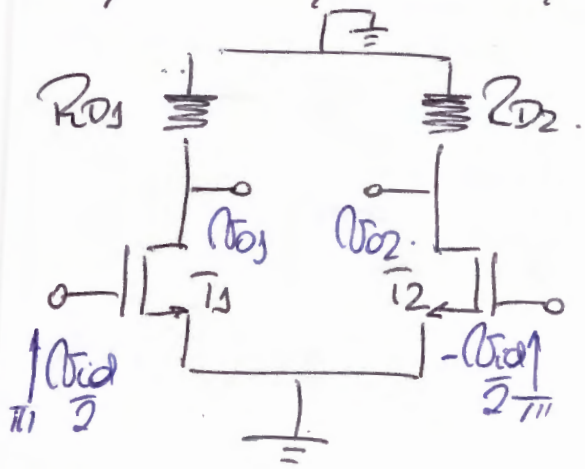
$$V_{od(1)} = A_{Vdd(1)} V_{id(1)} + A_{Vdc(1)} V_{ic(1)} \quad (2)$$

En AO1 hay desapareamiento $\rightarrow A_{Vdc(1)} \neq 0$.

(2) en (1)

$$V_{od} = A_{Vdd(2)} A_{Vdd(1)} V_{id(1)} + A_{Vdd(2)} A_{Vdc(1)} V_{ic(1)}$$

ENTRADA DIFERENCIAL PURA



$$v_{o1} = -i_{d1} R_{D1} = -g_{m1} v_{gs1} R_{D1}$$

$$v_{o1} = -g_{m1} R_{D1} \frac{v_{id}}{2}$$

$$v_{o2} = -i_{d2} R_{D2} = -g_{m2} v_{gs2} R_{D2}$$

$$v_{o2} = -g_{m2} R_{D2} \left(-\frac{v_{id}}{2}\right)$$

$$v_{o2} = g_{m2} R_{D2} \frac{v_{id}}{2}$$

$$\Rightarrow v_{od(1)} = v_{id(2)} = v_{o1} - v_{o2}$$

•) SI CONSIDERO QUE EL OFFSET SE AJUSTO PREVIAMENTE PUEDO CONSIDERAR QUE $I_{DQ1} = I_{DQ2} \Rightarrow g_{m1} = g_{m2} = g_{mAD1}$

$$v_{od(1)} = v_{id(2)} = -g_{m1} R_{D1} \frac{v_{id}}{2} - g_{m2} R_{D2} \frac{v_{id}}{2}$$

$$\left[v_{od(1)} = v_{id(2)} = -g_{mAD1} \frac{v_{id}}{2} (R_{D1} + R_{D2}) \right]$$

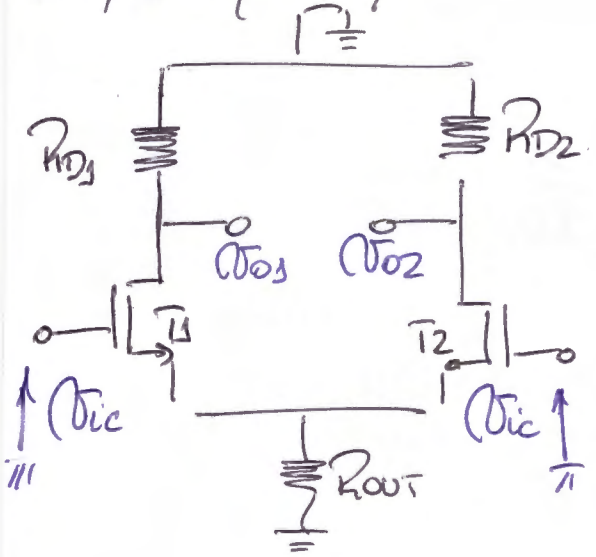
Y LUEGO: $\left[A_{vdd(1)} = \frac{v_{od(1)}}{v_{id}} = \frac{-g_{mAD1}}{2} (R_{D1} + R_{D2}) \right]$

PARA EL AD2 EL ANÁLISIS ES ANÁLOGO PERO SIN DESAFIAREATMENTO.

$$\Rightarrow R_{D3} = R_{D4} = R_{DAD2} \; ; \; g_{m3} = g_{m4} = g_{mAD2}$$

$$\Rightarrow \left[A_{vdd(2)} = \frac{v_{od}}{v_{id(2)}} = -g_{mAD2} R_{DAD2} \right]$$

ENTRADA COMUN TOKA



$$v_{o1} = -i_{d1} R_{D1} = -g_{m1} v_{gs1} R_{D1}$$

$$v_{\ 1} = v_{gs1} + i_{d1} 2R_{OUT}$$

$$v_{ic1} = v_{gs1}(1 + g_{m1} 2R_{OUT})$$

$$\Rightarrow v_{gs1} = \frac{v_{ic}}{1 + g_{m1} 2R_{OUT}}$$

$$\Rightarrow v_{o1} = -g_{m1} R_{D1} \frac{v_{ic}}{1 + g_{m1} 2R_{OUT}}$$

$$\Rightarrow v_{o2} = -g_{m2} R_{D2} \frac{v_{ic}}{1 + g_{m2} 2R_{OUT}}$$

$$\Rightarrow A_{vdc(1)} = \frac{v_{od(1)}}{v_{ic}} = \frac{v_{o1} - v_{o2}}{v_{ic}}$$

$$A_{vdc(1)} = \frac{-g_{m1} R_{D1}}{1 + g_{m1} 2R_{OUT}} + \frac{g_{m2} R_{D2}}{1 + g_{m2} 2R_{OUT}}$$

$$\left[A_{vdc(1)} = \frac{g_{mAD1}}{1 + g_{mAD1} 2R_{OUT}} (R_{D2} - R_{D1}) \right]$$

LUEGO:

$$A_{vd} = \frac{v_{od}}{v_{id}} \Big|_{v_{ic}=0} = A_{vdd(2)} A_{vdd(1)}$$

$$A_{vd} = +g_{mAD2} R_{DAD2} \frac{g_{mAD1}}{2} (R_{D1} + R_{D2})$$

$$A_{vd} = \frac{1}{2} g_{mAD2} g_{mAD1} R_{DAD2} (R_{D1} + R_{D2} + R_{D1} - R_{D1})$$

$$A_{vd} = \frac{1}{2} g_{m_{AD1}} g_{m_{AD2}} R_{DA2} \left(2R_{D1} + R_{D2} - R_{D1}\right)$$

$$A_{vd} = \frac{1}{2} g_{m_{AD1}} g_{m_{AD2}} R_{DA2} \cdot \left(2R_{D1} + R_{D1}\frac{\alpha}{100}\right)$$

$$\Rightarrow \left[A_{vd} = g_{m_{AD1}} g_{m_{AD2}} R_{DA2} R_{D1} \left(1 + \frac{\alpha}{200}\right) \right]$$

$$A_{vc} = \frac{v_{od}}{v_{ic}}\Big|_{v_{id}=0} = A_{vdd}(2)\, A_{vdc}(1).$$

$$A_{vc} = -g_{m_{AD2}} R_{D_{AD2}} \frac{g_{m_{AD1}}}{1 + g_{m_{AD1}} 2R_{OUT}} \left(R_{D2} - R_{D1}\right).$$

$$A_{vc} = \frac{-g_{m_{AD1}} g_{m_{AD2}} \cdot R_{D_{AD2}} R_{D1}}{1 + g_{m_{AD1}} 2R_{OUT}} \frac{R_{D2} - R_{D1}}{R_{D1}}.$$

$$\left[A_{vc} = \frac{-g_{m_{AD1}} g_{m_{AD2}} \cdot R_{D_{AD2}}}{1 + g_{m_{AD1}} 2R_{OUT}} \frac{\alpha}{100}. \right]$$

$$\left|\frac{A_{vd}}{A_{vc}}\right| = \frac{\cancel{g_{m_{AD1}}} \cancel{g_{m_{AD2}}} \cancel{R_{DA}} R_{D1} \left(1 + \frac{\alpha}{200}\right)}{\frac{\cancel{g_{m_{AD1}}} \cancel{g_{m_{AD2}}} \cdot \cancel{R_{D_{AD2}}}}{1 + g_{m_{AD1}} 2R_{OUT}} \alpha/100}$$

$$\left|\frac{A_{vd}}{A_{vc}}\right| = \left(1 + g_{m_{AD1}} 2R_{OUT}\right) R_{D1} \frac{100}{\alpha} \left(1 + \frac{\alpha}{200}\right)$$

$$\left[\left| \frac{A_{vd}}{A_{vc}} \right| = (1 + gm_{AD_1} 2R_{out}) R_{D_1} \frac{200+\alpha}{2\alpha} \right]$$

b) AHORA TENGO DESAPAREAMIENTO EN AD2 $\Rightarrow A_{vdc}(2) \neq 0$.

$$A_{vdc}(2) = \frac{v_{od}}{v_{ic}(2)} \Big|_{v_{id}(2)=0}.$$

Y NO TENGO DESAPAREAMIENTO EN AD1. $\Rightarrow \left[A_{vdc}(1) = 0. \right]$

ENTONCES:

MODO DIFERENCIAL PURO:

$$\left.\begin{aligned} v_{o1} &= -gm_1 R_{D_1} \frac{v_{id}}{2} \\ v_{o2} &= +gm_2 R_{D_2} \frac{v_{id}}{2} \end{aligned}\right\} \left[A_{vdd}(1) = \frac{v_{od}(1)}{v_{id}} = -gm_{AD_1} R_{D_{AD_1}} \right]$$

$$\left[A_{vdd}(2) = \frac{v_{od}}{v_{id}(2)} = \frac{-gm_{AD_2}}{2} \cdot (R_{D_3} + R_{D_4}). \right]$$

$$v_{od} = A_{vdd}(2) v_{id}(2) + A_{vdc}(2) v_{ic}(2).$$

$$v_{od}(1) = A_{vdd}(1) v_{id} + \cancel{A_{vdc}(1)}^{\,0} v_{ic} = v_{id}(2).$$

$$v_{ic}(2) = A_{vcc}(1) v_{ic} + \cancel{A_{vcd}(1)}^{\,0} v_{id}$$

$$\Rightarrow v_{od} = A_{vdd}(2) A_{vdd}(1) v_{id} + A_{vdc}(2) A_{vcc}(1) v_{ic}.$$

✓ ✓

$$\left[A_{vdc(2)} = \frac{g_{m_{AD2}}}{1+g_{m_{AD2}} 2R_{OUT}} (R_{D4} - R_{D3}) \right]$$

$$A_{vcc(1)} = \frac{v_{oc(1)}}{v_{ic}} \Big|_{v_{id}=0} \quad ; \quad v_{oc(1)} = \frac{v_{o1} + v_{o2}}{2}$$

$$\Rightarrow A_{vcc(1)} = \frac{v_{o1} + v_{o2}}{2 v_{ic}}$$

$$v_{o1} = -g_{m_1} \frac{R_{D1} v_{ic}}{1+g_{m_1} 2R_{OUT}} \quad ; \quad v_{o2} = -g_{m_2} \frac{R_{D2} v_{ic}}{1+g_{m_2} 2R_{OUT}}$$

$$v_{o1} + v_{o2} = \frac{-2 g_{m_{AD1}} R_{D_{AD1}} v_{ic}}{1+g_{m_{AD}} 2R_{OUT}}$$

$$\Rightarrow \left[A_{vcc(1)} = \frac{-g_{m_{AD1}} R_{D_{AD1}}}{1+g_{m_{AD}} 2R_{OUT}} \right]$$

LUEGO:

$$A_{vd} = \frac{v_{od}}{v_{id}} \Big|_{v_{ic}=0} = A_{vdd(2)} A_{vdd(1)}$$

$$A_{vd} = g_{m_{AD1}} R_{D_{AD1}} \frac{g_{m_{AD2}}}{2} (R_{D3} + R_{D4})$$

$$\left[A_{vd} = g_{m_{AD1}} g_{m_{AD2}} R_{D_{AD1}} R_{D3} \left(1 + \frac{\alpha}{200}\right) \right]$$

$$A_{vc} = \frac{v_{od}}{v_{ic}}\Big|_{v_{id}=0} = A_{vdc(2)}\, A_{vcc(1)}$$

$$A_{vc} = \frac{-g_{m_{AD2}}}{1+g_{m_{AD2}}2R_{OUT}}\,(R_{D4}-R_{D3})\,\frac{g_{m_{AD1}}R_{D_{AD1}}}{1+g_{m_{AD1}}2R_{OUT}}$$

$$\left[A_{vc} = \frac{-g_{m_{AD2}}}{1+g_{m_{AD2}}2R_{OUT}}\;\frac{g_{m_{AD1}}}{1+g_{m_{AD1}}2R_{OUT}}\;R_{D_{AD1}}R_{D_{AD2}}\frac{\alpha}{100}\right]$$

$$\left|\frac{A_{vd}}{A_{vc}}\right| = (1+g_{m_{AD2}}2R_{OUT})(1+g_{m_{AD1}}2R_{OUT})\frac{100}{\alpha}\left(1+\frac{\alpha}{200}\right)$$

$$\left[\left|\frac{A_{vd}}{A_{vc}}\right| = (1+g_{m_{AD1}}2R_{OUT})(1+g_{m_{AD2}}2R_{OUT})\;\frac{200+\alpha}{2\alpha}\right]$$

LAS EXPRESIONES DEL JUEGO 1 SON LAS QUE MÁS SE ACERCARAN A LOS VALORES DE LA RRMC SI AMBOS DESAPAREAMIENTOS EXISTEN A LA VEZ. ESTO SUCEDE PORQUE ES LA PRIMERA ETAPA QUIEN SE ENCARGA DE LIMITAR LA RRMC Y LA SEGUNDA DE AMPLIFICAR LA SEÑAL DE MODO DIFERENCIAL.

66.08 – 86-067 Evaluación integradora – 1/2014 - quinta fecha 01/08/14

APELLIDO	NOMBRE	PADRON	TURNO			Nº de HOJAS	Corrección
			M	T	N		

1.-

$$\beta = 100 \; ; \; f_T = 300 \text{ MHz} \; ; \; C_\mu = 2 \text{ pF} \; ; \; r_x = 100\ \Omega \; ; \; V_A = 100\text{V}$$

$$(W/L)_{1,2} = 1 \; ; \; k' = 0{,}1 \text{ mA/V}^2 \; ; \; V_{Th} = 1 \text{ V} \; ; \; \lambda = 0{,}01 \text{ V}^{-1} \; ; \; C_{gs} = 5 \text{ pF} \; ; \; C_{gd} = 2 \text{ pF}$$

$$V_{CC} = 5\text{V} \; ; \; R_{ref} = 1\ \text{K}\Omega \; ; \; R_E = 470\ \Omega \; ; \; R_L = 1\ \text{K}\Omega$$

a) Obtener los puntos de reposo, implementando los bloques de fuentes espejo con MOSFETs de canal inducido cuyas características son:

$(W/L)_{3,4,5,7} = 1$; $(W/L)_{6,8} = 50$

$|k'| = 0{,}1 \text{ mA/V}^2$; $|V_{Th}| = 1\text{V}$; $\lambda = 0{,}01 \text{ V}^{-1}$; $C_{gs} = 5\text{pF}$; $C_{gd} = 1\text{pF}$

¿Qué utilidad y características posee la fuente T9-T10 frente a una espejo?.

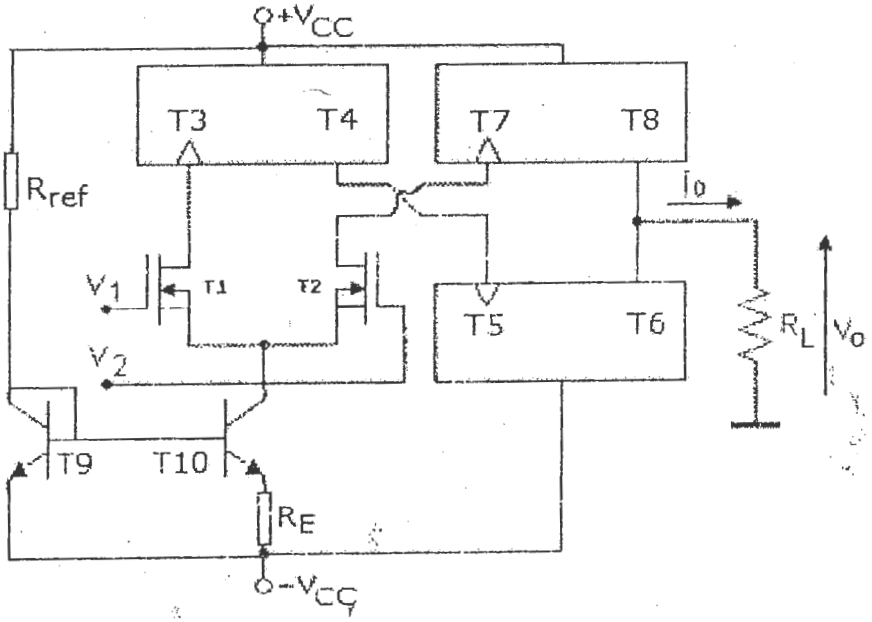
b) Dibujar el circuito de señal, sin reemplazar los transistores por su modelo. Definir y obtener el valor de R_{Id}, R_o y la transconductancia del circuito para modo diferencial. Obtener A_{vd}. ¿Cuál es el valor aproximado de la transconductancia de modo común? ¿Por qué su valor depende fuertemente de los desapareamientos existentes en cada bloque (par diferencial o fuente espejo)?

c) Obtener el valor aproximado de f_h para A_{vd}. PAJA

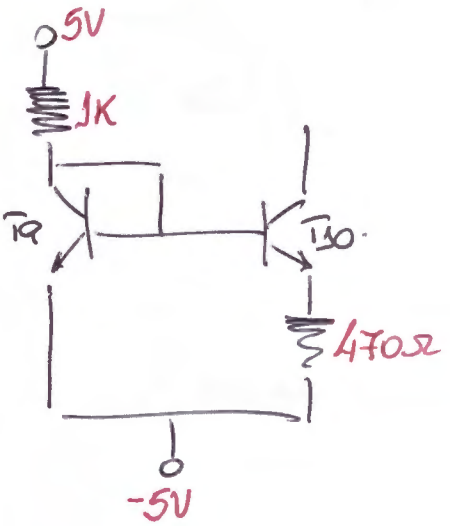
d) Obtener la frecuencia del cero impuesto por la fuente T9-T10 para modo común. ¿Cuál es la importancia de esta frecuencia? WTF?

e) Obtener el valor de la tensión de offset si: $(W/L)_1 = 0{,}98.(W/L)_2$

f) Definir y obtener el rango de tensión de modo común.



a) FUENTE WIDLAR.



$$V_{BE9} = V_{BE10} + I_{OUT} R_E$$

$$I_C = I_S e^{V_{BE}/V_{TH}} \Rightarrow V_{BE} = V_{TH} \ln(I_C/I_S)$$

$$V_{TH} \ln\left(\frac{I_{REF}}{I_{S9}}\right) = V_{TH} \ln\left(\frac{I_{OUT}}{I_{S10}}\right) + I_{OUT} R_E$$

$$I_{OUT} R_E = V_{TH} \ln\left(\frac{I_{REF}}{I_{S9}} \frac{I_{S10}}{I_{OUT}}\right)$$

$$I_{OUT} R_E = V_{TH} \ln\left(I_{REF}/I_{OUT}\right)$$

$$I_{REF} = \frac{5V - (-5V + 0{,}7V)}{1K} = 9{,}3mA$$

$$I_{OUT}\, 470\Omega = 25mV \ln\left(\frac{9{,}3mA}{I_{OUT}}\right)$$

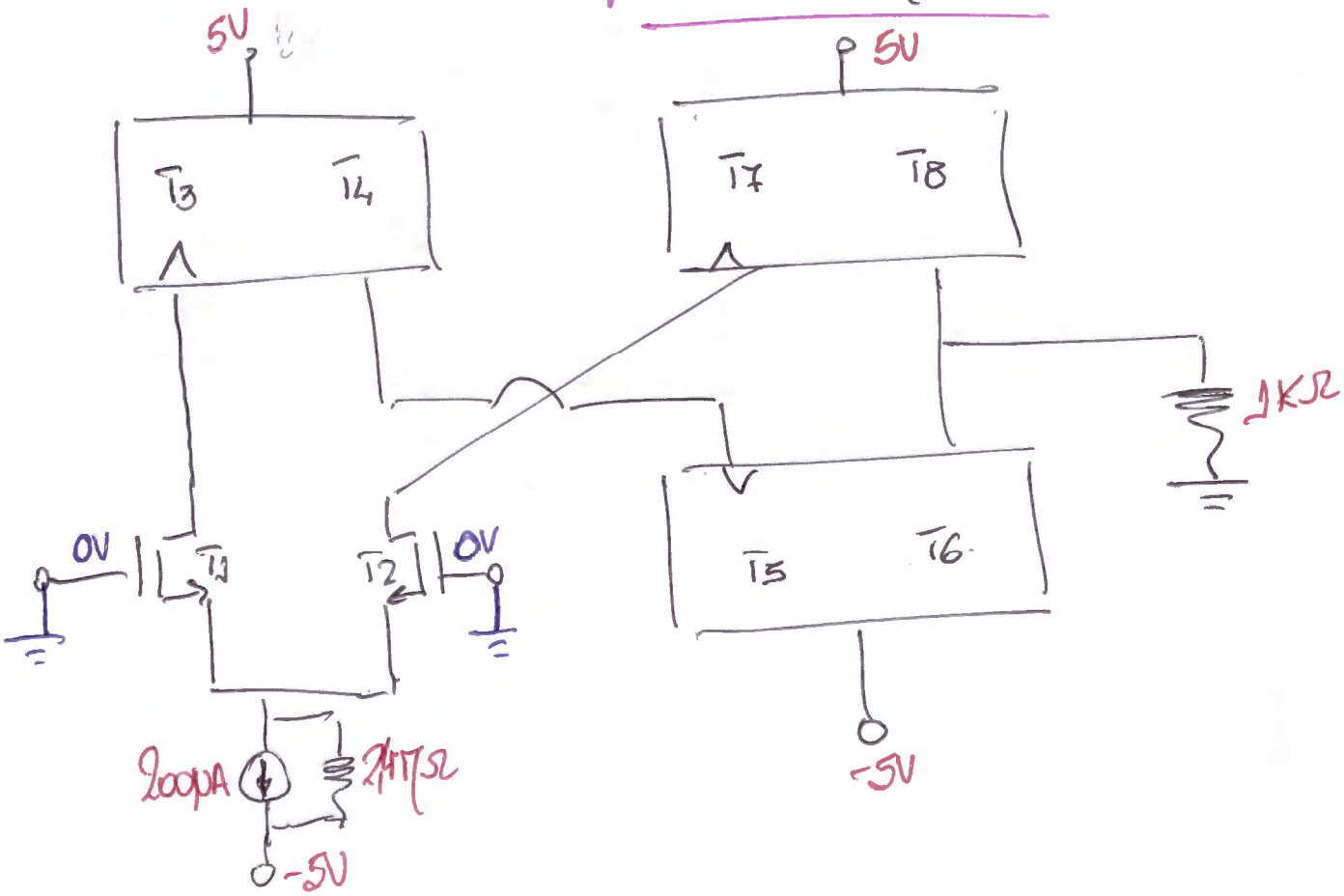
$$\hookrightarrow \boxed{I_{OUT} \cong 200\mu A}$$

$g_{m10} = 8m$

$r_{o10} = 500K$

$$R_{OUT} = r_{o10}(1 + g_{m10} R_E)$$

$$\boxed{R_{OUT} = 2{,}47M\Omega}$$



FUENTE ESPEJO:

$$I_{REF} = K'\left(\frac{W}{L}\right)_{REF}(V_{GSQ}-V_T)^2$$

$$I_{OUT} = K'\left(\frac{W}{L}\right)_{OUT}(V_{GSQ}-V_T)^2$$

$$I_{OUT} = I_{REF}\frac{\left(\frac{W}{L}\right)_{OUT}}{\left(\frac{W}{L}\right)_{REF}}$$

$$I_{DQ1} = I_{DQ2} = \frac{I_{OUT}}{2} = 100\mu A$$

$$I_{DQ3} = I_{DQ1} = 100\mu A$$

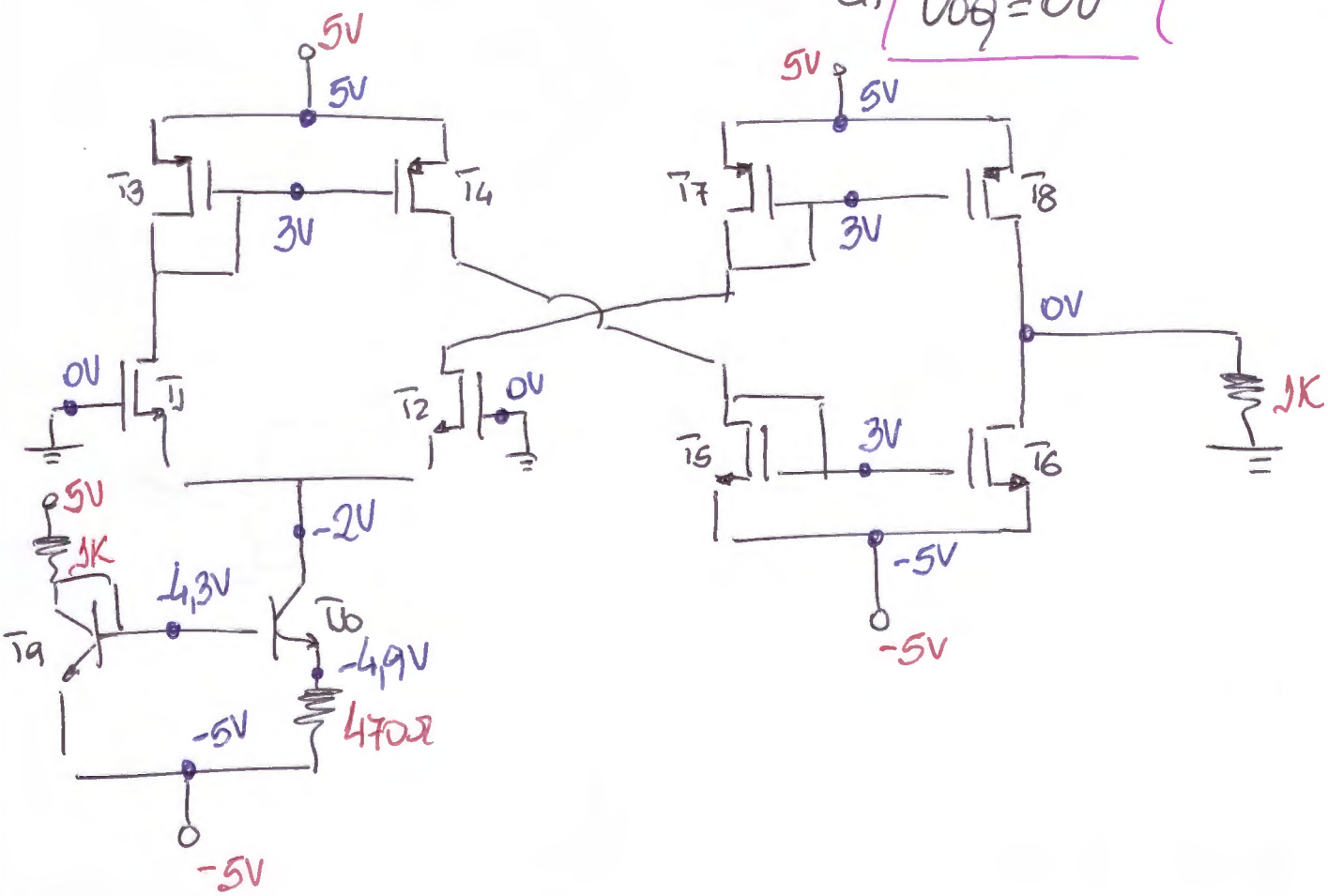
$$I_{DQ4} = I_{DQ5} = I_{DQ3} = 100\mu A$$

$$I_{DQ7} = I_{DQ2} = 100\mu A$$

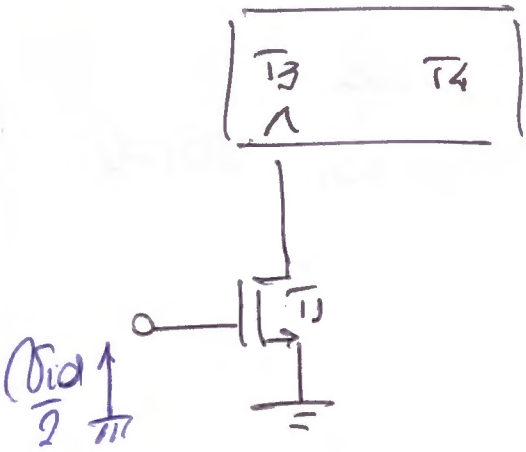
$$I_{DQ8} = I_{DQ6} = \frac{I_{DQ7}\left(W/L\right)_8}{\left(W/L\right)_7} = 100\mu A\ 50 = 5mA$$

$$I_{OQ} = I_{DQ8} - I_{DQ6} \Rightarrow I_{OQ} = 0V$$

$$\hookrightarrow V_{OQ} = 0V$$



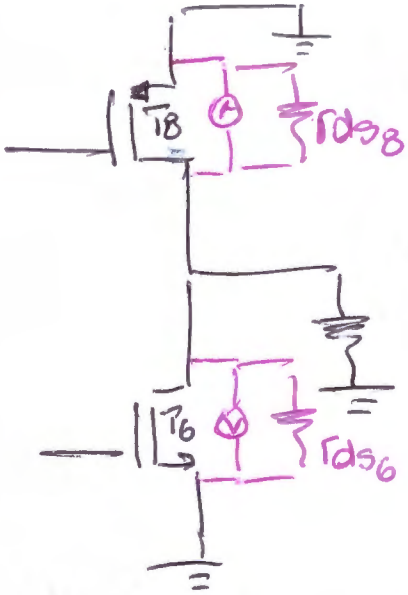
ENTRADA DIFERENCIAL POR



$$R_{id} = \frac{v_{id}}{i_g} \; ; \quad i_g r_{gs_1} = \frac{v_{id}}{2}.$$

$$\Rightarrow R_{id} = 2 r_{gs} \; ; \quad r_{gs} \to \infty.$$

$$\Rightarrow \boxed{R_{id} \to \infty.}$$



$$R_o = r_{ds6} \,//\, r_{ds8}.$$

AHORA BIEN $I_{DQ6} = I_{DQ8}$.

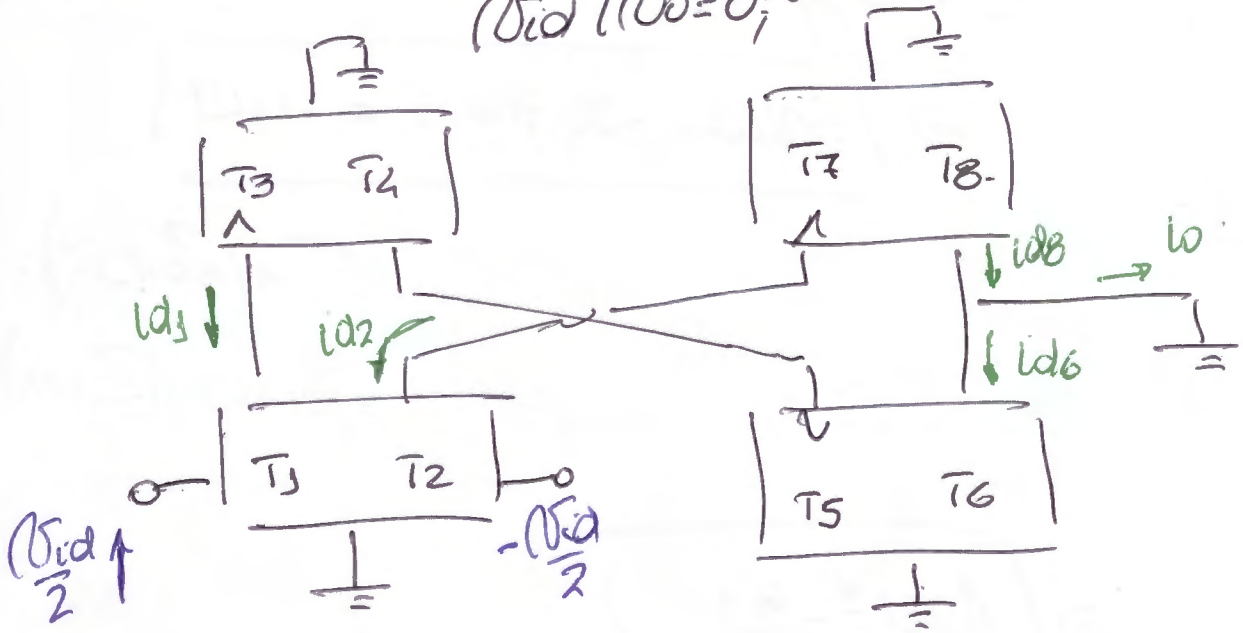
$$\Rightarrow r_{ds6} = r_{ds8}.$$

$$\Rightarrow R_o = r_{ds6}/2.$$

$$r_{ds6} = \frac{1}{\lambda I_{DQ6}} = 20K\Omega.$$

$$\Rightarrow \boxed{R_o = 10K}$$

SE DEFINE: $G_{md} = \frac{i_o}{v_{id}} \Big|_{v_o=0;\, v_{ic}=0}$



SE CUMPLE QUE

$$i_{d8} = i_o + i_{d6} \Rightarrow i_o = i_{d8} - i_{d6}$$

PERO:

$$i_{d8} = 50\, i_{d7} \; ; \; i_{d7} = i_{d2} \Rightarrow i_{d8} = 50\, i_{d2}.$$

$$i_{d6} = 50\, i_{d5} \; ; \; i_{d5} = i_{d4} = i_{d3} = i_{d1} \Rightarrow i_{d6} = 50\, i_{d1}$$

$$\Rightarrow i_o = 50\left(i_{d2} - i_{d1}\right)$$

AHORA BIEN:

$$i_{d1} = g_{m1} v_{gs1} = g_{m1} \frac{v_{id}}{2}$$

$$i_{d2} = g_{m2} v_{gs2} = g_{m2}\left(-\frac{v_{id}}{2}\right)$$

$$\Rightarrow i_o = 50\left(-g_{m2}\frac{v_{id}}{2} - g_{m1}\frac{v_{id}}{2}\right)$$

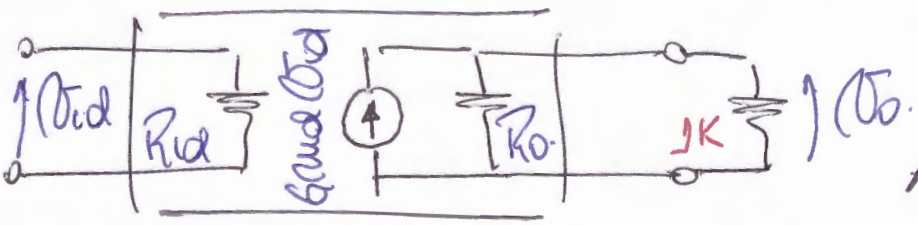
$$i_o = -50\frac{v_{id}}{2}\left(g_{m1} + g_{m2}\right).$$

SIENDO:

$$\left.\begin{array}{l} I_{DQ1} = I_{DQ2}. \\ K_1' = K_2' \\ (W/L)_1 = (W/L)_2 \end{array}\right\} g_{m1} = g_{m2} = g_{m1,2} = 200\mu.$$

$$\Rightarrow i_o = -50\, v_{id}\, g_{m1,2}.$$

$$\Rightarrow \boxed{G_{md} = -50\, g_{m1,2} = -0{,}01}$$



$$v_o = G_{md}\, v_{id}\,(R_o \parallel 1K)$$

$$A_{vd} = \frac{v_o}{v_{id}} = G_{md}\,(R_o \parallel 1K)$$

$$\Rightarrow \boxed{A_{vd} \cong -9{,}1.}$$

$$G_{mc} = \frac{i_o}{v_{ic}} \Big|_{v_o=0;\, v_{id}=0}$$

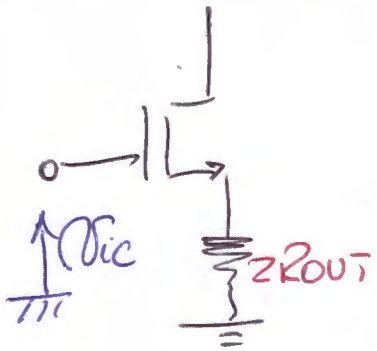
$$\boxed{G_{mc} = 0.}$$

ESTO SUCEDE DEBIDO A LA NO EXISTENCIA DE DESAPAREAMIENTOS!

DE NUEVO:

$$i_o = i_{d8} - i_{d6} = 50\,(i_{d2} - i_{d1}).$$

PERO PARA ENTRADA COMÚN:



$$i_{d1} = i_{d2} = g_{m1} v_{gs1}$$

$$i_{d1} = i_{d2} = g_{m1} \frac{v_{ic}\, r_{gs}}{r_{gs} + \beta_{FET}\, 2R_{OUT}}$$

$$i_{d1} = i_{d2} = \frac{g_{m1} v_{ic}}{1 + g_{m1}\, 2R_{OUT}}$$

$$\left\{ i_{d1} = i_{d2} = \frac{v_{ic}}{r_{d1} + 2R_{OUT}} = \frac{v_{ic}}{2R_{OUT}} \right\} \Rightarrow \boxed{i_{d2} - i_{d1} = 0.}$$

SI HUBIERA DESAPAREAMIENTO LOS g_m NO SERÍAN IGUALES Y ENTONCES $i_o \neq 0$.

e) $$\frac{v_{OFF}}{2} - v_{gs1} + v_{gs2} - \left(-\frac{v_{OFF}}{2}\right) = 0.$$

$$v_{OFF} = v_{gs1} - v_{gs2}. \quad ; \quad v_{gs} = \sqrt{\frac{I_{DQ}}{K'(W/L)}} + V_T$$

$$v_{OFF} = \sqrt{\frac{I_{DQ1}}{K'(W/L)_1}} + V_T - \sqrt{\frac{I_{DQ2}}{K'(W/L)_2}} - V_T$$

$$v_{OFF} = \sqrt{\frac{I_{DQ1}}{K'(W/L)_1}} - \sqrt{\frac{I_{DQ2}}{K'(W/L)_2}}.$$

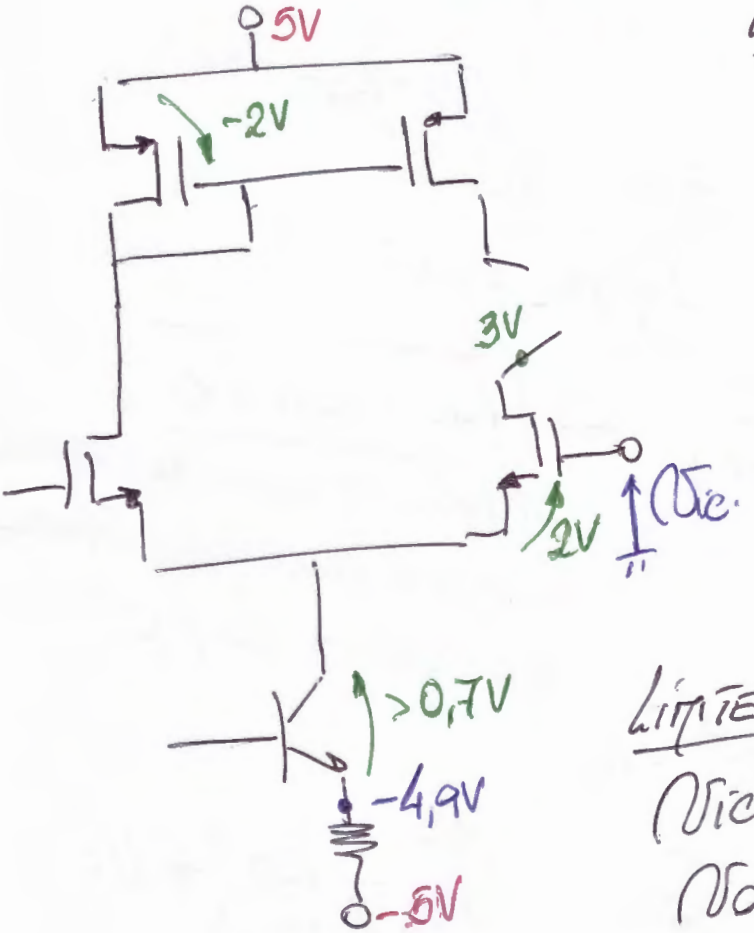
AL APLICAR v_{OFF}, PUEDO DECIR QUE: $I_{DQ1} = I_{DQ2}$.

$$V_{OFF} = \sqrt{\frac{I_{DQ1}}{K'}} \left\{ \sqrt{\frac{1}{(W/L)_1}} - \sqrt{\frac{1}{(W/L)_2}} \right\}.$$

$$V_{OFF} = \sqrt{\frac{I_{DQ1}}{K'(W/L)_2}} \left\{ \sqrt{\frac{1}{(W/L)_1/(W/L)_2}} - 1 \right\}.$$

$$\boxed{V_{OFF} = 10,15\,mV.}$$

F) RITC: RANGO DE TENSIÓN PARA EL CUAL SE ASEGURA QUE TODOS LOS TRANSISTORES SE ENCUENTRAN FUNCIONANDO DENTRO DE LA ZONA DE CARACTERÍSTICAS SATURADAS.



LÍMITE INFERIOR:

$$V_{IC} - 2V = V_C$$

$$V_C - (-4,9V) > 0,7V$$

$$V_C + 4,9V > 0,7V$$

$$V_{IC} - 2V + 4,9V > 0,7V$$

$$V_{IC} + 2,9V > 0,7V$$

$$\boxed{V_{IC} > -2,2V}$$

LÍMITE SUPERIOR:

$$V_{IC} - 2V = V_S.$$

$$V_{ds} > V_{gs} - V_T$$

$$3V - (V_{IC} - 2V) > 2V - 1V$$

$$5V - V_{IC} > 1V.$$

$$\Rightarrow \boxed{V_{IC} < 4V.}$$

$$\boxed{-2,2V < V_{IC} < 4V}$$

P/Fotocopiar

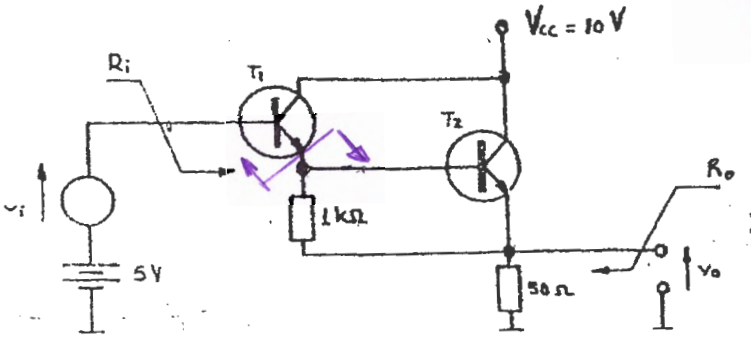
66.08 – 86.06 Eval. integradora – 1/2016 – 3era fecha 20/07/16

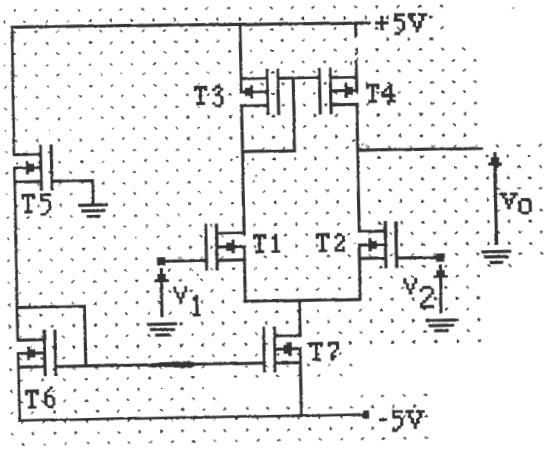
APELLIDO	NOMBRE	PADRON	TURNO			N° de HOJAS	Corrección	
				T	N			

1.- Para el siguiente circuito, donde v_i y la fuente de 5V representan la tensión que entrega la etapa anterior a la indicada en la figura (cc + señal):
Justificar en qué valor podría estimarse la frecuencia de corte superior de esta etapa.

$\beta = 200$; $r_x \rightarrow 0$; $V_A \rightarrow \infty$; $f_T = 300MHz$; $C_\mu \cong 1$ pF

Preguntar



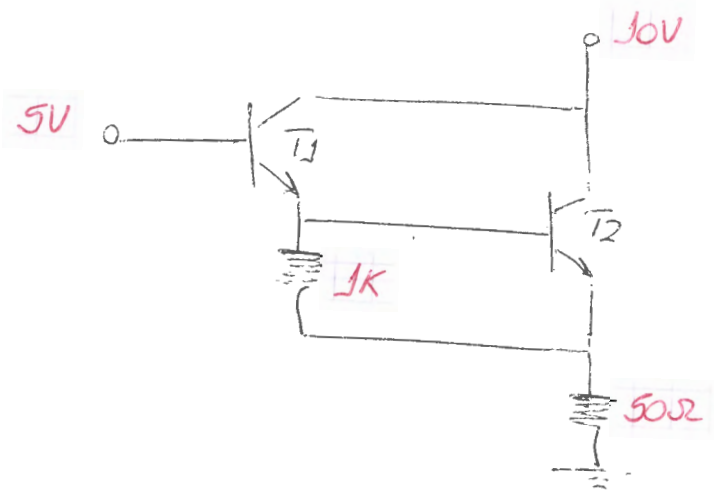


2.- MOSFET inducidos: $V_T = \pm 1{,}5V$; $k' = 100\mu A/V^2$; $\lambda = 0{,}01V^{-1}$; $(W/L)_{1,2,3,4} = 10$; $(W/L)_{5,6,7} = 2$

a) Definir y obtener la RRMC en dB.

b) Definir y obtener los valores del rango de tensión de modo común.

1)



$\beta = 200$

$r_x \to 0$

$V_A \to \infty$

$f_T = 300\,MHz$

$C_\mu = 1\,pF$

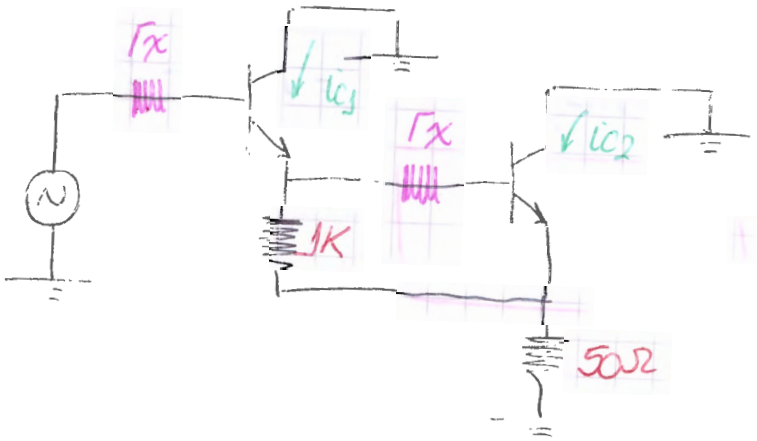
$$V_{BQ1} = 5V \Rightarrow V_{EQ1} = 4{,}3V = V_{BQ2} \Rightarrow V_{EQ2} = 3{,}6V$$

$$\Rightarrow I_{CQ2} + I_{1K} = 72\,mA$$

$$I_{1K} = \frac{4{,}3V - 3{,}6V}{1K} = 0{,}7\,mA \quad \Big\} \quad I_{CQ2} = 71{,}3\,mA$$

$$I_{CQ1} = I_{1K} + I_{BQ2} \Rightarrow I_{CQ1} = I_{1K} + \frac{I_{CQ2}}{\beta} = 1\,mA$$

SEÑAL:



PARÁMETROS:

$g_{m1} = 40\,m$ $\qquad$ $g_{m2} = 2{,}85$

$r_{\pi 1} = 5K$ $\qquad$ $r_{\pi 2} = 70\Omega$

$C_{\pi 1} = 20{,}22\,pF$ $\qquad$ $C_{\pi 2} = 1{,}51\,nF$

DESCARTO LOS EMISORES:

$\beta^* = g_{m2}(1K // 70\Omega) = 186,4$

•) BASE DE T1

$$C_{beq_1} = C_\mu + C_\pi\left(1 - \frac{v_{e_1}}{v_{bp_1}}\right)$$

$$C_{beq_1} = C_\mu + C_\pi\left(1 - \frac{(1K // (r_x + r_{\pi 2})) + \beta^* 50\Omega}{(1K // (r_x + r_{\pi 2})) + \beta^* 50\Omega + r_{d1}}\right)$$

$$C_{beq_1} = C_\mu + 2,67\,m\,C_{\pi_1} = 1,05\,pF$$

$$R_{beq_1} = r_x$$

VER

•) BASE DE T2:

$$C_{beq_2} = C_{\pi_1}\left(1 - \frac{v_{b_1}}{v_{ep}}\right) + C_\pi\left(1 - \frac{v_{e_2}}{v_{bp_2}}\right) + C_\mu\left(1 - \frac{v_{c_2}}{v_{bp_2}}\right)$$

$$C_{beq_2} = C_{\pi_1} + C_{\pi_2}\left(1 - \frac{50}{50 + 0,35}\right) + C_\mu$$

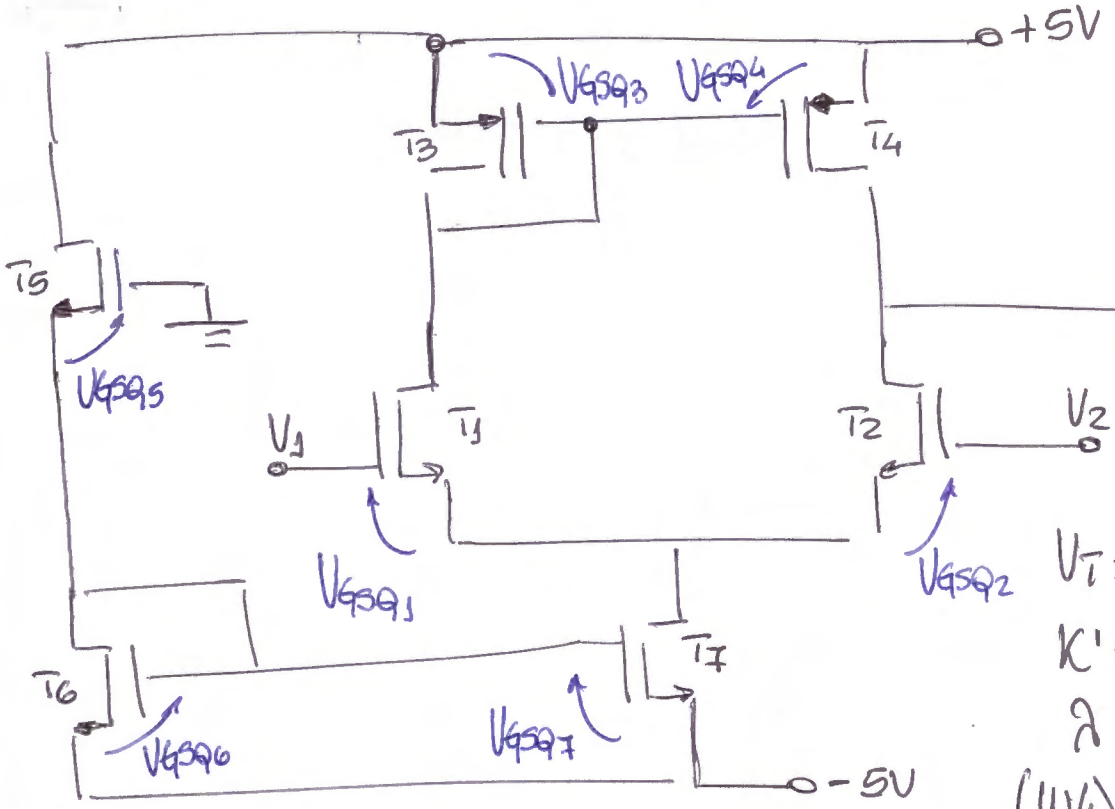
$$C_{beq_2} = 31,7\,pF$$

$$R_{beq_2} = r_{d1} // ((1K // r_{\pi 2}) + \beta 50\Omega) = r_{d1} = 25$$

$$\Rightarrow \boxed{f_h = 200\,MHz}$$

20/07/2016

1/4



$V_T = \pm 1{,}5V$

$K' = 100\,\mu A/V^2$

$\lambda = 0{,}01\,V^{-1}$

$(W/L)_{1,2,3,4} = 10.$

$(W/L)_{5,6,7} = 2.$

a) $RRMC = \left| \dfrac{A_{Vd}}{A_{Vc}} \right|$; $A_{Vd} = V_o/V_{id}$

$A_{Vc} = V_o/V_{ic}.$

<u>POLARIZACIÓN:</u>

$-5V + V_{GSQ6} + V_{GSQ5} = 0.$

<u>PERO:</u> $I_{DQ5} = I_{DQ6}$ Y DADO QUE $(W/L)_{5,6,7}$ Y K' Y V_T.

$\Rightarrow I_{DQ6} = I_{DQ7} \Rightarrow V_{GSQ5} = V_{GSQ6} = V_{GSQ7}.$

$\Rightarrow \boxed{V_{GSQ5} = 2{,}5V}$

$\hookrightarrow \boxed{I_{DQ5} = I_{DQ6} = I_{DQ7} = 0{,}2\,mA}$

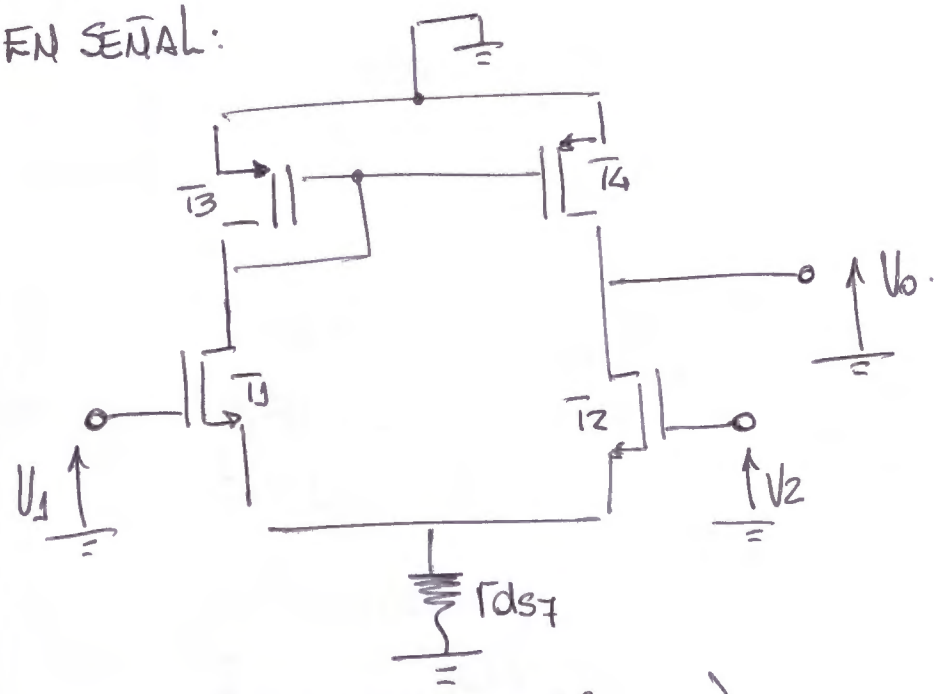
$\boxed{I_{DQ1} = I_{DQ2} = I_{DQ3} = I_{DQ4} = 0{,}1\,mA}$

$\boxed{V_{GSQ1} = V_{GSQ2} = 1{,}82V}$ $\boxed{V_{GSQ3} = V_{GSQ4} = -1{,}82V}$

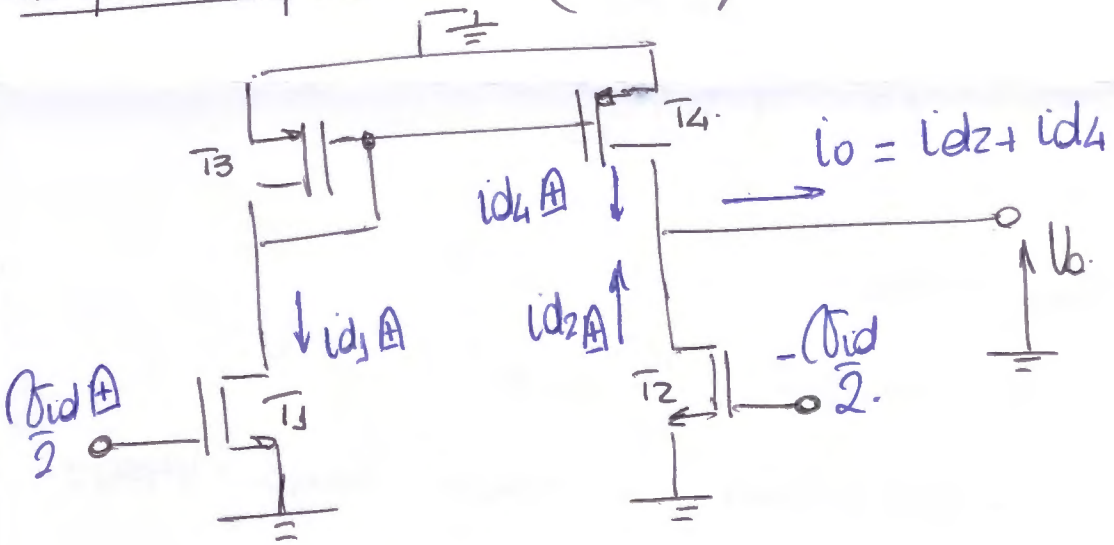
PARÁMETROS: $g_{m_{1A4}} = 0{,}2\,mA/V$.

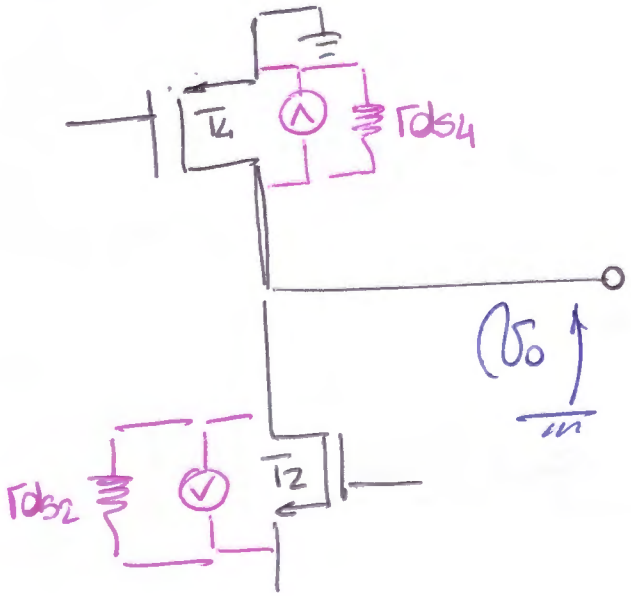
$r_{ds_{1A4}} = 1\,M\Omega$; $r_{ds_{5A7}} = 500\,K\Omega$.

EN SEÑAL:



ENTRADA DIFERENCIAL PURA $(v_{ic} = 0)$.





CORRIENTES:

$$g_{m4} v_{gs4} + g_{m2} v_{gs2} + \frac{v_o}{r_{ds2} // r_{ds4}} = 0$$

$$g_{m2}\left[v_{gs4} + v_{gs2}\right] + \frac{2 v_o}{r_{ds2}} = 0.$$

$$\cdot)\ v_{gs4} = v_{gs3} = -i_{d1}\, r_{d3}$$

$$= -i_{d1}\, 1/g_{m3}$$

$$g_{m2}\left[-i_{d1}\frac{1}{g_{m3}} + v_{gs2}\right] + \frac{2v_o}{r_{ds2}} = 0.$$

$$-i_{d1} + g_{m2}v_{gs2} + \frac{2v_o}{r_{ds2}} = 0.$$

$$-g_{m1}v_{gs1} + g_{m2}v_{gs2} + \frac{2v_o}{r_{ds2}} = 0.$$

$$g_{m1}\left[v_{gs2} - v_{gs1}\right] + \frac{2v_o}{r_{ds2}} = 0.$$

•) $\frac{v_{id}}{2} - v_{gs1} + v_{gs2} - \left(-\frac{v_{id}}{2}\right) = 0.$

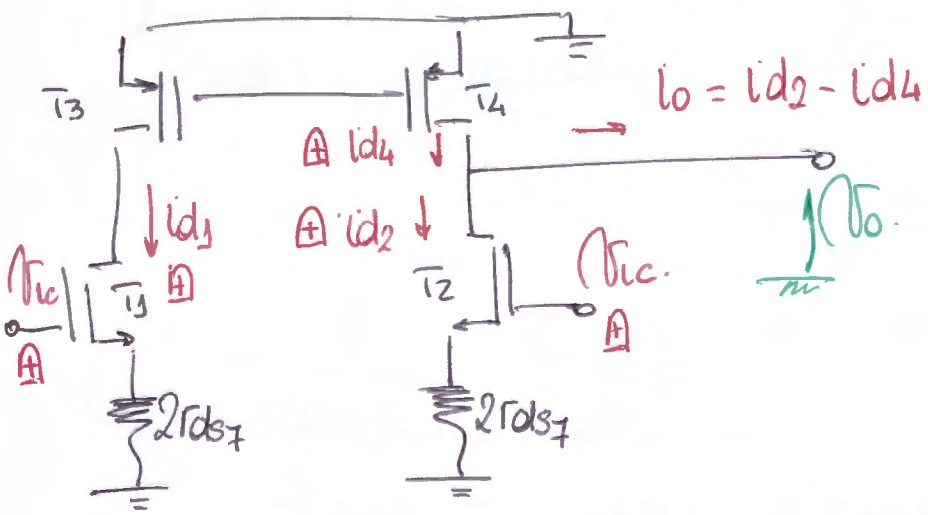
$$v_{id} = v_{gs1} - v_{gs2} \Rightarrow v_{gs2} - v_{gs1} = -v_{id}$$

$$\Rightarrow g_{m1}\left(-v_{id}\right) + \frac{2v_o}{r_{ds2}} = 0$$

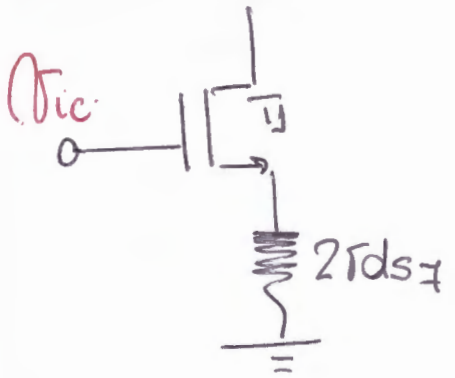
$$\frac{v_o}{v_{id}} = A_{vd} = \frac{g_{m1}\, r_{ds2}}{2}$$

$$\boxed{A_{vd} = 100}$$

ENTRADA COMÚN PURA $(v_{ic} = 0)$



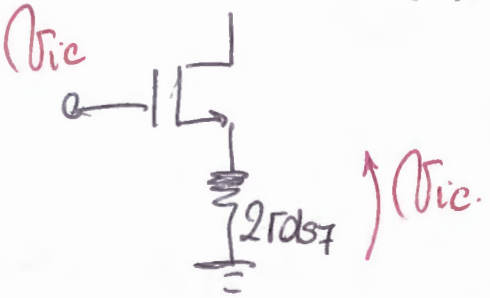
RESISTENCIA DE ENTRADA.



$$R_{ic} = r_{gs} + \beta_{FET}\, 2\, r_{ds7}$$

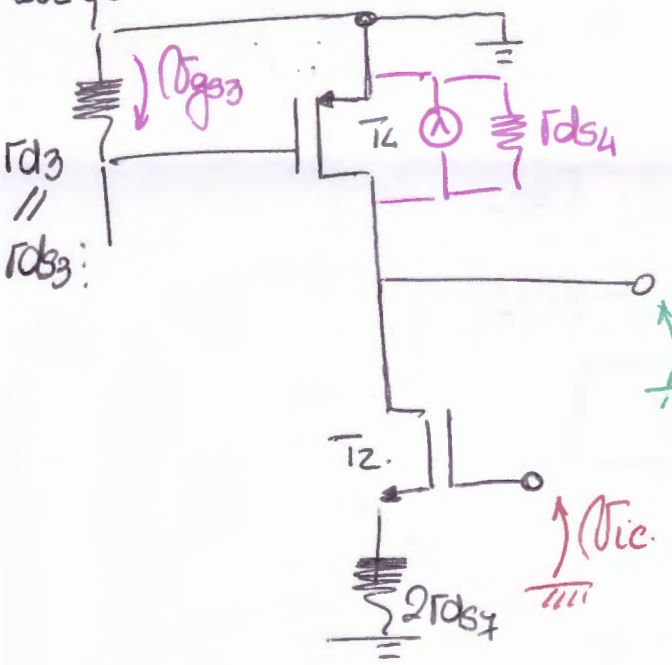
$$R_{ic} = r_{gs} + \underbrace{g_{m1}\, r_{gs}\, 2\, r_{ds7}}$$

ESTE TÉRMINO ES "$g_{m1}\, 2\, r_{ds7}$" VECES MÁS GRANDE QUE EL OTRO.



$$\Rightarrow i_{d1} = i_{d2} = \frac{v_{ic}}{2r_{ds7}}$$

LUEGO:



CORRIENTES:

$$\frac{v_{ic}}{2r_{ds7}} + g_{m4} v_{gs4} + \frac{v_o}{r_{ds4}} = 0.$$

$$\cdot)\ v_{gs4} = v_{gs3} = -i_{d1}\, 1/g_{m3}$$

$$= -\frac{v_{ic}}{2r_{ds7}}\left(r_{d3} // r_{ds3}\right)$$

$$\frac{v_{ic}}{2r_{ds7}}\left\{1 - g_{m4}\left(r_{d3} // r_{ds3}\right)\right\} + \frac{v_o}{r_{ds4}} = 0$$

$$\Rightarrow \frac{v_o}{v_{ic}} = \frac{r_{ds4}}{2r_{ds7}}\left[g_{m4}\left(r_{d3} // r_{ds3}\right) - 1\right]$$

$$\frac{v_o}{v_{ic}} = \frac{r_{ds4}}{2r_{ds7}}\left[\frac{g_{m4}\, r_{d3}\, r_{ds3}}{r_{d3} + r_{ds3}} - 1\right] = \frac{r_{ds4}}{2r_{ds7}}\left[\frac{r_{ds3}}{r_{d3} + r_{ds3}} - 1\right]$$

$$\frac{v_o}{v_{ic}} = \frac{r_{ds4}}{2r_{ds7}}\left[\frac{r_{ds3} - r_{d3} - r_{ds3}}{r_{d3} + r_{ds3}}\right] = \frac{r_{ds4}}{2r_{ds7}}\left[-\frac{r_{d3}}{r_{ds3}}\right]$$

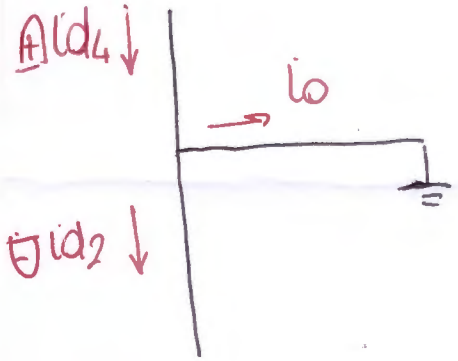
$$\Rightarrow \frac{v_o}{v_{ic}} = A_{vc} = -\frac{r_{ds3}}{2 r_{ds7}} \Rightarrow \boxed{A_{vc} = -1/200}$$ 3/4

$$\Rightarrow RRMC = \left|\frac{A_{vd}}{A_{vc}}\right| = \left|\frac{100}{-1/200}\right| = 20.000$$

ó $RRMC = 20 \log \left|\frac{A_{vd}}{A_{vc}}\right| = 86\ dB.$

OTRA FORMA

$$G_{md} = \frac{i_o}{v_{id}}\Big|_{v_o=0} \Rightarrow \boxed{i_o = i_{d2} - i_{d4}}$$



$$i_{d1} = g_{m1} v_{gs1} = g_{m1}\left(+\frac{v_{id}}{2}\right)$$

$$\hookrightarrow i_{d1} = +g_{m1}\frac{v_{id}}{2}$$

$$\hookrightarrow i_{d2} = -g_{m2}\frac{v_{id}}{2}$$

$i_{d1} = -i_{d2}$

•) $i_{d3} = i_{d1} \wedge i_{d4} = i_{d3}$

$$\Rightarrow i_o = -g_{m2}\frac{v_{id}}{2} - g_{m1}\frac{v_{id}}{2} \ ; \ g_{m1} = g_{m2}.$$

$$\hookrightarrow \boxed{\frac{i_o}{v_{id}} = G_{md} = -g_{m1} = -0{,}2\ mA/V}$$

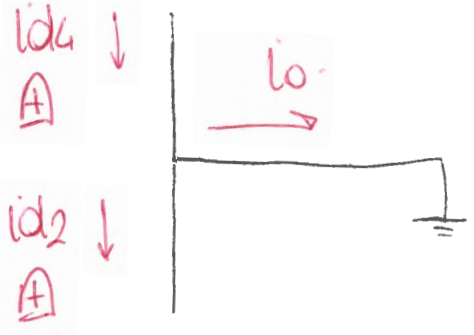
•) $R_o = r_{ds2} // r_{ds4} = 500 K\Omega$

$$\Rightarrow \boxed{A_{vd} = G_{md} R_o = -100}$$

SIGNO ≠ !!!
??

$$G_{mc} = \frac{i_o}{v_{ic}} \Big|_{v_o = 0}$$

$$i_o = i_{d2} - i_{d4}$$

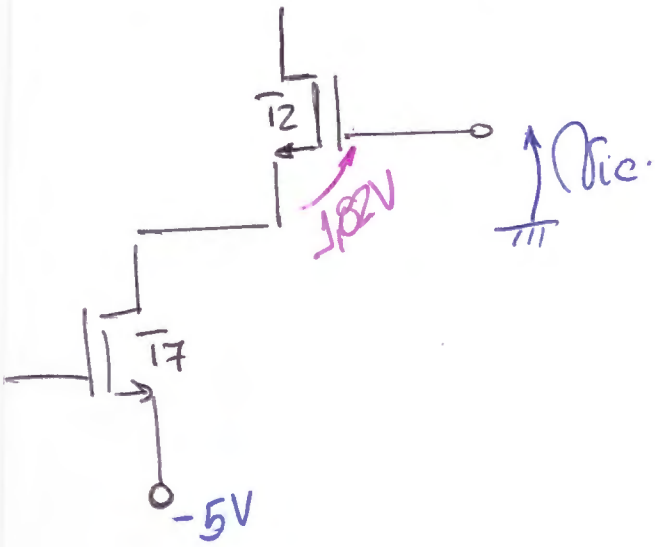


$$\circ)\ i_{d2} = v_{ic} / 2 r_{ds7}$$

Como sigo?

b) RTMC → RANGO DE TENSIÓN DE MODO COMÚN.

PARA T7 EN ZONA ÓHMICA:



•) PARA QUE T7 NO ENTRE EN ZONA ÓHMICA NECESITO QUE:

$$V_{DSQ7} > V_{GSQ7} - V_T$$

$$V_{DSQ7} > 2{,}5V - 1{,}5V = 1V$$

$$V_{DQ7} - V_{SQ7} > 1V$$

$$V_{DQ7} > 1V + V_{SQ7}$$

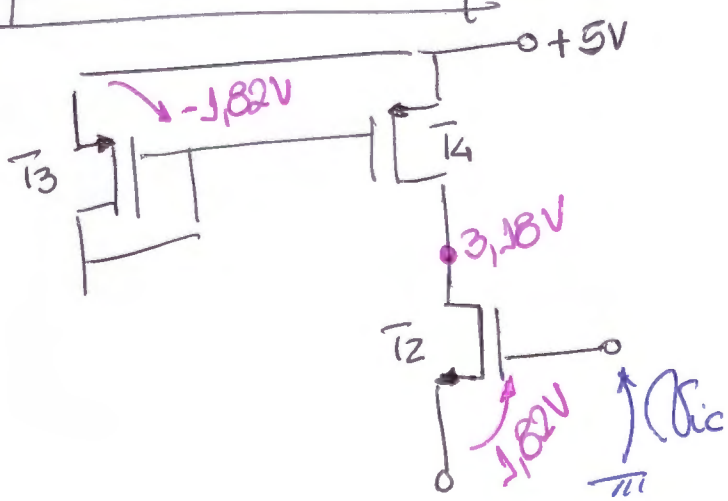
$$\boxed{V_{DQ7} > -4V}$$

A SU VEZ: $V_{DQ7} + V_{GSQ2} = V_{ic}$

$$V_{DQ7} + 1{,}82V = V_{ic} \longrightarrow V_{ic} > -4V + 1{,}82V$$

$$\boxed{V_{ic} > -2{,}18V}$$

PARA T1 Y T2 EN ZONA ÓHMICA:



NECESITO QUE:

$$V_{DSQ2} > V_{GSQ2} - V_T$$

$$V_{DSQ2} > 1{,}82V - 1{,}5V$$

$$V_{DSQ2} > 0{,}32V$$

$$\hookrightarrow V_{SQ2} < 2{,}86V$$

$$\Rightarrow V_{ic} < 2{,}86V + 1{,}82V$$

$$\boxed{V_{ic} < 4{,}68V}$$

$$\Rightarrow \text{RTMC: } \boxed{-2{,}18V < V_{ic} < 4{,}68V}$$

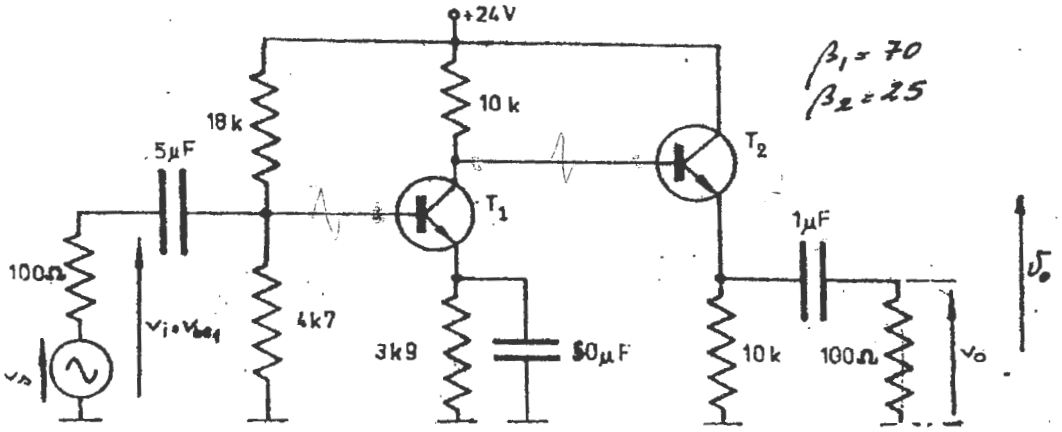
P/ fotocopiar.

66.08 – 86.06 Evaluación integradora – 1/2016 - segunda fecha 13/07/16

APELLIDO	NOMBRE	PADRON	TURNO			N° de HOJAS	Corrección	
				T	N			

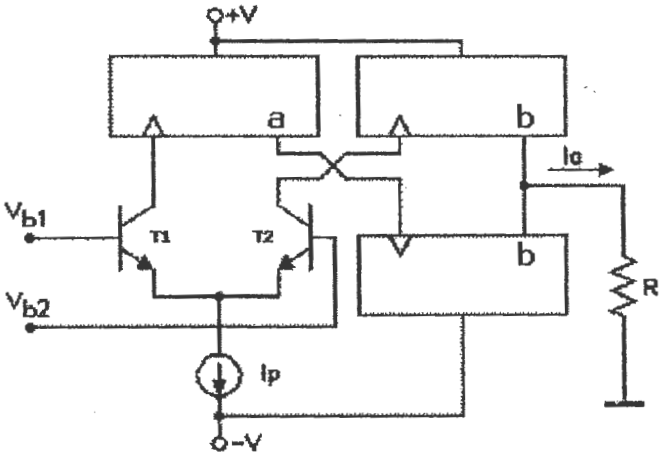
1.-

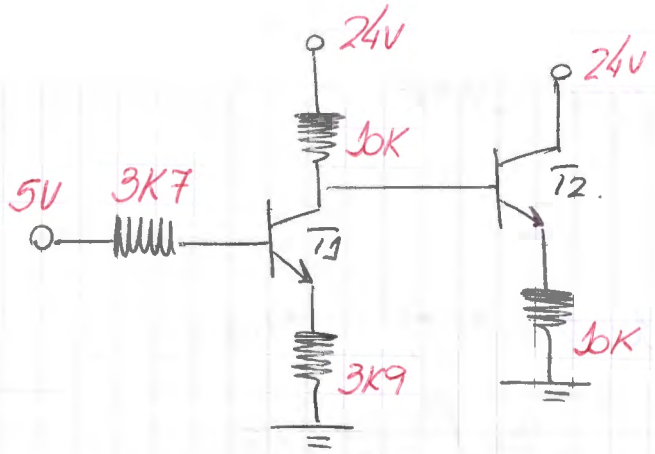
f_T = 300 MHz ; C_μ = 1 pF ; r_x = 100 Ω ; $V_A \to \infty$



Obtener los valores aproximados de f_l y f_h. Trazar un diagrama de Bode aproximado de módulo y argumento de A_{vs}.

2.- Los bloques representan fuentes espejo de copia "*a*" y "b", respectivamente. ¿Cuál es el valor de I_{OQ}, si $a = b = 1$?. Obtener la expresión de la transconductancia del circuito $G_{md} = i_O/v_{id}$ en función de Ip.





$\beta_1 = 70$ $\beta_2 = 25$

$r_x = 100$ $V_A \to \infty$

$f_T = 300\,MHz$; $C_\mu = 1\,pF$

DESPRECIO CAIDA EN BASE DE T_1:

$$V_{BQ1} = 5V \Rightarrow V_{EQ1} = 4{,}3V \Rightarrow I_{CQ1} = 1{,}1mA$$

DESPRECIO I_{BQ2}.

$$V_{CQ1} = V_{BQ2} = 24V - 1{,}1mA\ 10K.$$

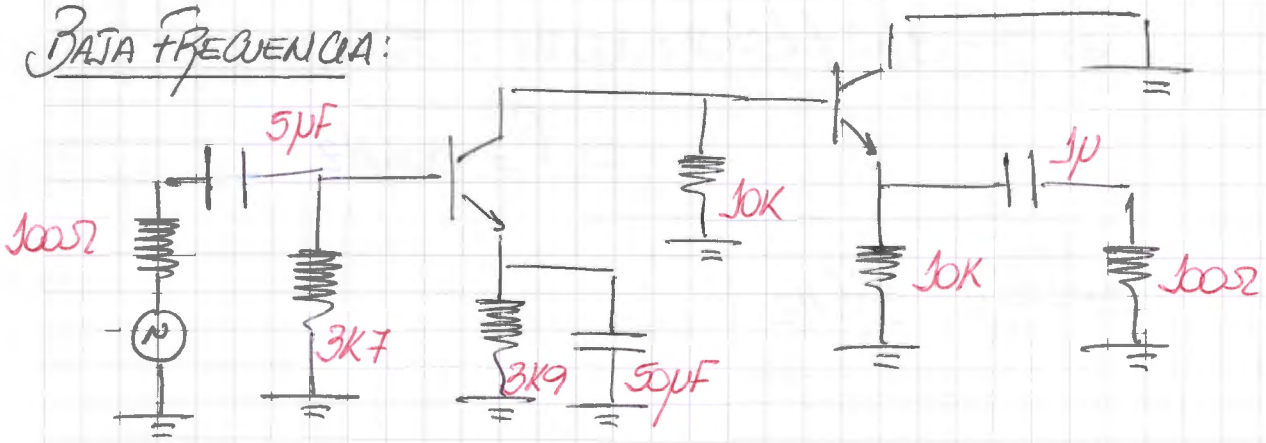
$$V_{CQ1} = V_{BQ2} = 13V$$

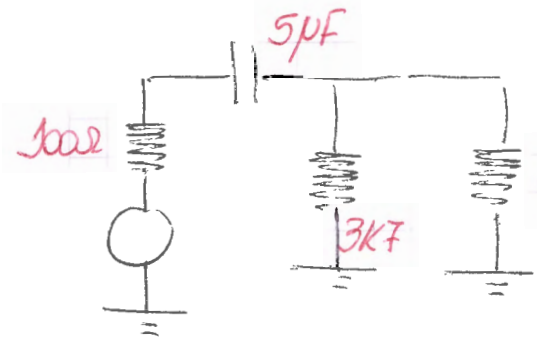
$$\Rightarrow V_{EQ2} = 12{,}3V \Rightarrow I_{CQ2} = 1{,}23mA$$

PARÁMETROS: $g_{m1} = 44m$ $g_{m2} = 49m$

$r_{\pi 1} = 1K6$ $r_{\pi 2} = 508\,\Omega$.

BAJA FRECUENCIA:

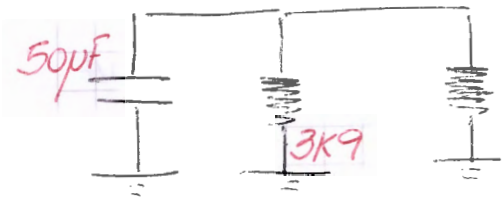




$r_\pi + \beta_1 3K9 = 275K$

$\Rightarrow \tau = 5\mu F\,(100\Omega + 3K7) = 19ms$

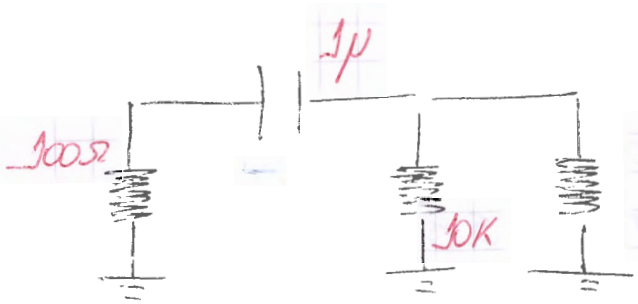
$\hookrightarrow f = 8{,}4\,Hz$



$\frac{100\Omega + r_x + r_{\pi 1}}{\beta_1} = 25{,}7\,\Omega$

$\Rightarrow \tau = 50\mu F\,(3K9 \,//\, 25{,}7\Omega) = 1{,}29ms$

$\hookrightarrow f = 124\,Hz$



$\frac{10K + r_x + r_{\pi 2}}{\beta_2} = 424\,\Omega$

$\Rightarrow \tau = 1\mu F\,(424\Omega + 100\Omega) = 524\,\mu s$

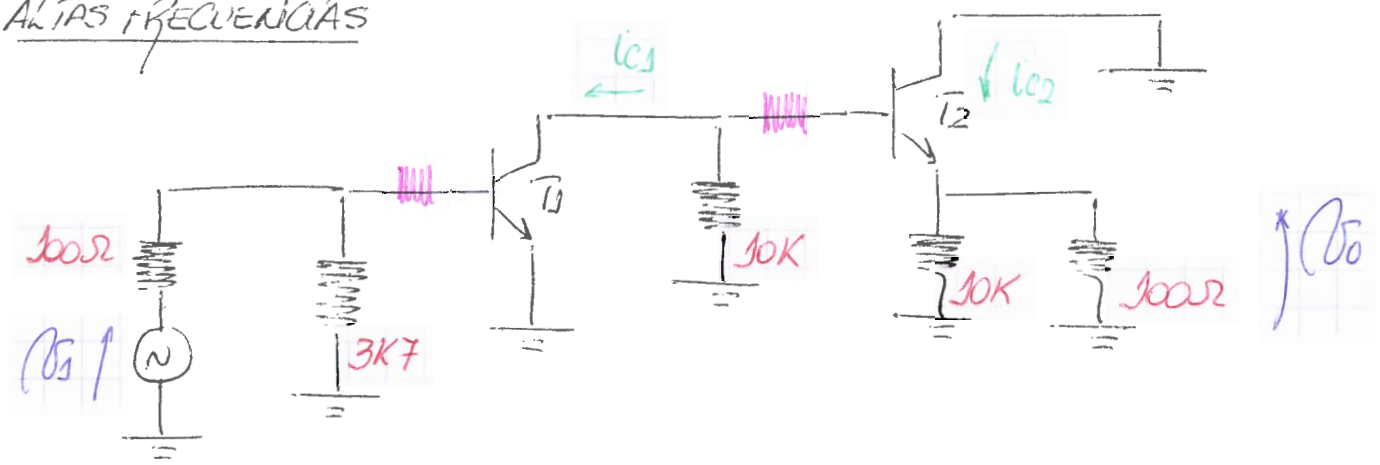
$\hookrightarrow f = 304\,Hz$

$\Rightarrow \boxed{f_\ell = 304\,Hz}$

$C_{\pi_1} = 22{,}3\,pF$

$C_{\pi_2} = 25\,pF \;;\; C_\mu = 1\,pF$

ALTAS FRECUENCIAS



BASE DE T_1

$$C_{beq} = C_{\pi_1} + C_\mu\left(1 + g_{m1}\left(10K \,//\, (r_x + r_{\pi_2} + \beta_2\, 100\Omega)\right)\right)$$

$$C_{beq} = C_{\pi_1} + C_\mu\, 105 = 127{,}3\,pF$$

$$R_{beq} = (100\Omega + r_x) \,//\, r_{\pi_1} = 178\Omega$$

$$f_h = 7\,MHz$$

DADO QUE $10K \gg r_x$ CONSIDERO BASE (T2) Y COLECTOR (T1) COMO EL MISMO NODO

$$C_{beq} = C_\mu + C_\mu + C_{\pi_2}\left(1 - \frac{100\Omega}{100\Omega + r_{\pi_2}}\right)$$

$$C_{beq} = 2\,C_\mu + 0{,}17\,C_{\pi_2} = 6{,}25\,pF$$

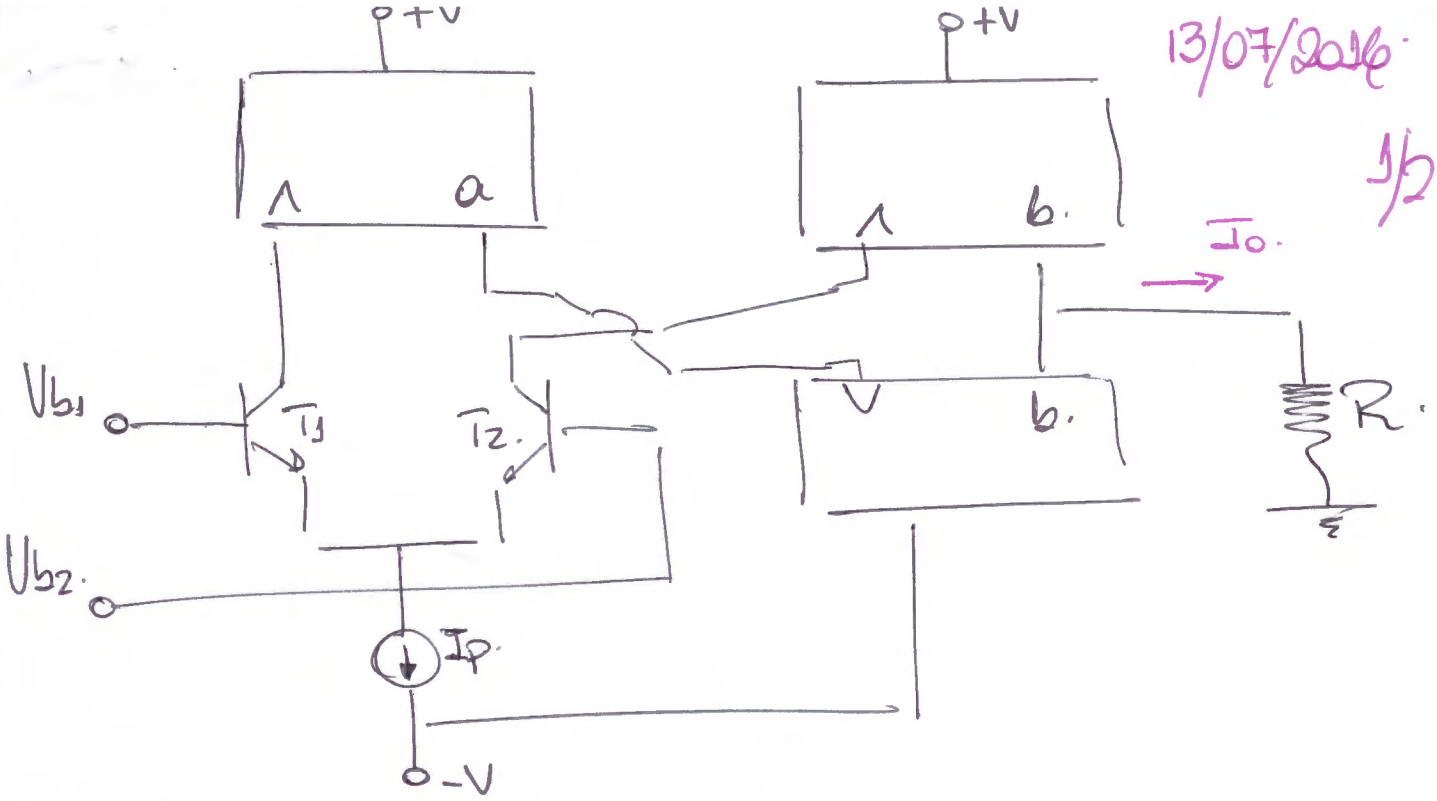
$$R_{beq} = 10K \,//\, (r_{\pi_2} + \beta_2\, 100) = 2312\Omega$$

$$f_h = 11{,}7\,MHz$$

$$\Rightarrow \boxed{f_h = 7\,MHz}$$

13/07/2016

1/2

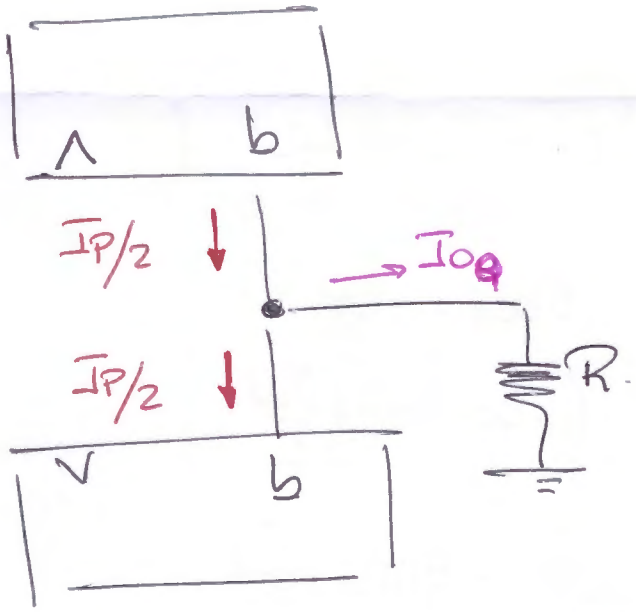


$$\boxed{I_{CQ1} = I_{CQ2} = I_P/2}$$

Si $a = b = 1$

↳ LAS COPIAS SON IGUALES.

⇒

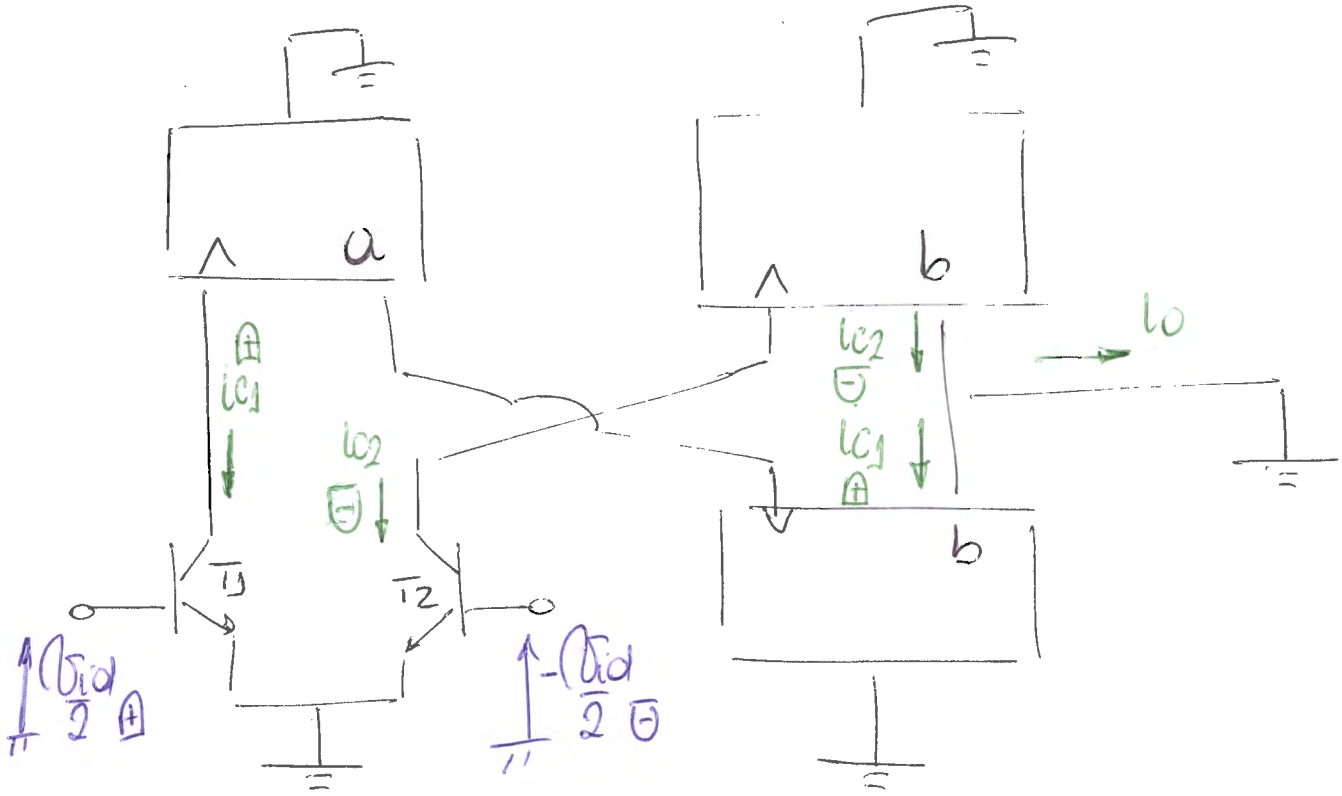


$$\Rightarrow \boxed{I_{oQ} = 0\,A}$$

$G_{md} = \dfrac{I_o}{V_{id}}$ EN FUNCIÓN DE I_P ?

PERO CÓMO HAGO ? CUANDO APLICO V_{id} (SEÑAL), EL GENERADOR I_P ES UN CARC. ABIERTO ✓

SE DEFINE: $G_{md} = \left.\dfrac{I_o}{v_{id}}\right|_{v_o=0}$



$$\Rightarrow i_{c2} = i_o + i_{c1} \Rightarrow \boxed{i_o = i_{c2} - i_{c1}}$$

LUEGO

$$i_{c1} = g_{m1} v_{be1} \wedge v_{be1} = \frac{v_{id}}{2}$$

$$i_{c2} = g_{m2} v_{be2} \wedge v_{be2} = -\frac{v_{id}}{2}$$

$$i_{c1} = g_{m1}\frac{v_{id}}{2} \; ; \; i_{c2} = -g_{m2}\frac{v_{id}}{2}$$

$$\Rightarrow i_o = -g_{m2}\frac{v_{id}}{2} - g_{m1}\frac{v_{id}}{2} \Rightarrow \frac{i_o}{v_{id}} = -\frac{1}{2}(g_{m1}+g_{m2})$$

$$G_{md} = -\frac{1}{2}(g_{m1}+g_{m2})$$

2/2

BIEN: $g_m = \frac{I_{CQ}}{V_T}$

$$g_{m1} = \frac{I_{CQ1}}{V_T} = \frac{I_P}{2V_T}$$

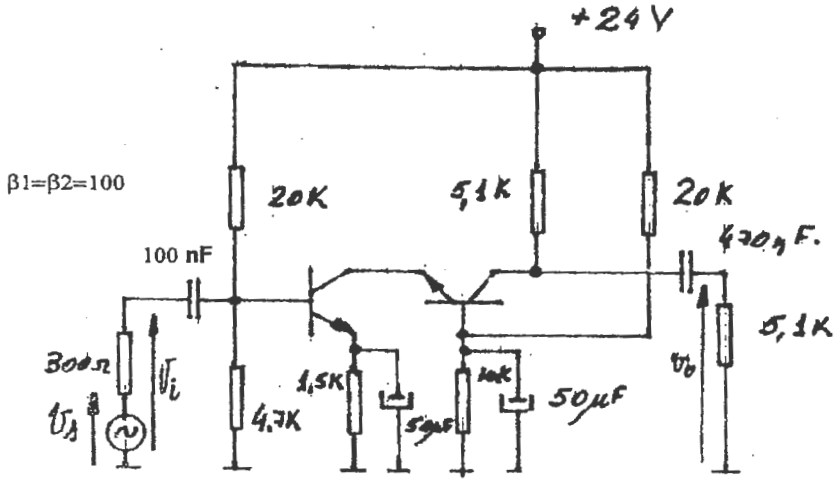
$$g_{m2} = \frac{I_{CQ2}}{V_T} = \frac{I_P}{2V_T}$$

$$\boxed{g_{md} = -\frac{1}{2}\frac{I_P}{V_T}}$$

66.08 – 86.06 Evaluación integradora – 1/2016 – 1era fecha – 1/7/16

APELLIDO	NOMBRE	PADRON	TURNO			N° de HOJAS	Corrección	
				T	N			

1. Obtener el valor garantizable de f_h para A_{vs}.
C_μ = 1 pF ; f_T = 300 MHZ ; r_x = 100 Ω

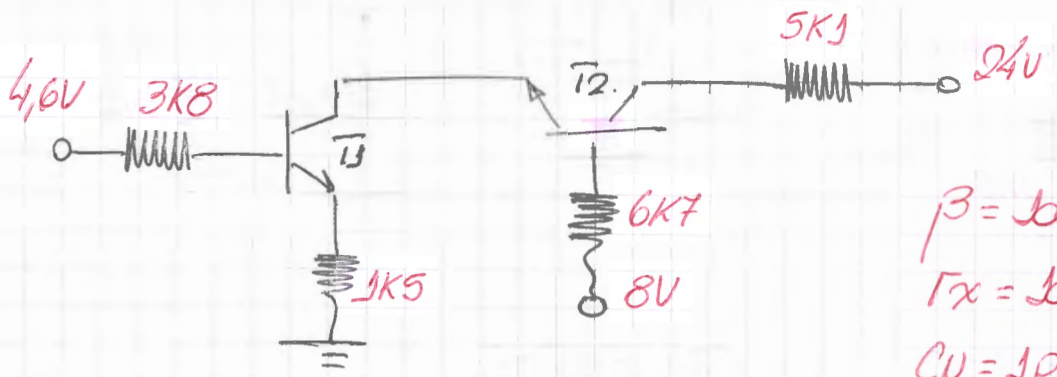


2.- Dibujar el circuito de un par diferencial NMOSFET (T_1 – T_2) con carga resistiva en ambas ramas R_{D1} = R_{D2} = 10KΩ y polarizado mediante una fuente de corriente cascode con rama de referencia: R_{ref} = 8KΩ, T_3 y T_4; y rama de salida: T_5 y T_6. Se alimenta todo entre ± 6V.
Los transistores son idénticos y de características:

$$V_T = 1\ V;\ k' = 1\ mA/V^2\ ;\ (W/L) = 1,\ \lambda = 0{,}01\ V^{-1}.$$

Hallar las expresiones y el valor de Av_{1d}, Av_{1c}, Av_{dd}, Av_{dc}. Justificar cuál es la más sensible a posibles desapareamientos.

↳ VER BIEN!



$\beta = 100$

$r_x = 100$

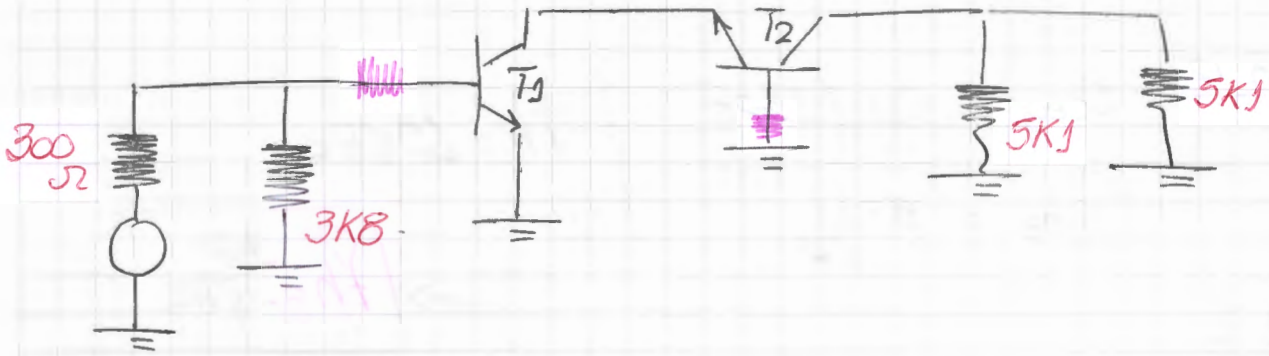
$C_\mu = 1pF$; $f_T = 300M$

DESPRECIO CAIDA EN BASE DE T1:

$$V_{BQ1} = 4,6V \Rightarrow V_{EQ1} = 3,9V$$

$$\Rightarrow I_{CQ1} = I_{CQ2} = \frac{3,9V}{1K5} = 2,6mA.$$

EN SEÑAL:

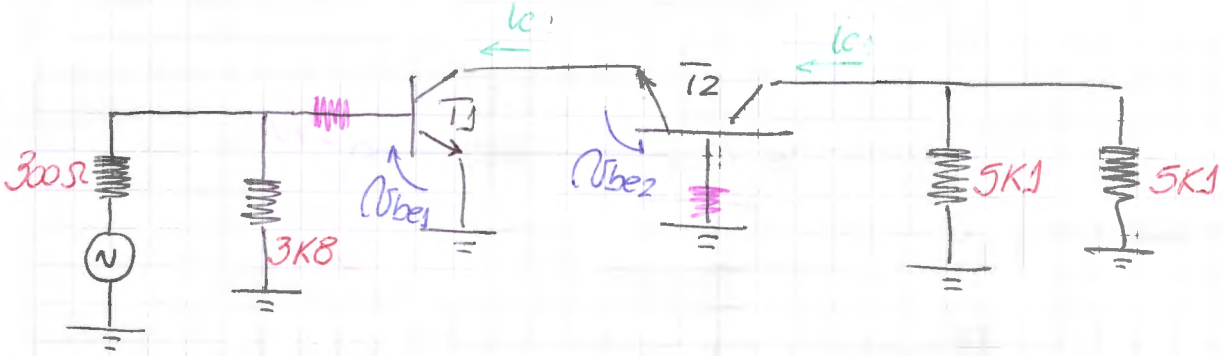


PARÁMETROS: $g_m = g_{m1} = g_{m2} = 104m$

$$r_\pi = r_{\pi 1} = r_{\pi 2} = 962\Omega$$

c) SI BIEN EN EMISOR DE T2 C↑↑, K↓↓ (rd)

EN SEÑAL



$C_\mu = 1pF$; $C_\pi = 54{,}2pF$

BASE T1

$$C_{beq} = C_\pi + C_\mu\left(1 - \frac{V_c}{V_{bp}}\right)$$

$$C_{beq} = C_\pi + C_\mu\left(1 + g_m\frac{(r_{\pi 2} + r_x)}{\beta}\right) = 56{,}3pF$$

$$R_{beq} = (300\Omega + 100\Omega) \,//\, r_\pi = 283\Omega$$

$f_h = 10MHz$

COLECTOR T2

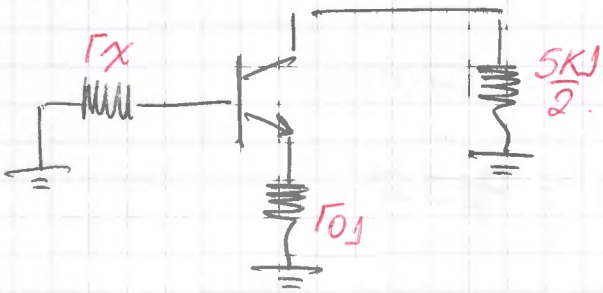
$C_{ceq} = C_\mu = 1pF$

$R_{ceq} = 5K1/2$

$f_h = 62MHz$

$\Rightarrow \boxed{f_h = 10MHz}$

BASE DE T2



$R_{beq} = r_x$

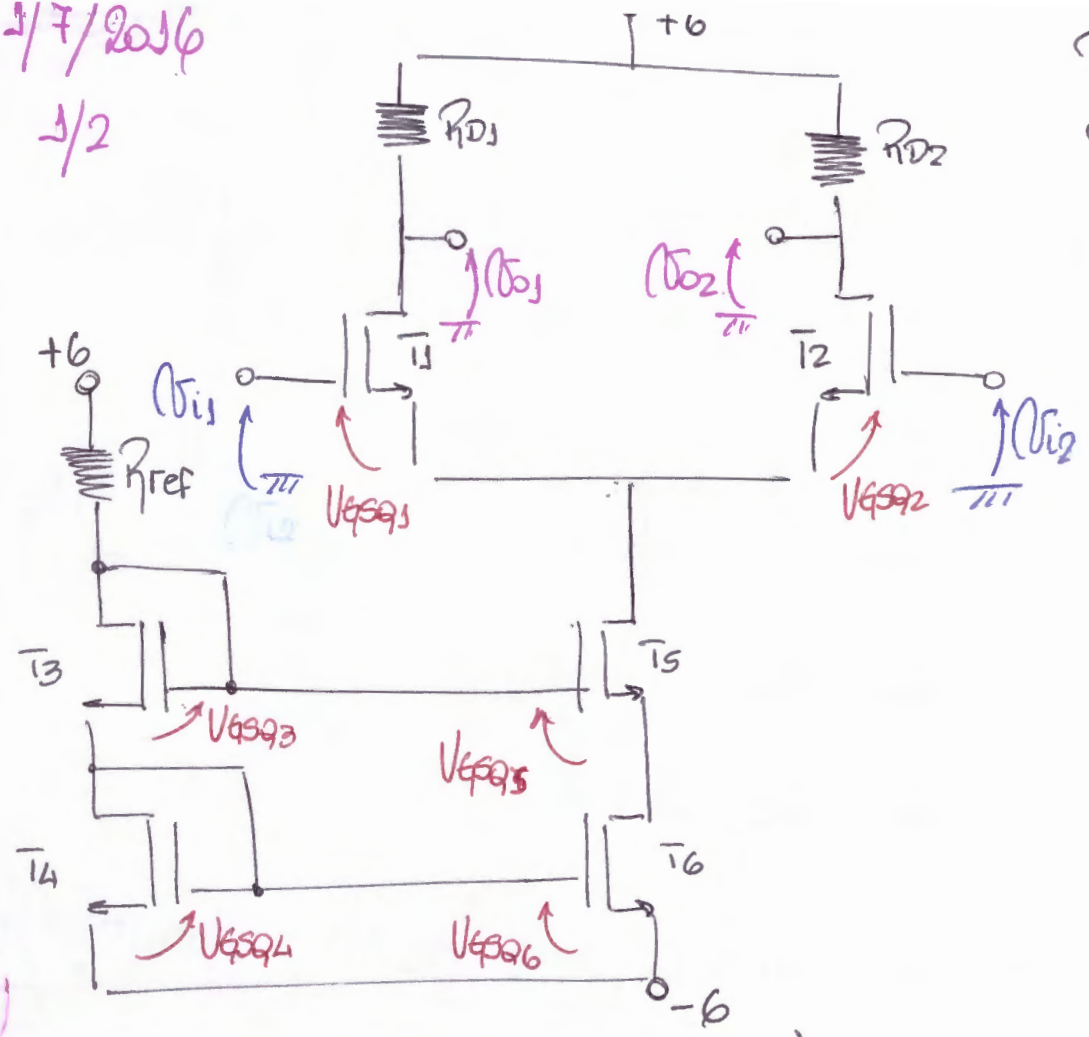
$$C_{beq} = C_\pi\left(1 - \frac{V_e}{V_{bp}}\right) + C_\mu\left(1 - \frac{V_c}{V_{bp}}\right)$$

$$C_{beq} = C_\pi\left(1 - \frac{r_{o1}}{r_{o1} + r_d}\right) + C_\mu\left(1 - \frac{-5K1/2}{r_{o1} + r_d}\right) \approx C_\mu = 1pF$$

$\hookrightarrow f_h = 1{,}6GHz$

1/7/2016

1/2



$R_{D1} = R_{D2} = 10K\Omega$

$R_{ref} = 8K\Omega$

$V_T = 1V$

$K' = 1mA/V^2$

$(W/L) = 1$

$\lambda = 0{,}01V^{-1}$

$$6V - I_{ref}\,8K - V_{GSQ3} - V_{GSQ4} - (-6V) = 0.$$

•) $V_{GSQ3} = V_{GSQ4} \Rightarrow V_{GSQ3} = 6V - 4K\,I_{ref}.$

$$\Rightarrow I_{ref} = K'W/L\,(V_{GSQ3} - V_T)^2 = K'W/L\,(6V - 4K\,I_{ref} - V_T)^2.$$

$$1000\,I_{ref} = (5V - 4K\,I_{ref})^2$$

$$1000\,I_{ref} = 25 + 16\times10^6\,I_{ref}^2 - 40.000\,I_{ref}$$

$$0 = I_{ref}^2(16\times10^6) + I_{ref}(-41000) + (25)$$

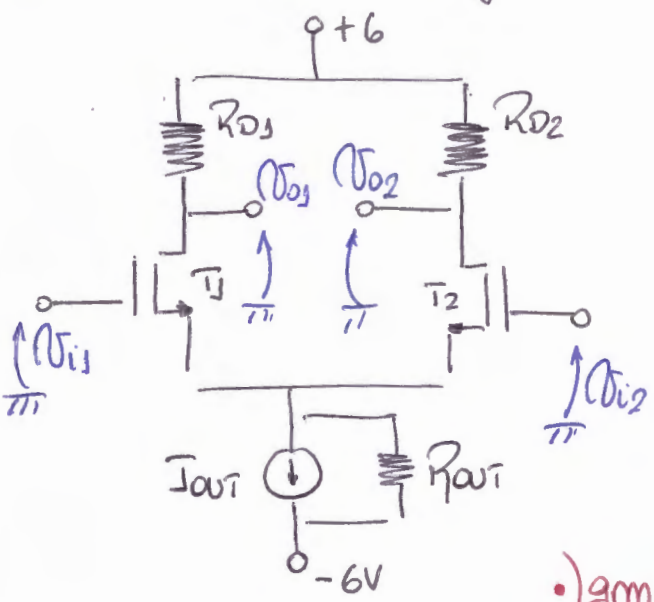
$$\frac{41.000 \pm 9000}{32\times10^6} \nearrow 1{,}56mA \Rightarrow V_{GSQ3} = -0{,}24V \times$$

$$\searrow 1mA \Rightarrow V_{GSQ3} = 2V \checkmark$$

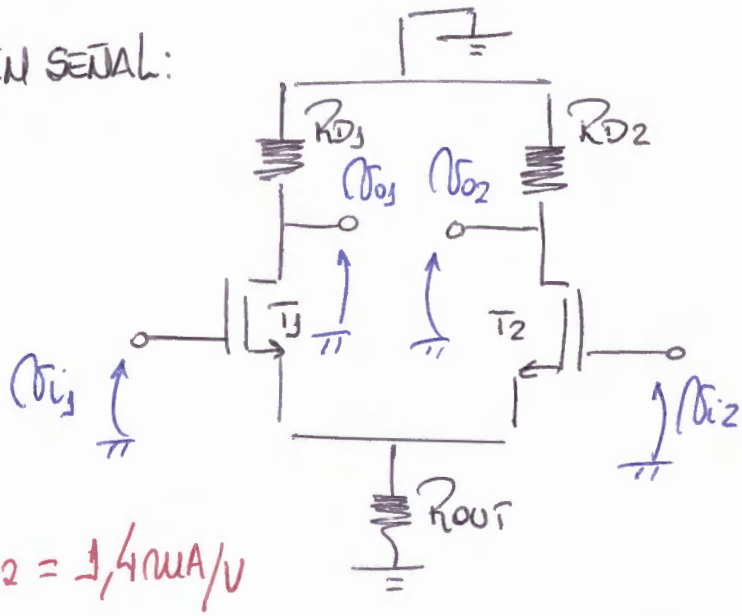
$$\Rightarrow \boxed{I_{ref} = 1mA} \Rightarrow \boxed{I_{OUT} = 1mA.}$$

$$r_{dsOUT} = \frac{1}{\lambda I_{OUT}} \Rightarrow \boxed{r_{dsOUT} = 100K}$$

$\Rightarrow I_{OUT} = 1mA \Rightarrow g_{m5} = 2mA/V \Rightarrow R_{OUT} = g_{m5} r_{ds_{OUT}}^2 = 20M\Omega$



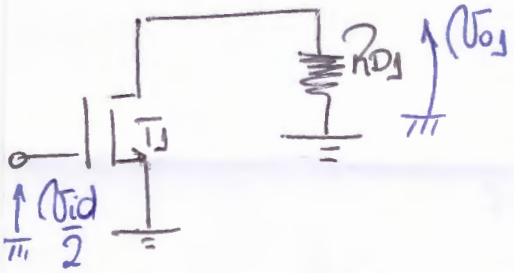
EN SEÑAL:



- $g_{m1} = g_{m2} = 1,4mA/V$
- $r_{ds1} = r_{ds2} = 200K\Omega$

$I_{DQ1} = I_{DQ2} = 0,5mA$

MODO DIFERENCIAL



- $v_{o1} = -i_{d1} R_{D1} = -g_{m1} v_{gs1} R_{D1} = -g_{m1}\left(+\frac{v_{id}}{2}\right) R_{D1}$

$v_{o1} = -g_{m1} \frac{v_{id} R_{D1}}{2} \Rightarrow \boxed{A_{v1d} = \frac{v_{o1}}{v_{id}} = -\frac{g_{m1} R_{D1}}{2} \quad A_{v1d} = -7}$

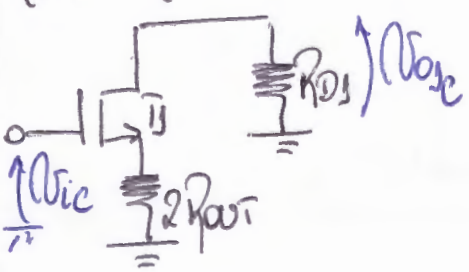
- $v_{o2} = -i_{d2} R_{D2} = -g_{m2}\left(-\frac{v_{id}}{2}\right) R_{D2} = g_{m2} \frac{v_{id} R_{D2}}{2}$

$\hookrightarrow \frac{v_{o2}}{v_{id}} = \frac{g_{m2} R_{D2}}{2} = A_{v2d} = 7$

- $A_{vdd} = \frac{v_{od}}{v_{id}} = \frac{v_{o1} - v_{o2}}{v_{id}} = A_{v1d} - A_{v2d} = g_{m1,2} R_{D1,2}$

$\rightarrow \boxed{A_{vdd} = -14}$

MODO COMÚN:



- $\frac{v_{o1c}}{v_{ic}} = A_{v1c} = \frac{-i_{d1} R_{D1}}{i_{d1} 2R_{OUT} + v_{gs1}} = \frac{-R_{D1}}{2R_{OUT} + 1/g_{m1}}$

$\boxed{A_{v1c} \approx \frac{-R_{D1}}{2R_{OUT}} = 0,25m}$

•) $A_{vdc} = \frac{v_{od}}{v_{ic}} = \frac{v_{o1} - v_{o2}}{v_{ic}} = \frac{v_{o1}}{v_{ic}} - \frac{v_{o2}}{v_{ic}} = A_{v1c} - A_{v2c}$.

2/2

PERO $A_{v1c} = A_{v2c}$ (SI ESTAN 100% APAREADOS).

$\Rightarrow \boxed{A_{vdc} = 0}$ RRMC $\rightarrow \infty$ $\left(\left|\frac{A_{vdd}}{A_{vdc}}\right|\right)$

CON DESAPAREAMIENTO!

Ej) R_{D1} y R_{D2}.

•) $A_{vdd} = \frac{v_{od}}{v_{id}} = \frac{v_{o1}}{v_{id}} - \frac{v_{o2}}{v_{id}} = A_{v1d} - A_{vd2}$.

$A_{vdd} = -\frac{g_{m1}}{2} R_{D1} - \frac{g_{m2}}{2} R_{D2} = -\frac{g_{m1,2}}{2} \{R_{D1} + R_{D2}\}$

PERO $R_{D1} \approx R_{D2}$ $(R_{D2} = R_{D1} + \Delta R_D)$

$\Rightarrow \boxed{A_{vdd} = -g_{m1,2} R_{D1,2}}$

•) $A_{vdc} = \frac{v_{od}}{v_{ic}} = \frac{v_{o1} - v_{o2}}{v_{ic}} = \frac{v_{o1}}{v_{ic}} - \frac{v_{o2}}{v_{ic}} = A_{v1c} - A_{v2c}$

$A_{vdc} = -\frac{R_{D1}}{2R_{OUT}} - \left[-\frac{R_{D2}}{2R_{OUT}}\right] = \frac{1}{2R_{OUT}} \left[R_{D2} - R_{D1}\right]$

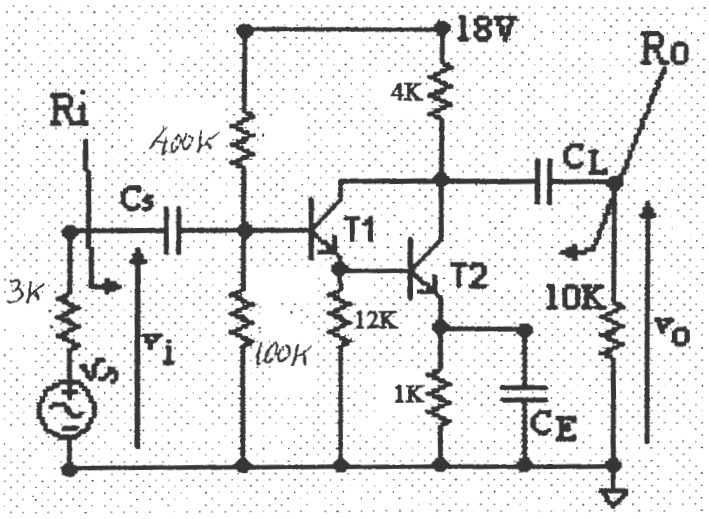
$\Rightarrow \boxed{A_{vdc} = \frac{\Delta R_D}{2R_{OUT}} \neq 0}$ RRMC YA NO TIENDE A ∞.

$\Rightarrow$ EL DESAPAREAMIENTO AFECTA DE MANERA CONSIDERABLE A A_{vdc} PERO NO ASÍ A A_{vdd}

P/ Fotocopiar

66.08 - Circuitos Electrónicos I — Evaluación integradora- 1/2016 quinta fecha 3/8/16

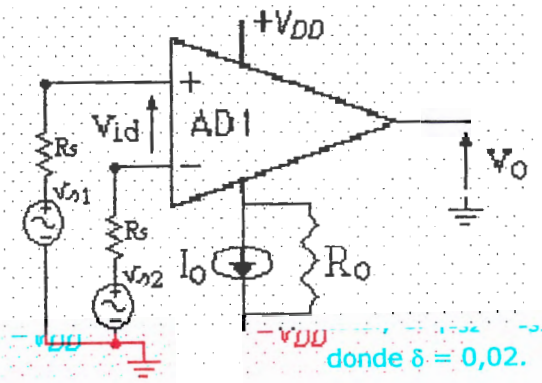
APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
				T	N			



1. β= 100 ; C_μ= 2 pF ; f_T= 300 MHz.
r_x=100Ω

Justificar *cualitativamente* cuál será el nodo dominante para la respuesta en alta frecuencia de A_{vs}. Calcular el valor aproximado de f_h en base a este nodo.

↳ Preguntar



2. AD1 es un par acoplado por emisor de TBJs (T_1 - T_2), con una fuente espejo PMOSFET como carga (T_3 - T_4).

Se admiten transistores con características nominalmente similares (T_1 = T_2 y T_3 = T_4).

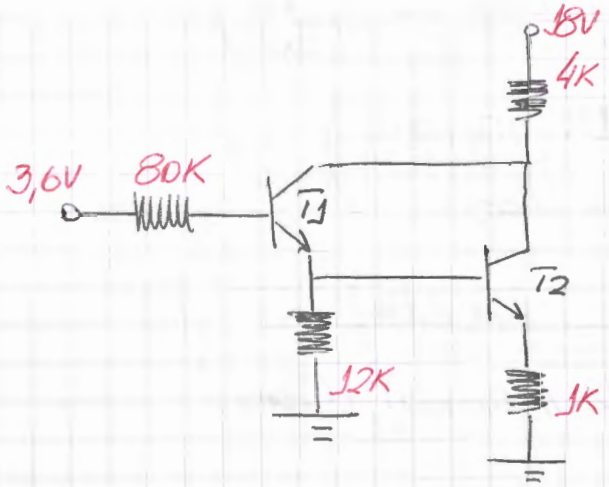
Io = 200 uA ; k´= 100 uA/V^2 ; W/L = 1

Definir y hallar el valor de la tensión de offset total, si $|I_{D2}| = |I_{D1}|/(1+\delta)$; $|W_4/W_3| = 0,$

donde δ = 0,02.

donde δ = 0,02.

1)



$\beta = 100$

$r_x = 100\,\Omega$

$C_\mu = 2\,pF$

$f_T = 300\,MHz$

DESPRECIO CAIDA EN BASE DE T1.

$\Rightarrow V_{BQ1} = 3{,}6\,V \Rightarrow V_{EQ1} = V_{BQ2} = 2{,}9\,V$

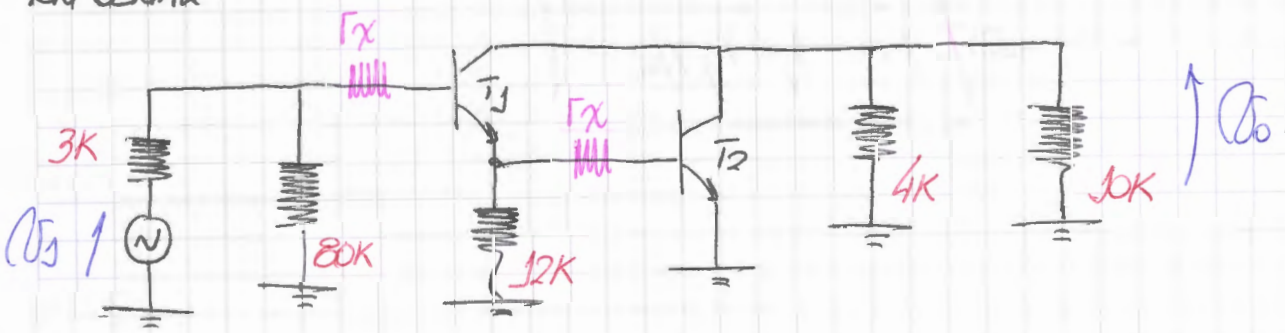
$\Rightarrow V_{EQ2} = 2{,}2\,V \Rightarrow I_{CQ2} = 2{,}2\,mA$

$\Rightarrow I_{BQ2} = 22\,\mu A$

$\Rightarrow I_{12K} = 0{,}24\,mA$

DADO QUE: $I_{BQ2} << I_{12K}$; $I_{CQ1} = 0{,}24\,mA$

EN SEÑAL:



PARÁMETROS:

$g_{m1} = 9{,}6\,m$ $\qquad$ $g_{m2} = 88\,m$

$r_{\pi 1} = 10{,}4\,K$ $\qquad$ $r_{\pi 2} = 1{,}1\,K$

$C_{\pi 1} = 3{,}1\,pF$ $\qquad$ $C_{\pi 2} = 4{,}5\,pF$

BASE DE T1

$$C_{beq} = C_{\pi 1}\left(1 - \frac{V_{be}}{V_{bp}}\right) + C_\mu\left(1 - \frac{V_{be}}{V_{bp}}\right)$$

$$C_{beq} = C_{\pi 1}\left(1 - \frac{\omega_1 (12K // (r_x + r_{\pi 2}))}{\omega_1 (\ ) + V_{be1}}\right) +$$

$$+ C_\mu\left(1 - \frac{-\omega_1 (4K // 30K)}{\omega_1 (12K // (r_x + r_{\pi 2})) + V_{be1}}\right)$$

$C_{beq} = 0{,}067\, C_{\pi 1} + 3{,}4\, C_\mu = 7{,}06\ pF$

$R_{beq} = 3K + 100\,\Omega = 3100\,\Omega$

$f_h = 7{,}26\ MHz$

BASE DE T2:

$$C_{beq} = C_{\pi 2} + C_\mu\left(1 - g_{m2}(4K // 30K)\right)$$

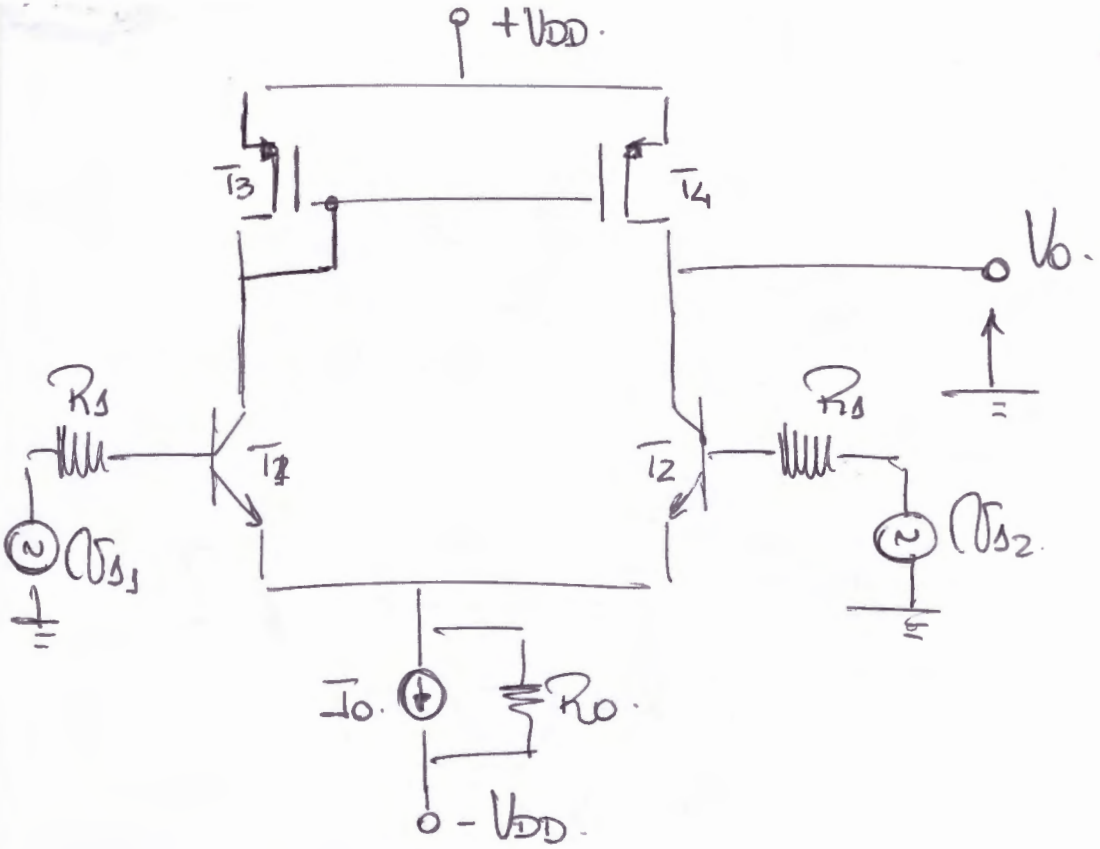
$C_{beq} = C_{\pi 2} + 256\, C_\mu = 557\ pF$

$R_{beq} = 1{,}4\,\Omega$

$f_h = 1{,}47\ MHz$

$$\Rightarrow \boxed{f_h = 1{,}47\ MHz}$$

3/8/2016



$T_1 = T_2$.

$T_3 = T_4$.

$I_o = 200\,\mu A$.

$K' = 100\,\mu A/V^2$.

$W/L = 1$.

TENSIÓN DE OFFSET.

$$V_{s1} - \cancel{V_{R1}} - V_{BE1} + V_{BE2} + \cancel{V_{R1}} - V_{s2} = 0. \; ?$$

$$V_{s1} - V_{s2} = V_{BE1} - V_{BE2}.$$

$$V_{off} = V_{BE1} - V_{BE2}.$$

•) DESAPAREAMIENTO ENTRE T1 Y T2 (I_{S1} E I_{S2}).

SEA: $I_{C1} = I_{S1}\, e^{V_{BE1}/V_{TH}} \Rightarrow V_{BE1} = V_{TH} \ln\left(\frac{I_{C1}}{I_{S1}}\right)$

ENTONCES: $V_{off} = V_{TH} \ln\left(\frac{I_{C1}}{I_{S1}}\right) - V_{TH} \ln\left(\frac{I_{C2}}{I_{S2}}\right)$

$$V_{off} = V_{TH} \ln\left(\frac{I_{C1}}{I_{S1}} \; \frac{I_{S2}}{I_{C2}}\right)$$

CONSIDERO QUE $I_{C1} = I_{C2}$

$$V_{off} = V_{TH} \ln\left(\frac{I_{S2}}{I_{S1}}\right);$$

$$\frac{I_{S2} - I_{S1}}{I_{S1}} \leq \delta.$$

$$\frac{I_{S2}}{I_{S1}} \leq 1 + \delta.$$

$$\frac{I_{S2}}{I_{S1}} \leq 51/50.$$

$$\Rightarrow \boxed{V_{off_1} \cong 0{,}5\,mV.}$$

•) DESAJUSTE REAPAREJAMIENTO ENTRE T3 Y T4 (W_4 Y W_3).

$$I_{C1} = I_{D3} \Rightarrow I_{C1} = \frac{I_0}{2} = 100\,\mu A$$

$$I_{D3} = K_3' \frac{W_3}{L_3}\left(V_{gs3} - V_{T3}\right)^2 = I_{S1}\, e^{V_{BE1}/V_{TH}}$$

$$I_{D4} = K_4' \frac{W_4}{L_4}\left(V_{gs4} - V_{T4}\right)^2 = I_{S2}\, e^{V_{BE2}/V_{TH}}$$

$$V_{off} = V_{BE1} - V_{BE2} = V_{TH} \ln\left(\frac{I_{C1}}{I_{S1}} \frac{I_{S2}}{I_{C2}}\right)$$ ¿?

CONSIDERO $I_{S1} = I_{S2}$ $\quad V_{off} = V_{TH} \ln\left(I_{C1}/I_{C2}\right)$

$$V_{off} = V_{TH} \ln\left[\frac{K_3' W_3/L_3 \left(V_{gs3} - V_{T3}\right)^2}{K_4' W_4/L_4 \left(V_{gs4} - V_{T4}\right)^2}\right]$$

$$V_{off} = V_{TH} \ln\left[W_3/W_4\right]$$

$$\frac{W_3 - W_4}{W_3} \leq \delta$$

$$1 - \frac{W_4}{W_3} \leq \delta$$

$$W_4/W_3 \geq 1 - \delta = 0{,}98$$

$$\frac{W_3}{W_4} \leq 1{,}02$$

$$\boxed{V_{off_2} = 0{,}5\,mV}$$

OFFSET TOTAL:

$$V_{off_{TOT}} = V_{off_1} + V_{off_2}$$

$$\boxed{V_{off_{TOT}} = 1\,mV}$$

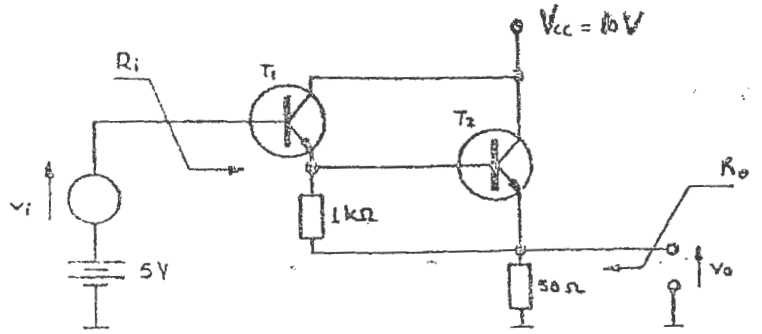
66.08 – 8606 **Evaluación Integradora 2014/2** - tercera **fecha – 11/02/15**

APELLIDO	NOMBRE	PADRON	TURNO			Nro. de HOJAS	Corrección	
			M	T	N			

1.- Para el siguiente circuito, donde v_i y la fuente de 5V representan la tensión que entrega la etapa anterior a la indicada en la figura (cc + señal), calcular (suponiendo β = 200; $r_x \rightarrow 0$; $V_A \rightarrow \infty$; f_T =300MHz; $C_\mu \cong 1$ pF):

a) Los puntos de reposo. Las expresiones ***por inspección*** y sus valores, de las resistencias de entrada y salida, y la amplificación de tensión $A_v = v_o/v_i$.

b) Justificar en qué valor podría estimarse la frecuencia de corte superior de esta etapa. ¿Qué utilidad tiene esta etapa?.



2.- Dibujar el circuito de un par acoplado por source con NMOSFET inducidos (T_1-T_2), polarizado mediante una fuente cascode con MOSFET (T_5-T_6 y T_7-T_8), de R_{ref} = 20 KΩ conocida y carga activa espejo simple, también con MOSFET (T_3-T_4), alimentado todo entre $\pm V_{DD} = \pm 12$ V. **Los transistores son idénticos** y se conocen todos sus parámetros ($|V_T| = 1$ V ; $|k'| = 1$ mA/V^2 ; W/L = 1 ; $\lambda = 0{,}01$ V^{-1})

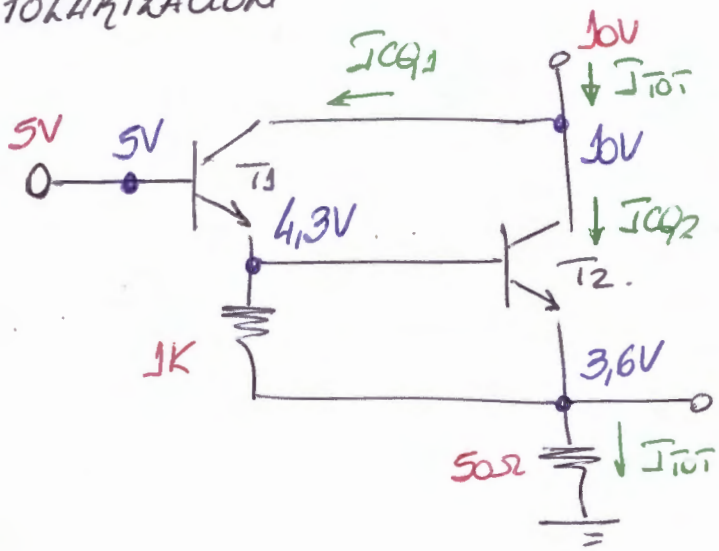
a) Obtener lospuntos de reposo, justificando por inspección el valor de la tensión de salida V_{OQ}.

b) Obtener *por inspección*, justificando el procedimiento, el valor de las amplificaciones de tensión para modo diferencial y común para la salida simple convencional. Definir y obtener la RRMC en veces y en dB. ¿Cómo influyen los desapareamientos en su valor?.

c) Obtener el rango de tensión de modo común. ¿Cuál es su utilidad?. → Preg

d) Definir y obtener la tensión de Offset para un desapareamiento entre $W_{(T1)}$ y $W_{(T2)}$ del 2%. → VER

1) POLARIZACION



$$I_{TOT} = I_{CQ2} + I_{BQ1} + I_{CQ1}$$

$$I_{TOT} = I_{CQ2} + \frac{I_{CQ1}}{\beta} + I_{CQ1}$$

$$I_{TOT} = I_{CQ2} + I_{CQ1}\left(1 + \frac{1}{\beta}\right)$$

$$I_{TOT} = \frac{5V - 1,4V}{50\Omega} = 72\,mA.$$

a)

$$\cancel{I_{CQ1} = \frac{V_{BEQ2}}{1K} = 0,7\,mA.}$$

$$\cancel{I_{CQ1} = 71,3\,mA.}$$

$$I_{1K} = \frac{V_{BEQ2}}{1K} = 0,7\,mA.$$

$$I_{CQ1} = I_{1K} + I_{BQ2} = I_{1K} + \frac{I_{CQ2}}{\beta}.$$

$$\Rightarrow I_{TOT} = I_{1K} + I_{CQ2}\left(1 + \frac{1}{\beta}\right) \Rightarrow I_{CQ2} = 70,95\,mA.$$

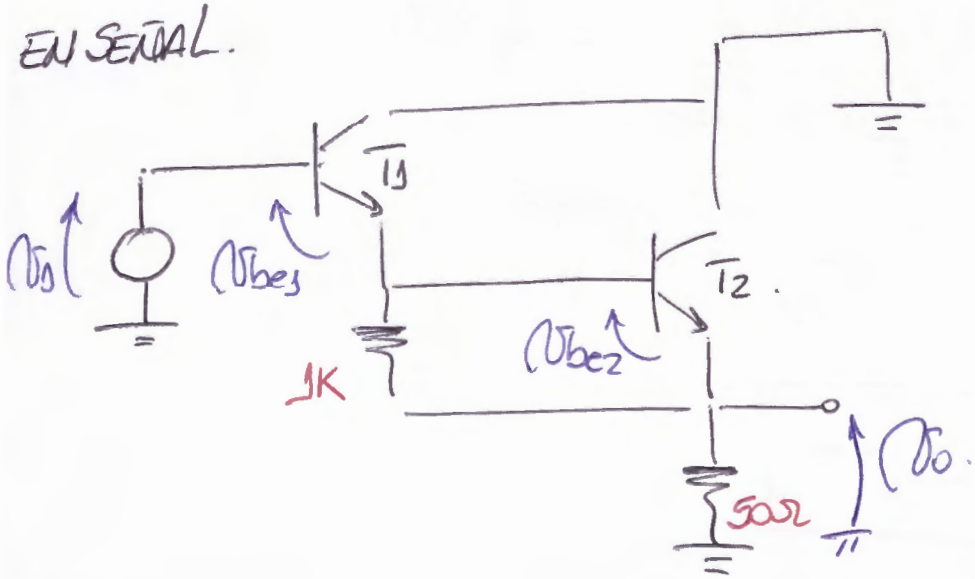
$$\Rightarrow I_{CQ1} = 1,05\,mA.$$

$g_{m1} = 42\,m$ $\qquad$ $g_{m2} = 2,84$

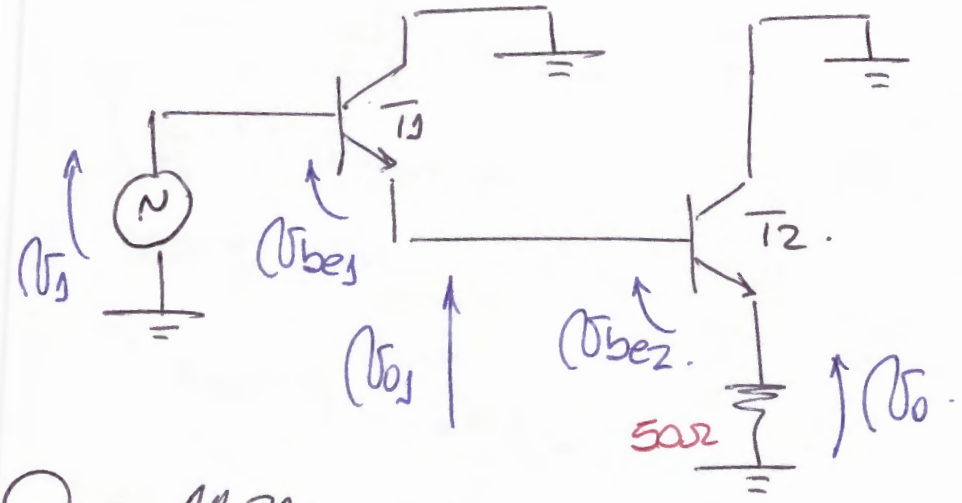
$r_{\pi 1} = 4K8.$ $\qquad$ $r_{\pi 2} = 70,5\,\Omega.$

$C_{\pi 1} = 21,3\,pF$ $\qquad$ $C_{\pi 2} = 1,51\,nF.$

EN SEÑAL.



TUEDO CONSIDERAR.



DONDE AHORA:

$$r_{\pi 2}^{*} = r_{\pi 2} \,//\, 1K \cong 66\Omega.$$

$$\Rightarrow \beta_2^{*} = g_{m2}\, r_{\pi 2}^{*} \cong 187.$$

$$R_i = r_{\pi 1} + \beta\left[r_{\pi 2}^{*} + \beta_2^{*}\, 50\Omega\right]. \Rightarrow \boxed{R_i = 1{,}97\,M\Omega}$$

$$R_o = R_{oE} \,//\, 50\Omega.$$

$$\hookrightarrow R_{oE} = \frac{r_{\pi 2}^{*} + r_{d1}}{\beta_2^{*}} \cong 0{,}48\Omega.$$

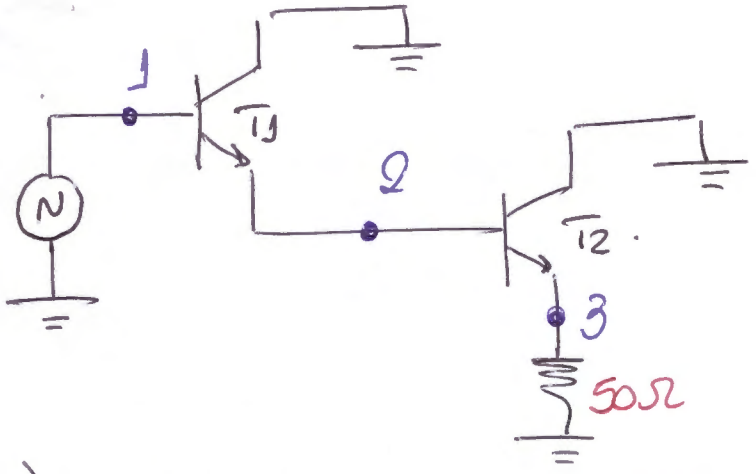
$$\Rightarrow \boxed{R_o = 0{,}48\Omega.}$$

$$A_{v1} = \frac{v_{o1}}{v_1} = \frac{i_{c1}\cdot\left(r_{\pi 2}^{*} + \beta_2^{*}\, 50\Omega\right)}{i_{c1}\left(r_{\pi 2}^{*} + \beta_2^{*}\, 50\Omega\right) + v_{be1}} = 0{,}997.$$

$$A_{v2} = \frac{v_o}{v_{o1}} = \frac{i_{c2}\, 50\Omega}{i_{c2}\, 50\Omega + v_{be2}} = 0{,}993.$$

$$\Rightarrow \boxed{A_{v_{TOT}} = 0{,}99}$$

b)



1) $R_{eq} = r_{\pi 1} + \beta [\cdots] = R_i = 1{,}97\,M\Omega$

$C_{eq} = C_\mu + C_{\pi 1}(1 - A_{v1}) = 1{,}06\,pF$

$\tau \cong 2\,\mu s$

2) $R_{eq} = r_{d1} \,//\, (r_{\pi 2}^* + \beta_2^* 50\Omega) = 24\Omega \,//\, 9416\Omega \cong 24\Omega$

$C_{eq} = C_\mu + C_{\pi 2}(1 - A_{v2}) + C_{\pi 1}\left(1 - \frac{v_{b1}}{v_{ep1}}\right)$

$C_{eq} = C_\mu + C_{\pi 2}(1 - A_{v2}) + C_{\pi 1}(1 - 0)$

$C_{eq} = C_\mu + C_{\pi 2}(1 - A_{v2}) + C_{\pi 1} \cong 33\,pF$

$\Rightarrow \tau = 0{,}792\,ns$

3) $R_{eq} = R_o = 0{,}48\Omega$

$C_{eq} = C_{\pi 2}\left(1 - \frac{r_{d1}}{r_{\pi 2}^* + r_{d1}}\right) = 1{,}11\,nF$

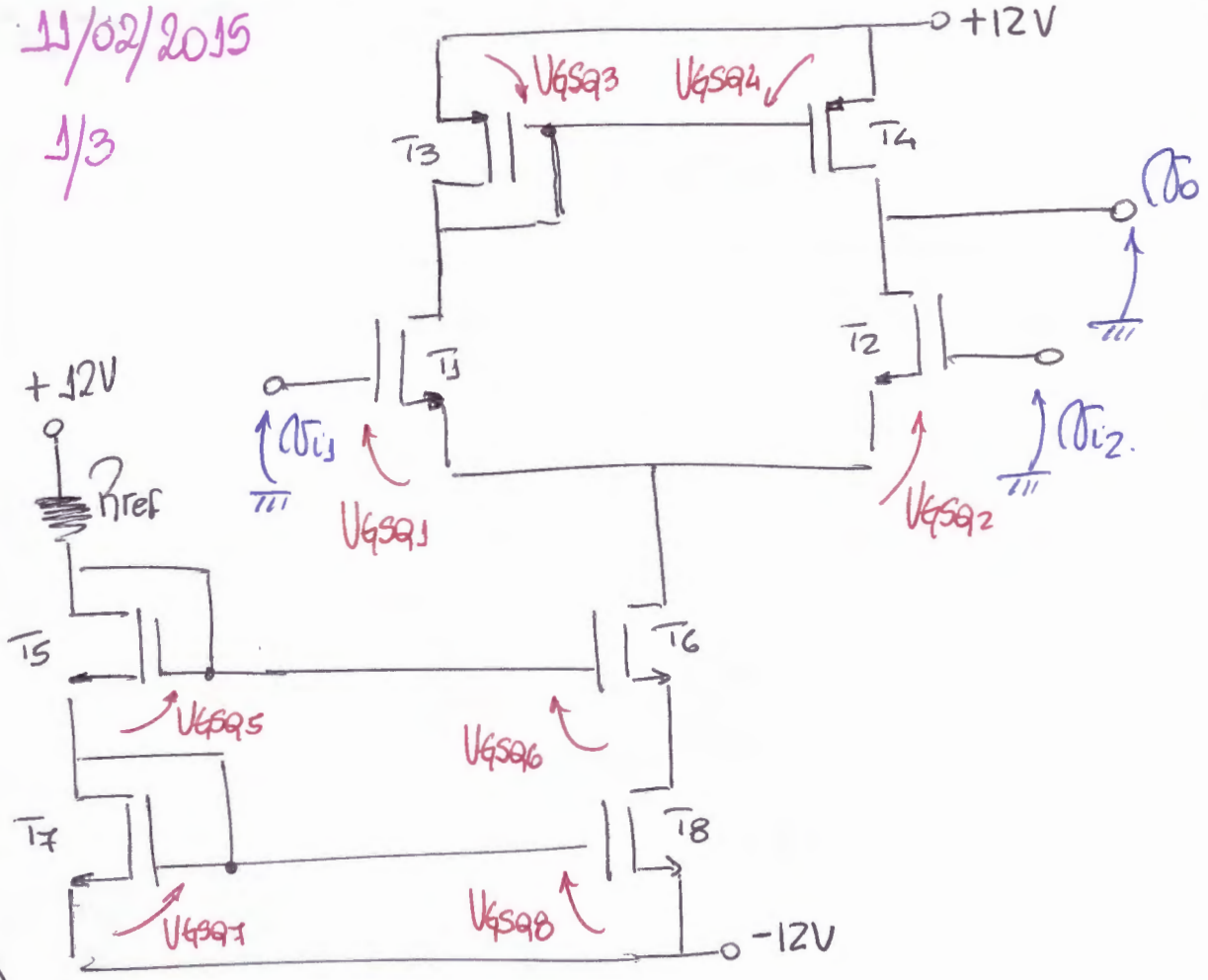
$\Rightarrow \tau = 0{,}53\,ns$

$\Rightarrow$ LIMITA EL NODO 1

$$\boxed{f_h = 79{,}57\,MHz}$$

11/02/2015

1/3



$R_{ref} = 20K\Omega$

$|V_T| = 1V$

$K' = 1mA/V$

$W/L = 1$

$\lambda = 0{,}01 V^{-1}$

a) $12V - I_{ref}\,20K - V_{GSQ5} - V_{GSQ7} - (-12V) = 0$.

•) DADO QUE $I_{DQ5} = I_{DQ7}$; Y LOS TRANSISTORES SON IDÉNTICOS:

$V_{GSQ5} = V_{GSQ7}$

$\Rightarrow V_{GSQ5} = 12V - 10K\,I_{ref}$

$I_{DQ5} = K'\frac{W}{L}(V_{GSQ5} - V_T)^2 = K'\frac{W}{L}(12 - 10K\,I_{ref} - 1)^2$; $I_{DQ5} = I_{ref}$.

$1000\,I_{ref} = 121 + 100 \times 10^6\,I_{ref}^2 - 220K\,I_{ref}$.

[illegible] $(100K) + 121$

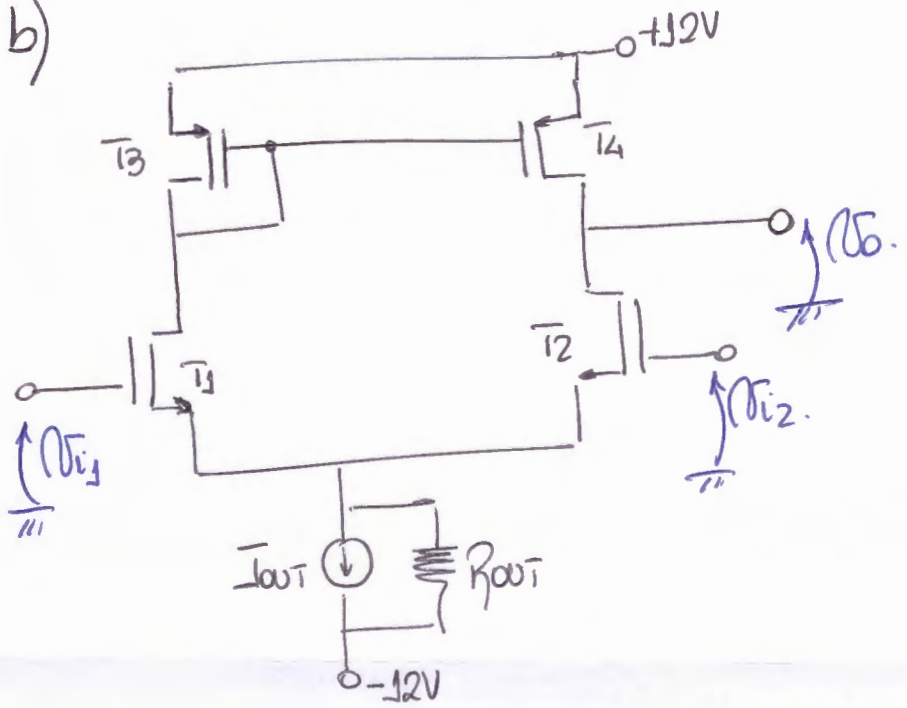
$\rightarrow V_{GSQ5} = 0V$ $\rightarrow V_{GSQ5} = 0V$ X

$I_{DQ1} = I_{DQ2} = 0{,}5\,mA \Rightarrow g_{m1-4} = 1{,}4\,mA/V \quad r_{ds1-4} = 200\,K\Omega$

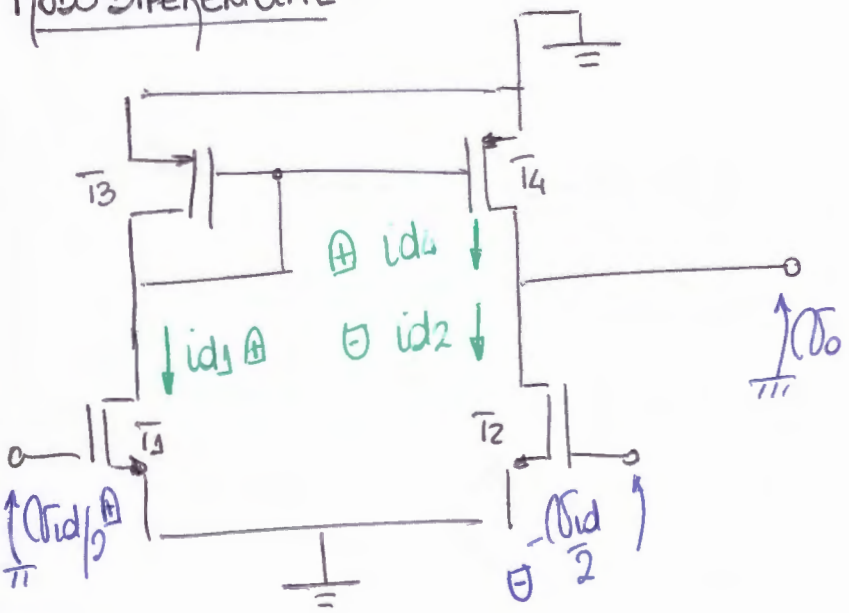
$\hookrightarrow V_{GSQ1} = V_{GSQ2} = 1{,}7V \Rightarrow V_{GSQ3} = V_{GSQ4} = -1{,}7V$

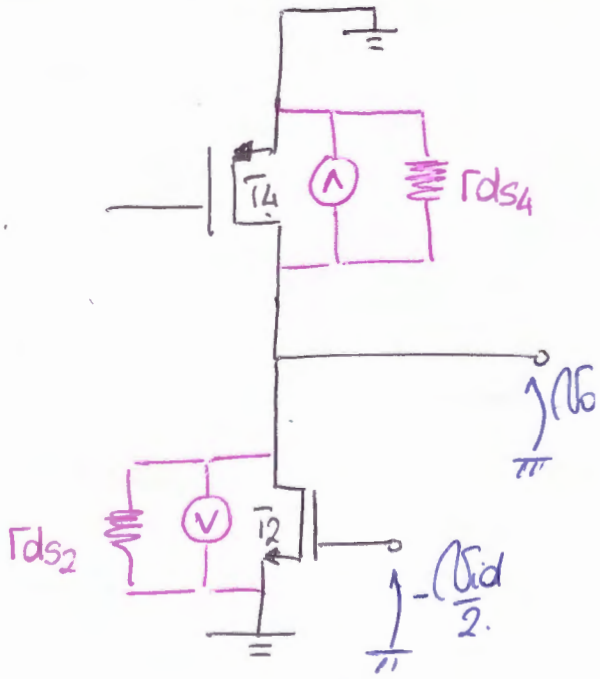
$$\Rightarrow \boxed{V_{OQ} = 12V - 1{,}7V = 10{,}3V}$$

b)



MODO DIFERENCIAL





POR CORRIENTES:

$$g_{m2} v_{gs2} + g_{m4} v_{gs4} + \frac{v_o}{r_{ds2} // r_{ds4}} = 0 \quad ; \quad i_{d2} = -i_{d1}$$

$\cdot)\ v_{gs4} = v_{gs3} = -i_{d1} r_{d3}$

$$g_{m2} v_{gs2} - i_{d1} g_{m4} r_{d3} + \frac{v_o}{r_{ds2} // r_{ds4}} = 0.$$

$$g_{m2} v_{gs2} - i_{d1} \cancel{g_{m1}} \frac{1}{\cancel{g_{m3}}} + \frac{v_o}{r_{ds2} // r_{ds4}} = 0.$$

$$g_{m2} v_{gs2} - g_{m1} v_{gs1} + \frac{v_o}{r_{ds2} // r_{ds4}} = 0.$$

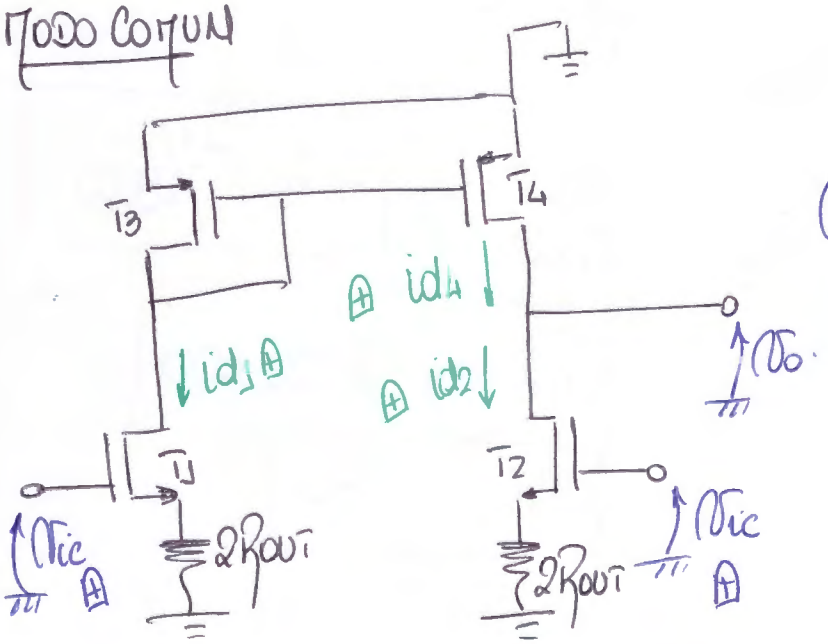
$$g_{m1,2} \left(v_{gs2} - v_{gs1} \right) + \frac{v_o}{r_{ds2} // r_{ds4}} = 0.$$

$$\begin{cases} v_{gs2} = -v_{id}/2. \\ v_{gs1} = v_{id}/2. \end{cases} \Rightarrow g_{m1,2} \left(-v_{id} \right) + \frac{v_o}{r_{ds2} // r_{ds4}} = 0.$$

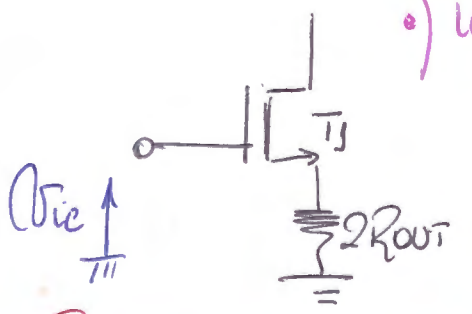
$$A_{vd} = \frac{v_o}{v_{id}} = g_{m1,2} \left(r_{ds2} // r_{ds4} \right).$$

$$\boxed{A_{vd} = 140.}$$

MODO COMÚN



•) $i_{d1} = i_{d2}$.



RESISTENCIA DE ENTRADA.

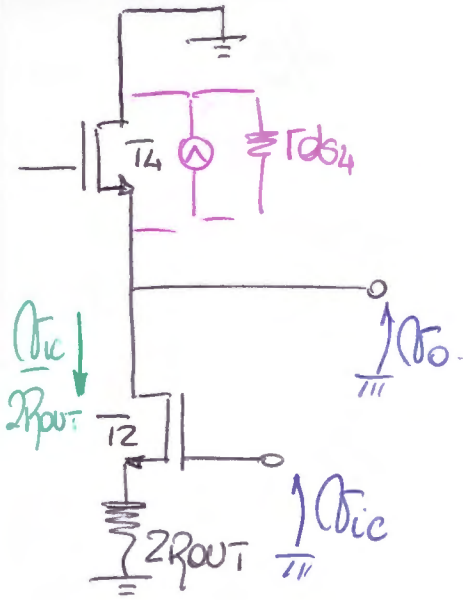
$$R_{ic} = r_{gs1} + \beta_{FET} 2R_{out}$$

$$R_{ic} = r_{gs1} + g_{m1} r_{gs1} 2R_{out}$$

$$R_{ic} = r_{gs1} + r_{gs1} 2 g_{m1} R_{out}$$

EL 2DO TERMINO ES "$2 g_{m1} R_{out}$" VECES MÁS GRANDE QUE EL PRIMERO. ENTONCES PUEDO CONSIDERAR QUE v_{ic} CAE PRACTICAMENTE EN "$2R_{out}$" Y POR ENDE:

$$i_{d1} = v_{ic}/2R_{out}$$



CORRIENTES:

$$g_{m4} v_{gs4} + \frac{v_{ic}}{2R_{OUT}} + \frac{v_o}{r_{ds4}} = 0$$

$$g_{m3} v_{gs3} + \frac{v_{ic}}{2R_{OUT}} + \frac{v_o}{r_{ds4}} = 0$$

$$g_{m3}\left(-i_{d1}\left(r_{d3} // r_{ds3}\right)\right) + \frac{v_{ic}}{2R_{OUT}} + \frac{v_o}{r_{ds4}} = 0$$

$$-i_{d1}\, \cancel{g_{m3}} \frac{\cancel{r_{d3}} \cdot r_{ds3}}{r_{d3} + r_{ds3}} + \frac{v_{ic}}{2R_{OUT}} + \frac{v_o}{r_{ds4}} = 0$$

$$-\frac{v_{ic}}{2R_{OUT}} \frac{r_{ds3}}{r_{d3} + r_{ds3}} + \frac{v_{ic}}{2R_{OUT}} + \frac{v_o}{r_{ds4}} = 0$$

$$\frac{v_{ic}}{2R_{OUT}} \left\{ 1 - \frac{r_{ds3}}{r_{d3} + r_{ds3}} \right\} + \frac{v_o}{r_{ds4}} = 0$$

$$\frac{v_{ic}}{2R_{OUT}} \left\{ \frac{r_{d3}}{r_{d3} + r_{ds3}} \right\} + \frac{v_o}{r_{ds4}} = 0$$

$$\frac{v_{ic}}{2R_{OUT}} \frac{r_{d3}}{r_{ds3}} + \frac{v_o}{r_{ds4}} = 0$$

$$A_{vc} = \frac{v_o}{v_{ic}} = -\frac{r_{d3}}{2R_{OUT}} \Rightarrow \boxed{A_{vc} = -1/28000}$$

$$RRMC = \left| \frac{A_{vd}}{A_{vc}} \right| = 28.000 \cdot 140 \Rightarrow \boxed{RRMC = 3.920.000}$$

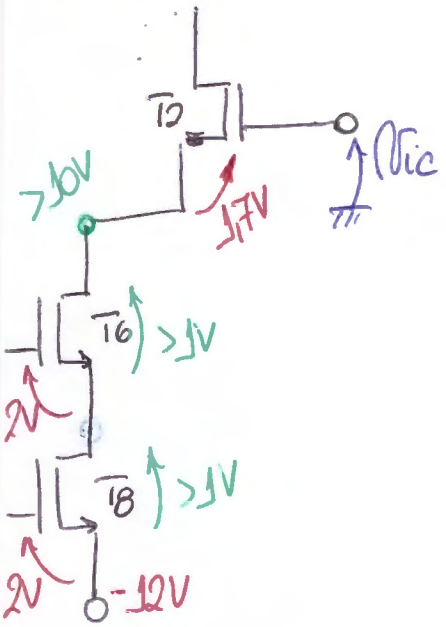
$$\boxed{RRMC \cong 132}$$

c) RTMC → RANGO DE TENSIÓN DE MODO COMÚN

↳ ES EL RANGO DE TENSIÓN QUE ME ASEGURA QUE TODOS LOS TRANSISTORES TRABAJEN EN LA ZONA LINEAL.

3/3

VALOR MÍNIMO:



$$V_{DS_6} > V_{GS_6} - V_T = 1V$$

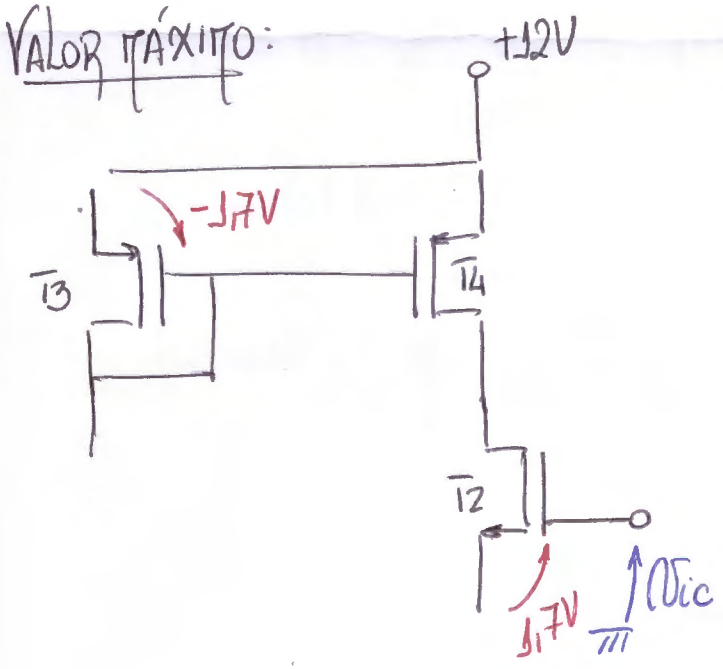
$$V_{DS_8} > V_{GS_8} - V_T = 1V$$

$$\Rightarrow V_{D6} = V_{S2} > -10V$$

$$\underbrace{V_{S2}}_{>-10V} + \underbrace{V_{GS_2}}_{1,7V} = V_{ic}$$

$$\Rightarrow \boxed{V_{ic} > -8,3V}$$

VALOR MÁXIMO:



$$V_{DS_2} > V_{GS_2} - V_T$$

$$V_{DS_2} > 1,7V - 1V = 0,7V$$

$$V_{D2} - V_{S2} > 0,7V$$

$$12V + (-1,7V) - V_{S2} > 0,7V$$

$$V_{S2} < 9,6V$$

•) $V_{S2} + V_{GS_2} = V_{ic}$

$$\Rightarrow V_{ic} - V_{GS_2} < 9,6V$$

$$\boxed{V_{ic} < 11,3V}$$

$$\Rightarrow \boxed{\text{RTMC: } -8,3V < V_{ic} < 11,3V}$$

d) $V_{off} = V_{gs1} - V_{gs2}$; $I_D = K'\frac{W}{L}(V_{gs} - V_T)^2$

$\hookrightarrow V_{gs} = \sqrt{\frac{I_D}{K'W/L}} + V_T$

$$V_{off} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} + V_{T1} - \sqrt{\frac{I_{D2}}{K_2' W_2/L_2}} - V_{T2}$$

- DESAPAREAMIENTO SOLO ENTRE W_1 Y W_2 $\Rightarrow$ $\begin{cases} V_{T1} = V_{T2} \\ L_1 = L_2 \\ K_1' = K_2' \end{cases}$

- EL OFFSET SE APLICA PARA LOGRAR: $I_{D1} = I_{D2}$

$$\Rightarrow V_{off} = \sqrt{\frac{I_{D1}}{K_1'/L_1}} \left\{ \frac{1}{\sqrt{W_1}} - \frac{1}{\sqrt{W_2}} \right\}$$

$$V_{off} = \sqrt{\frac{I_{D1}}{K_1'/L_1}} \frac{1}{\sqrt{W_1}} \left\{ 1 - \frac{1}{\sqrt{W_2/W_1}} \right\} ; \quad \frac{W_2 - W_1}{W_1} = \delta = 0{,}02$$

$$\frac{W_2}{W_1} = 1 + \delta$$

$$V_{off} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \left\{ 1 - \frac{1}{\sqrt{1+\delta}} \right\}$$

$\sqrt{1+x} \approx 1 + \frac{x}{2}$ (x pequeño)

$$V_{off} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \left\{ 1 - \frac{1}{1+\delta/2} \right\}$$

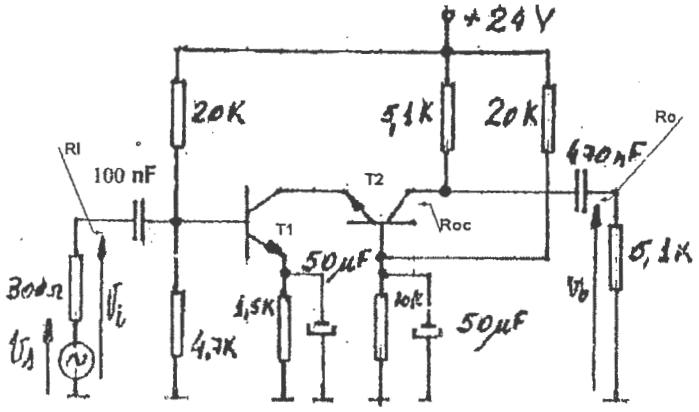
$$V_{off} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \frac{\delta/2}{1+\delta/2} \approx \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \frac{\delta}{2}$$

$$\Rightarrow \boxed{V_{off} = 7\,mV}$$

P/Fotocopia

66.08 - Circuitos Electrónicos I — Evaluación Integradora 2/2012 - quinta fecha - 27/02/13

APELLIDO	NOMBRE	PADRON	TURNO			Nro. de HOJAS	Corrección	
			M	T	N			

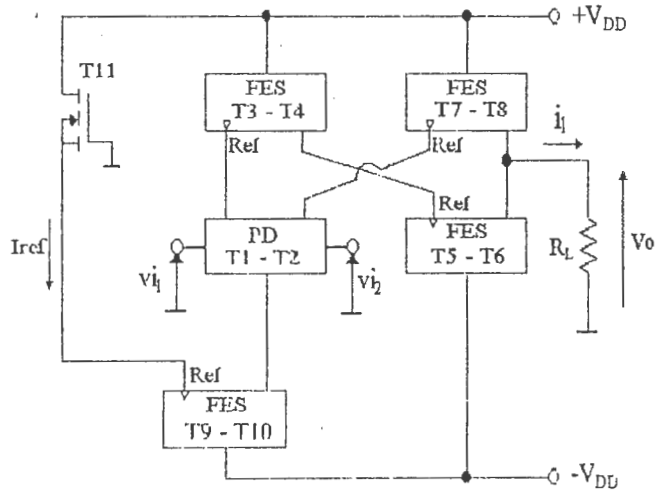


1. Para el siguiente amplificador (T_1=T_2: β= 100; V_A= 100 V; r_x= 100 Ω; f_T= 300 MHz; C_μ= 1 pF)

a) Definir, obtener *por inspección* y calcular A_v, R_i, R_o, A_{vs} a frecuencias medias.

b) Justificar *cualitativamente* cuál será el nodo potencialmente dominante para la respuesta en altas frecuencias Obtener la f_h a partir de dicho nodo.

c) Si se desconecta el capacitor de desacople de la base de T_2, ¿varía f_h?, varía f_l? ***Justificar.***



2. - a) Hallar las corrientes de reposo y las tensiones contra común de los terminales de cada transistor (despreciar la corrección de I_{DQ} por el λ).

b) Hallar $Gm_d = i_l / v_{id} \,|_{vo=0}$. Definir y hallar la R_o vista por la carga. Obtener $Av_d = v_o/v_{id}$.

c) Hallar $Gm_c = i_l / v_{ic} \,|_{vo=0}$. si se admite un desapareamiento $|W_1 - W_2|/W_1 = \delta << 1$. Obtener $Av_c = v_o/v_{ic}$ y la correspondiente RRMC en dB.

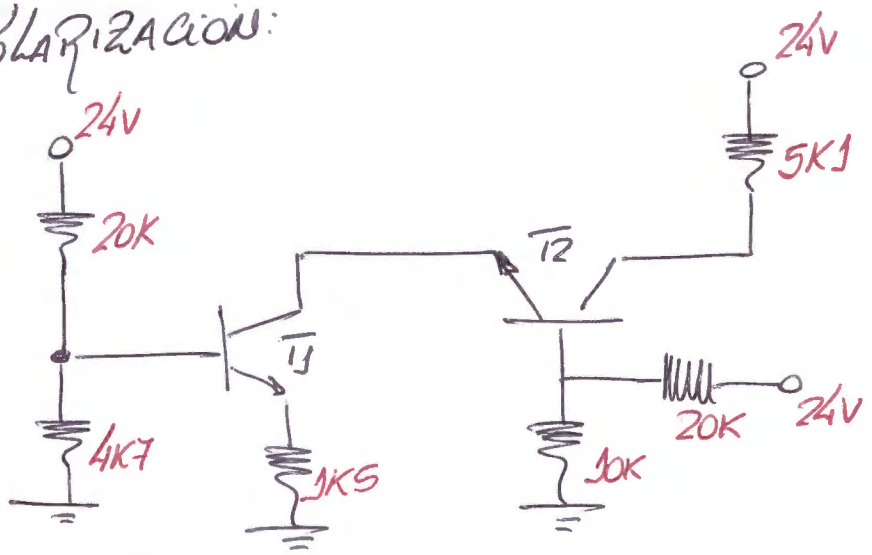
FES: Fuente Espejo Simple – **PD:** Par Diferencial.

MOSFETs de canal inducido (N ó P según corresponda) – (admitir source y sustrato unidos en cada transistor).

$\pm V_{DD}$= ± 6 V ; $|V_T|$= 2 V ; $|K'|$= 100 µA/V^2 ; W/L= 2 ; λ= 0,01 V^{-1} ; R_L = 10 KΩ.

Se definen: $v_{id} = v_{i1} - v_{i2}$ $v_{ic} = 0{,}5.(v_{i1} + v_{i2})$

1) POLARIZACION:



$\beta = 100$
$V_A = 100V$
$r_x = 100\Omega$
$f_T = 300MHz$
$C_\mu = 1pF$

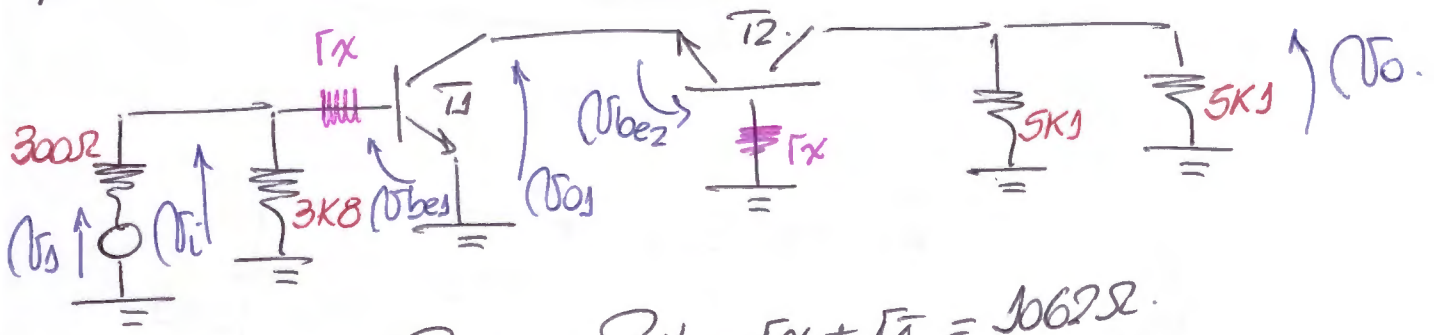
$$V_{BQ1} = 24V \frac{4K7}{4K7+20K} \cong 4,6V \Rightarrow V_{EQ1} = V_{BQ1} - 0,7V = 3,9V$$

$$\Rightarrow I_{CQ1} = I_{CQ2} = 2,6mA.$$

$$\Rightarrow r_\pi = 962\Omega. \quad g_m = 104m.$$
$$r_o = 38,5K\Omega.$$

$\hookrightarrow C_\pi = 54,2pF.$

a) A FRECUENCIAS MEDIAS.



$$R_i = 3K8 \,//\, R_{ib}; \quad R_{ib} = r_x + r_\pi = 1062\Omega.$$

$$\Rightarrow \boxed{R_i = 830\Omega}$$

$$R_{oc} = r_{o2}\left(1 + \beta \frac{r_{o1}}{r_{o1} + r_\pi + r_x}\right) \approx r_{o1}(1+\beta) \approx r_{o1}\beta.$$

$$\Rightarrow R_o = R_{oc} \,//\, 5K1; \quad R_{oc} >> 5K1$$

$$\Rightarrow \boxed{R_o \cong 5K1.}$$

$$A_{v_{TOT}} = A_{v_1} \cdot A_{v_2}$$

$$A_{v_1} = \frac{v_{o_1}}{v_i} = \frac{-i_c\left(\frac{r_\pi + r_x}{\beta}\right)}{v_{be_1} + i_b r_x} = \frac{-i_c\left(\frac{r_\pi + r_x}{\beta}\right)}{v_{be_1} + \frac{i_c r_x}{\beta}}$$

$$A_{v_1} = \frac{-\left(\frac{r_\pi + r_x}{\beta}\right)}{r_d + r_x/\beta} = -1.$$

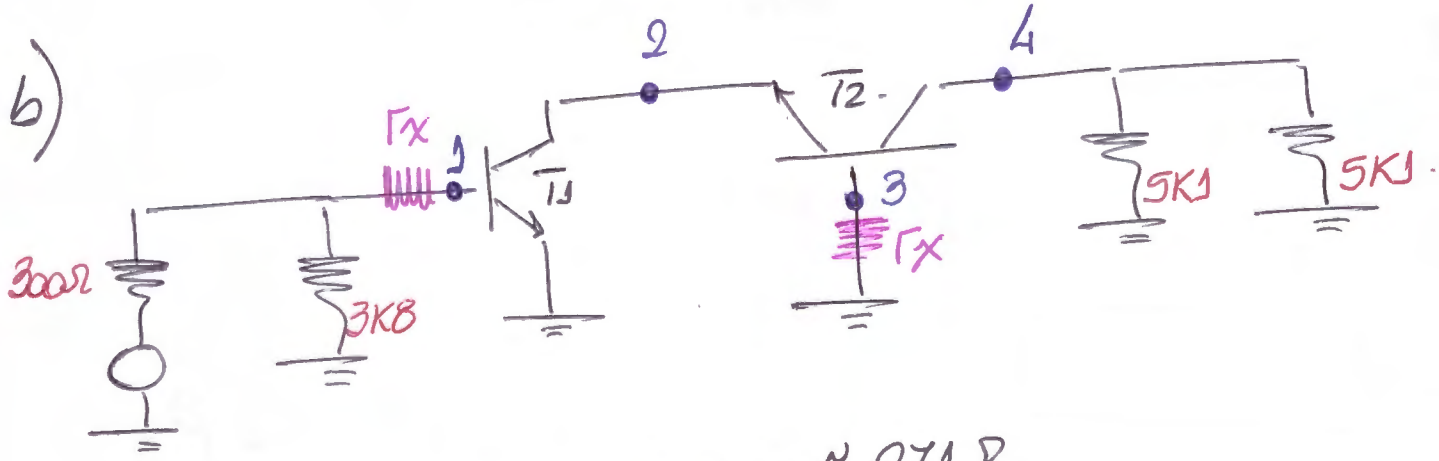
$$A_{v_2} = \frac{v_o}{v_{o_1}} = \frac{-i_c \, 5k1/2}{-i_b r_x - v_{be_2}} = \frac{5k1/2}{r_x/\beta + r_d} = 240.$$

$$\Rightarrow \boxed{A_{v_{TOT}} = -240.}$$

$$A_{v_s} = \frac{v_o}{v_s} = \frac{v_o}{v_s} \cdot \frac{v_i}{v_i} = \frac{v_o}{v_i} \cdot \frac{v_i}{v_s} = A_{v_{TOT}} \frac{v_i}{v_s}.$$

$$A_{v_s} = A_{v_{TOT}} \frac{R_i}{R_i + 300\Omega} \Rightarrow \boxed{A_{v_s} \cong -176}$$

b)



1) $R_{eq} = [(300\Omega // 3k8) + r_x] // r_\pi \cong 271\Omega.$

$$C_{eq} = C_\pi + C_\mu \left(1 - \frac{-i_{c_1}\left(\frac{r_\pi + r_x}{\beta}\right)}{v_{be}}\right) = C_\pi + C_\mu \, 2{,}1$$

$C_{eq} = 56{,}3pF.$ $\Rightarrow \tau = 15{,}26ns.$

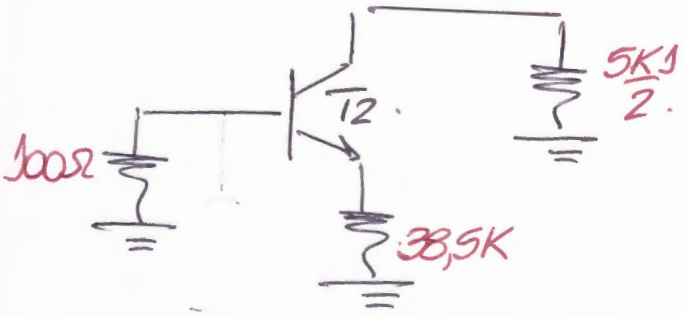
2) $R_{eq} = \frac{r_\pi + r_x}{\beta} = 10{,}62$.

$$C_{eq} = C_\mu + C_\pi \left(1 - \frac{r_x}{r_x + r_\pi}\right) = C_\mu + C_\pi\, 0{,}906$$

$C_{eq} \cong 50pF$

$\Rightarrow \tau = 0{,}53ns$.

3) $R_{eq} = r_x = 100\Omega$.



$$C_{eq} = C_\pi \left(1 - \frac{i_c\, 38{,}5K}{i_c\, 38{,}5K + r_{be}}\right) + C_\mu \left(1 - \frac{-i_c \frac{5K1}{2}}{i_c\, 38K5 + r_{be}}\right)$$

$$C_{eq} = C_\pi (1 - 0{,}999) + C_\mu (1 - 0{,}066).$$

$C_{eq} \cong 1pF$.

$\Rightarrow \tau = 0{,}1ns$.

4) $R_{eq} = \frac{5K1}{2} = 2550\Omega$.

$C_{eq} = C_\mu = 1pF$

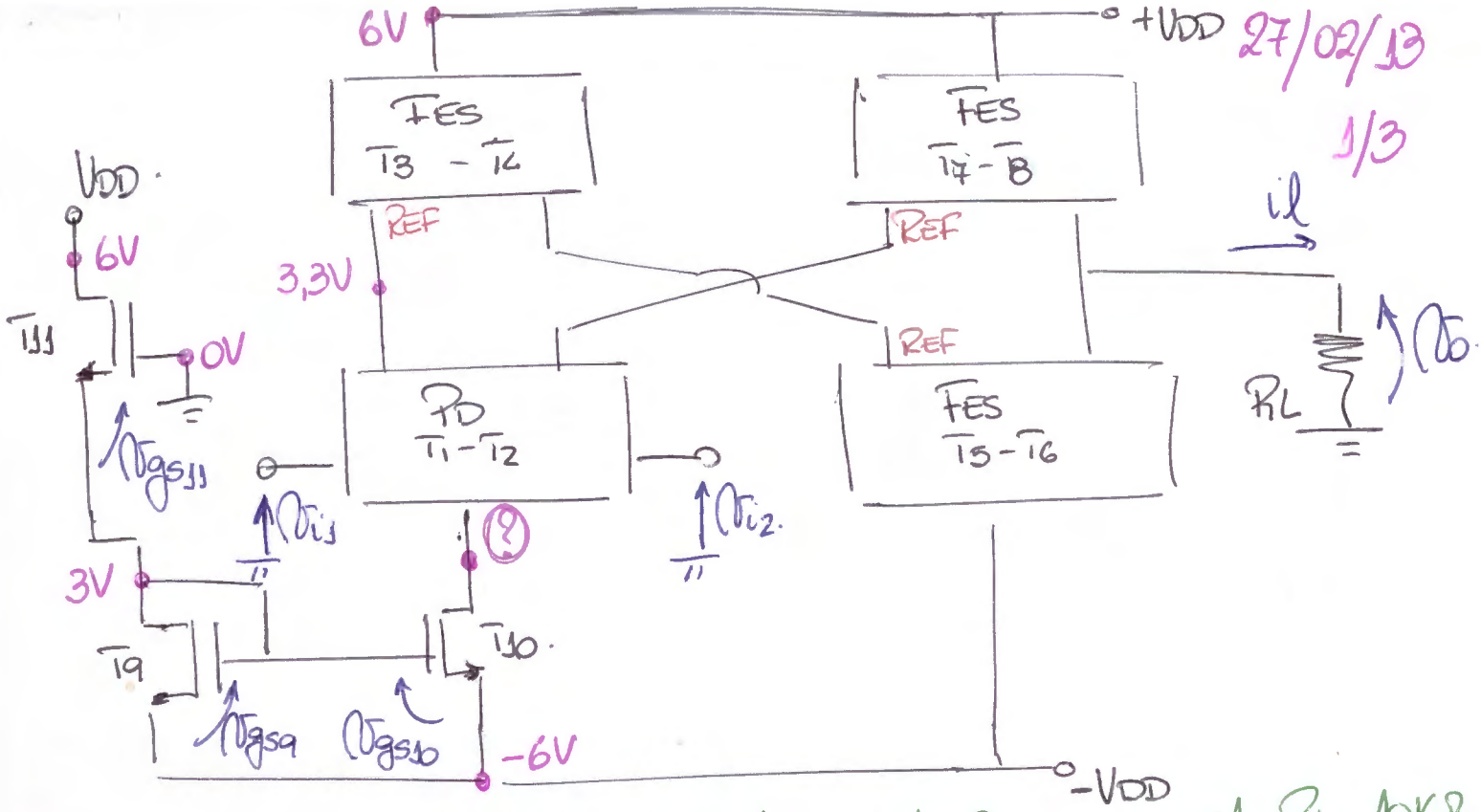
$\Rightarrow \tau = 2{,}55ns$.

$\Rightarrow$ NODO DOMINANTE ES EL 1

$$\boxed{f_h \cong 10{,}4MHz}$$

27/02/13

1/3



$\pm V_{DD} = \pm 6V$; $|V_T| = 2V$; $|K'| = 100\,\mu A/V^2$; $W/L = 2$; $\lambda = 0{,}01\,V^{-1}$; $R_L = 10K\Omega$

POR SER LOS TRANSISTORES IGUALES Y LAS CORRIENTES TAMBIÉN EN LA RAMA DE REFERENCIA: $V_{GSQ9} = V_{GSQ10} = V_{GSQ11}$

LUEGO: $-V_{DD} + V_{GSQ9} + V_{GSQ11} = 0 \Rightarrow \boxed{V_{GSQ9} = V_{GSQ10} = V_{GSQ11} = 3V}$

$\Rightarrow \boxed{I_{DQ9} = I_{DQ10} = I_{DQ11} = 0{,}2\,mA}$ $\Rightarrow \boxed{I_{DQ1} = I_{DQ2} = 0{,}1\,mA}$

$\boxed{I_{DQ3} = I_{DQ4} = I_{DQ1} = 0{,}1\,mA}$

↳ $\boxed{V_{GSQ1} = V_{GSQ2} = 2{,}7V}$

↳ $\boxed{V_{GSQ3} = V_{GSQ4} = -2{,}7V}$

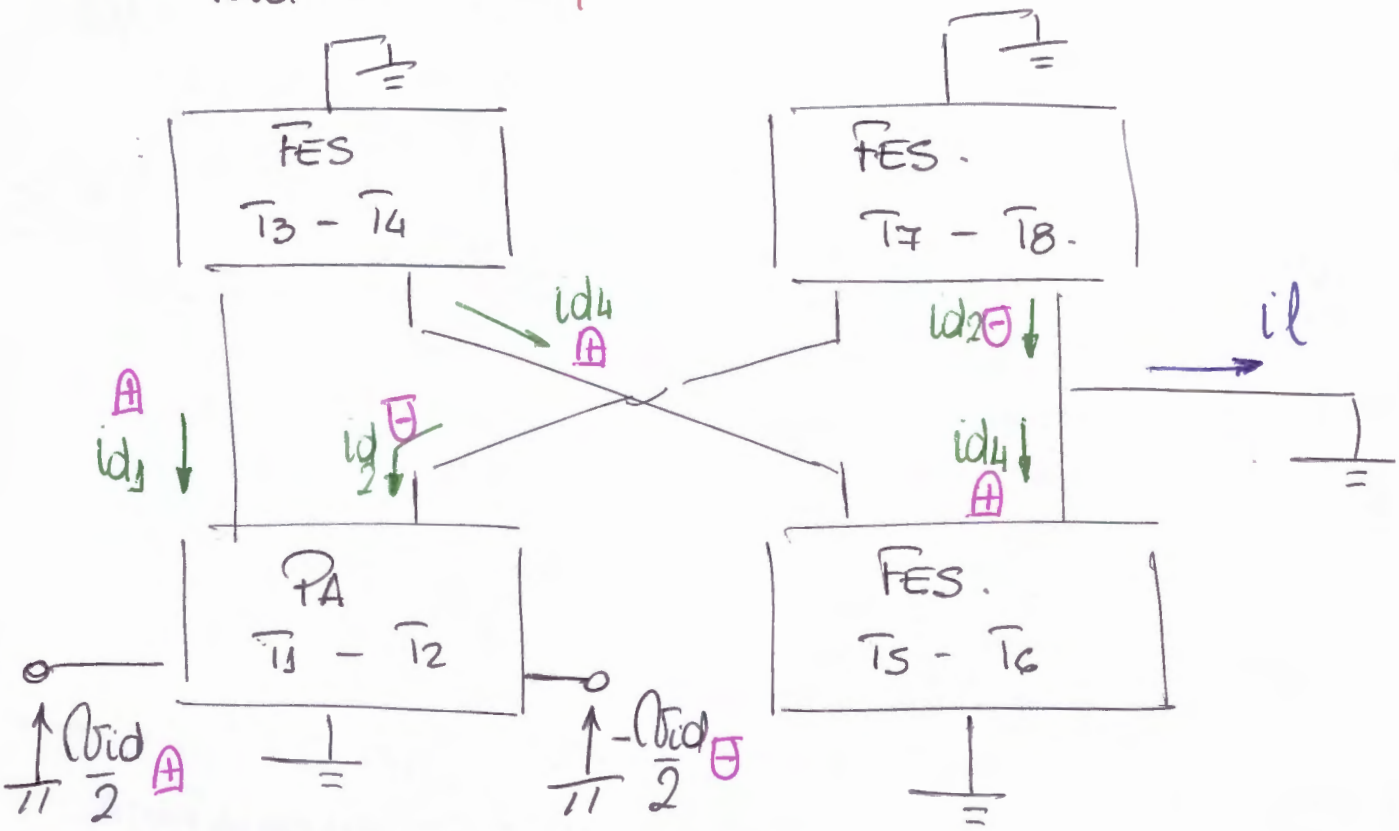
$R_{OUT} = r_{ds10}$; $r_{ds} = \dfrac{1}{\lambda I_{DQ}}$

$\boxed{r_{ds1A8} = 1M\Omega}$

$\Rightarrow \boxed{R_{OUT} = 500K\Omega}$

↳ $\boxed{g_{m1A8} \cong 0{,}2\,mA/V}$

b) $G_{md} = \left.\frac{i_l}{v_{id}}\right|_{v_o=0}$ MODO DIFERENCIAL!



$\Rightarrow i_{d2} = i_l + i_{d4} \Rightarrow i_l = i_{d2} - i_{d4}$; PERO $i_{d4} = i_{d1}$

$i_l = i_{d2} - i_{d1}$; $i_d = g_m v_{gs}$

PARA T1: $v_{gs_1} = \frac{v_{id}}{2}$

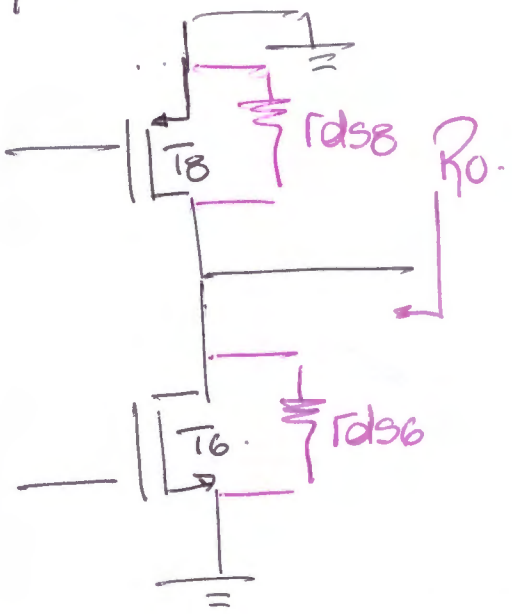
PARA T2: $v_{gs2} = -\frac{v_{id}}{2}$

LUEGO:

$$i_l = g_{m2}\left(-\frac{v_{id}}{2}\right) - g_{m1}\left(\frac{v_{id}}{2}\right) \; ; \; g_{m1} = g_{m2}$$

$$i_l = -g_{m1} v_{id} \Rightarrow \boxed{G_{md} = \frac{i_l}{v_{id}} = -g_{m1} = -0{,}22\,\frac{mA}{V}}$$

RESISTENCIA DE SALIDA

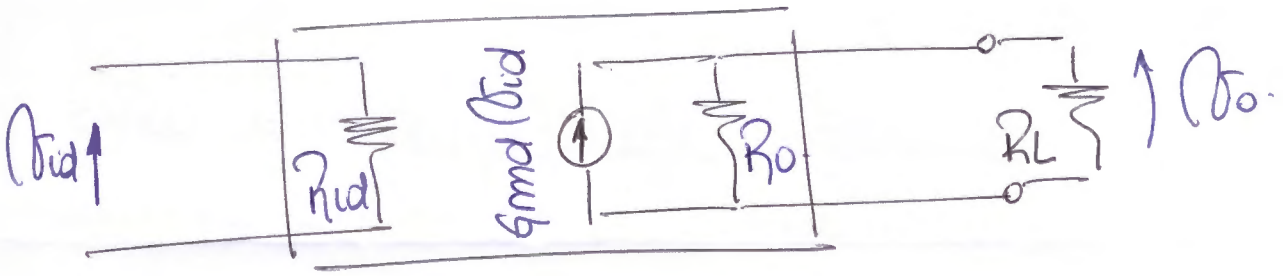


$$R_o = r_{ds6} // r_{ds8}$$

$$r_{ds6} = r_{ds8}$$

$$\Rightarrow \boxed{R_o = \frac{r_{ds6}}{2} = 500K\Omega}$$

GANANCIA DE MODO DIFERENCIAL



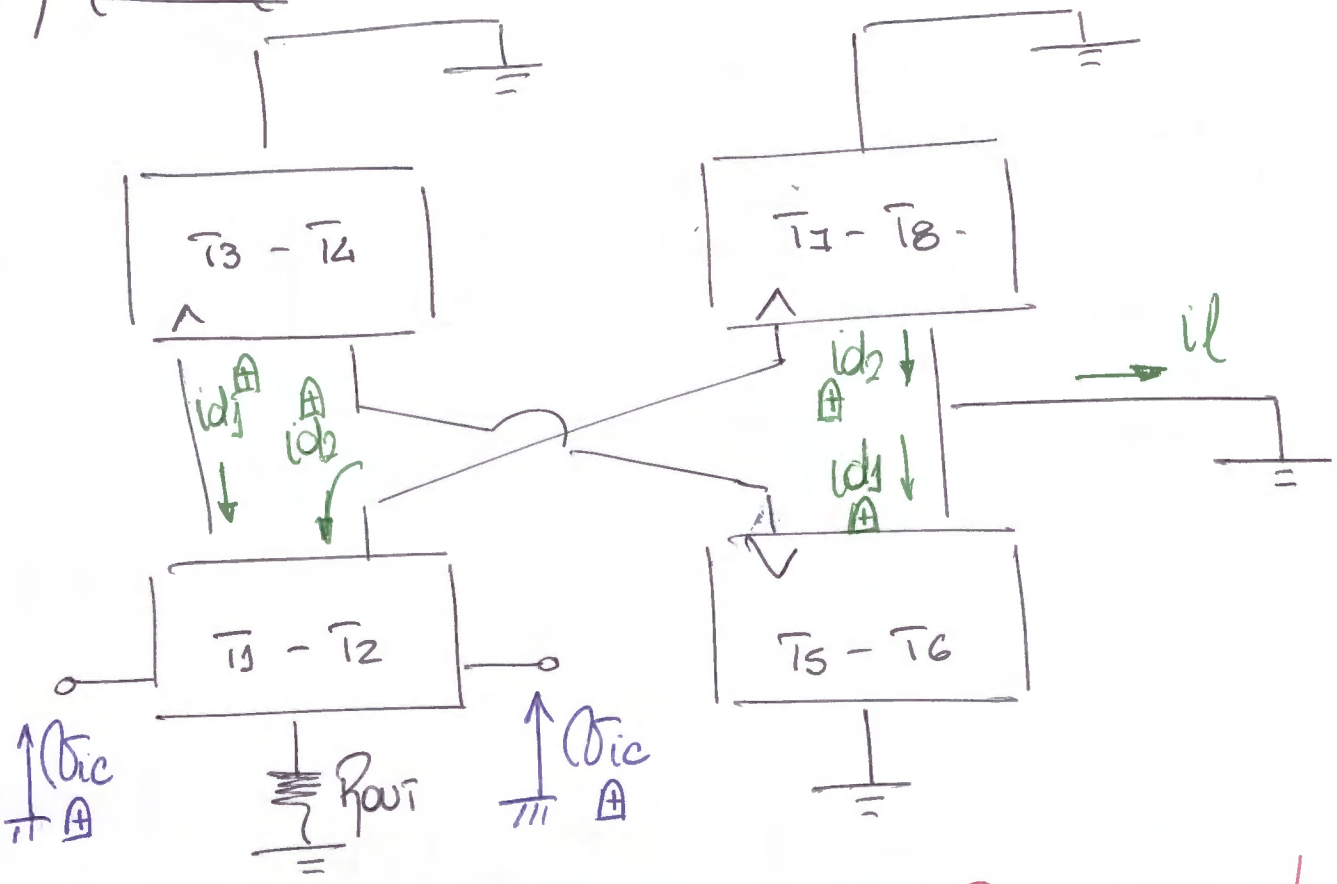
$$\Rightarrow v_o = g_{md}\, v_{id}\, (R_o // R_L)$$

$$A_{vd} = \frac{v_o}{v_{id}} = g_{md}\,(R_o // R_L) \; ; \; R_o >> R_L$$

$$\Rightarrow R_o // R_L \approx R_L$$

$$\Rightarrow \boxed{A_{vd} \approx g_{md} R_L = -2}$$

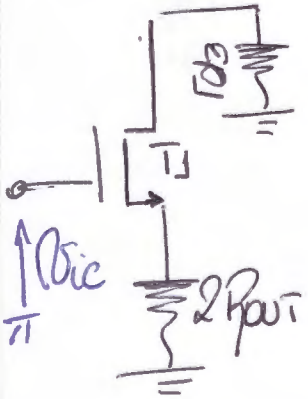
c) MODO COMÚN!



$$id_2 = i_l + id_1$$

; SI NO HUBIERA DESAPAREAMIENTO Y LAS COPIAS FUERAN IDEALES $\Rightarrow$ $i_l = 0$ PUES $id_1 = id_2$.

$$\boxed{i_l = id_2 - id_1}$$



$$id_1 = g_{m1} v_{gs1} \quad ; \quad v_{gs1} = v_{ic} \frac{r_{gs1}}{r_{gs1} + \beta 2 R_{out}}$$

$$v_{gs1} = v_{ic} \frac{r_{gs1}}{r_{gs1} + g_{m1} r_{gs1} 2 R_{out}}$$

$$v_{gs1} = \frac{v_{ic}}{1 + 2 g_{m1} R_{out}}$$

$$\Rightarrow \quad id_1 = \frac{g_{m1} v_{ic}}{1 + 2 g_{m1} R_{out}} \quad ; \quad id_2 = \frac{g_{m2} v_{ic}}{1 + 2 g_{m2} R_{out}}$$

LUEGO:

$$i_l = \frac{g_{m2}\, v_{ic}}{1+2g_{m2}R_{OUT}} - \frac{g_{m1}\, v_{ic}}{1+2g_{m1}R_{OUT}}$$

$$G_{mc} = \frac{i_l}{v_{ic}} = \frac{g_{m2}}{1+2g_{m2}R_{OUT}} - \frac{g_{m1}}{1+2g_{m1}R_{OUT}}$$

$$G_{mc} = \frac{g_{m2} - g_{m1}}{1+2g_{m1,2}R_{OUT}};$$

$$g_m = \frac{\partial i_D}{\partial v_{gs}}\Big|_Q = 2K'\frac{W}{L}(V_{GSQ}-V_T)$$

$$\frac{|W_1 - W_2|}{W_1} = \delta \Rightarrow W_2 = W_1(1\pm\delta)$$

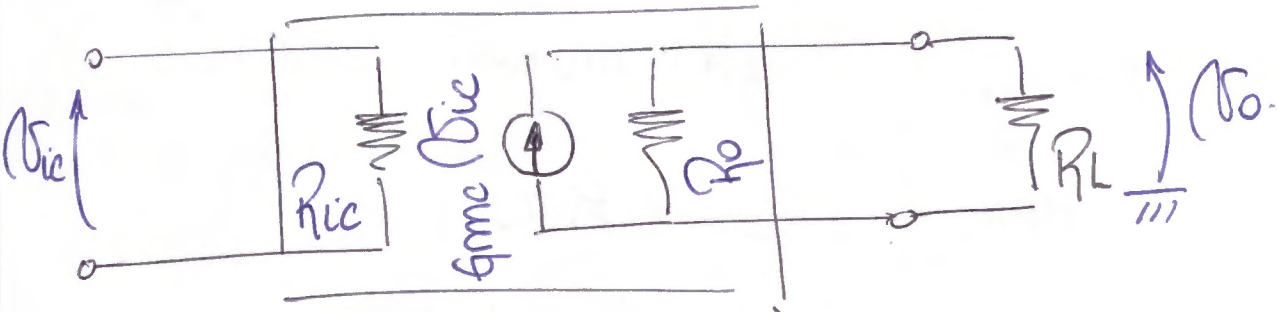
$$g_{m2} = 2\frac{K'}{L}(V_{GSQ}-V_T)W_2 = 2\frac{K'}{L}(V_{GSQ}-V_T)W_1(1\pm\delta)$$

$$g_{m2} = 2K'\frac{W_1}{L}(V_{GSQ}-V_T)(1\pm\delta) = g_{m1}(1\pm\delta)$$

$$\hookrightarrow W_2 = W_1(1\pm\delta) \Leftrightarrow g_{m2} = g_{m1}(1\pm\delta)$$

$$\Rightarrow G_{mc} = \frac{g_{m2} - g_{m1}}{1+2g_{m1}R_{OUT}} = \frac{g_{m1}(1\pm\delta) - g_{m1}}{1+2g_{m1}R_{OUT}}$$

$$G_{mc} = \frac{(1\pm\delta)-1}{r_{o1}+2R_{OUT}} \Rightarrow \boxed{G_{mc} = \frac{\delta}{2R_{OUT}}}$$



$$v_o = g_{mc} v_{ic} (R_o // R_L)$$

$$A_{vc} = \frac{v_o}{v_{ic}} = g_{mc} (R_o // R_L)$$

PERO: $R_L << R_o \Rightarrow R_o // R_L \cong R_L$

$$\Rightarrow \boxed{A_{vc} = g_{mc} R_L = \frac{\delta}{2R_{OUT}} R_L}$$

$$RRMC = \left| \frac{A_{vd}}{A_{vc}} \right| = \left| \frac{g_{md}}{g_{mc}} \right| = \frac{g_{md} \cdot 2R_{OUT}}{\delta}$$

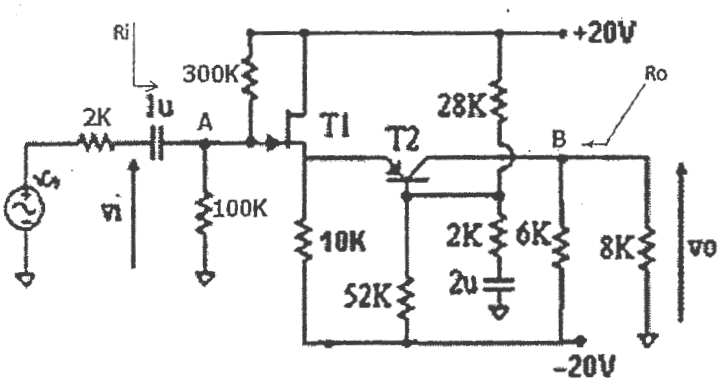
$$\boxed{RRMC = 20 \log \left| \frac{g_{md} 2R_{OUT}}{\delta} \right|}$$

P/ Fotocopiar

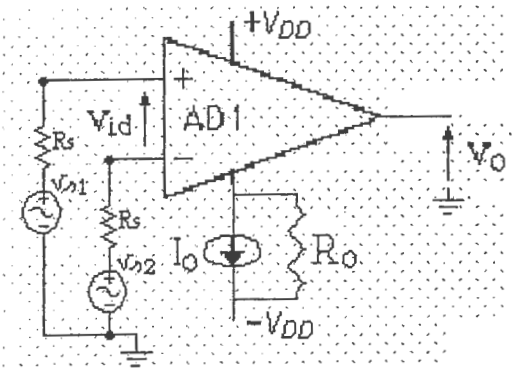
66.08 – 86.06 Evaluación integradora 1/2016- cuarta fecha - 27/07/16

APELLIDO	NOMBRE	PADRON	TURNO		N° de hojas	Corrección	
			T	N			

1.- $\beta = 200$; $V_A \rightarrow \infty$; $r_x = 100\Omega$; $I_{DSS} = 12mA$; $V_P = -6V$; $\lambda = 0$; $f_T = 200MHz$; $C_\mu = 1pF$; $C_{gs} = 5pF$; $C_{gd} = 1pF$



Analizar *cualitativamente* cuál podría considerarse el nodo dominante que determine el valor de f_h. Obtener f_h.

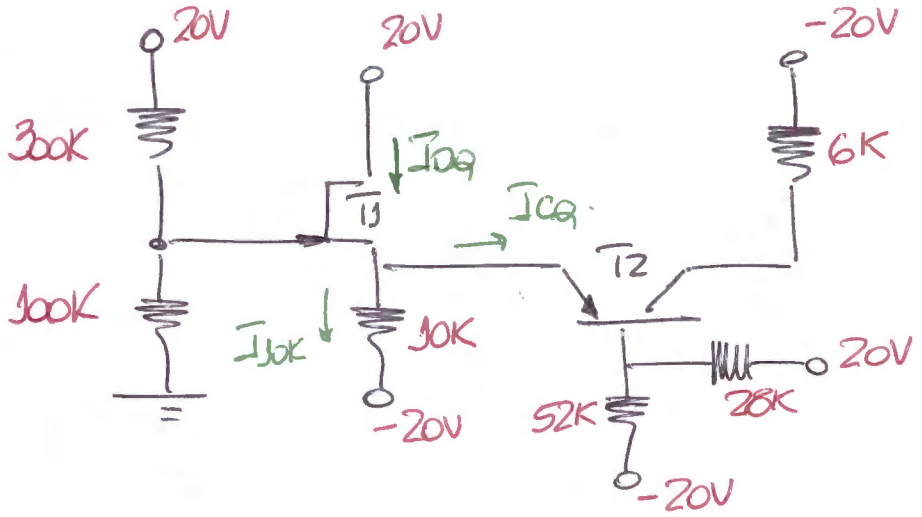


2.- AD1 es un par acoplado por source de NMOSFETs de canal inducido (T_1 - T_2), con una fuente espejo PMOSFET como carga (T_3 - T_4).
Se admiten transistores con características nominalmente similares ($T_1 = T_2$ y $T_3 = T_4$). *Definir y hallar la expresión* de la tensión de offset, V_{off}, para los siguientes casos:

a) $|V_{T2} - V_{T1}| / V_{T1} = \delta$, donde $\delta << 1$.

b) $|W_2 - W_1| / W_1 = \delta$, donde $\delta << 1$.

1) POLARIZACIÓN:



$\beta = 200$; $V_A \to \infty$

$r_x = 100\Omega$; $I_{DSS} = 12mA$

$V_P = -6V$; $\lambda = 0$

$f_T = 200MHz$.

$C_\mu = 1pF$

$C_{gs} = 5pF$; $C_{gd} = 1pF$.

$$V_{GQ} = \frac{20V \; 100K}{100K + 300K} = 5V \quad ; \quad V_{BQ} = \frac{40V \; 52K}{52K + 28K} - 20V$$

$$V_{BQ} = 6V$$

$$\Rightarrow V_{SQ} = V_{EQ} = V_{BQ} + 0{,}7V = 6{,}7V$$

$$\Rightarrow I_{10K} = \frac{6{,}7V - (-20V)}{10K} = 2{,}67mA$$

AHORA BIEN:

$$V_{GSQ} = V_{GQ} - V_{SQ} = 5V - 6{,}7V = -1{,}7V$$

$$\hookrightarrow I_{DQ} = I_{DSS}\left(1 - \frac{V_{GSQ}}{V_P}\right)^2 = 6{,}2mA$$

$$\Rightarrow I_{CQ} = 6{,}2mA - 2{,}67mA = 3{,}53mA$$

PARÁMETROS:

$g_{m1} = 17{,}2m$

$r_{ds} \to \infty$

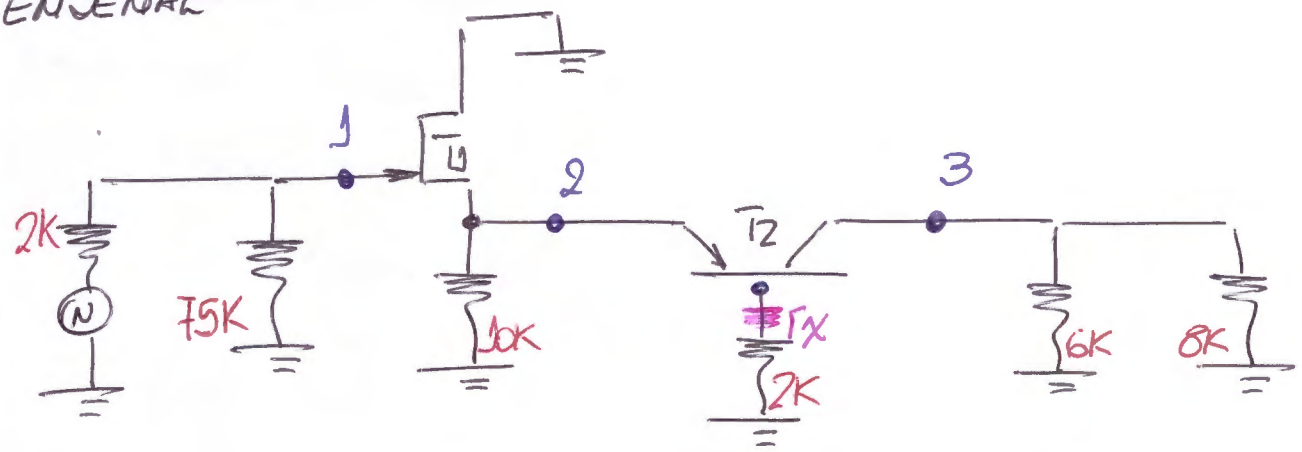
$g_{m2} = 141{,}2m$

$r_o \to \infty$

$r_\pi = 1K4$

$C_\pi = 111pF$

ENSEÑAL.



1) $R_{eq} = (75K \,//\, 2K) \approx 2K$

$C_{eq} = C_{gd} + C_{gs}\left(1 - \frac{v_s}{v_{gp}}\right)$; $\frac{v_s}{v_{gp}} = \frac{i_d\left(10K \,//\, \frac{r_\pi + r_x + 2K}{\beta}\right)}{i_d(\;) + v_{gs}}$

$C_{eq} = 4{,}85\,pF$

$\frac{v_s}{v_{gp}} = 0{,}23$

↳ $\tau = 9{,}7\,ns$

2). $R_{eq} = r_{d_{FET}} \,//\, \frac{r_x + r_\pi + 2K}{\beta} \cong 13\,\Omega$

$C_{eq} = C_\pi\left(1 - \frac{2K + r_x}{2K + r_x + r_\pi}\right) + C_{gs}\left(1 - \frac{2K}{2K + r_{gs}}\right)$ $\rightarrow 0$

$C_{eq} = C_\pi(1 - 0{,}6) + C_{gs} = 49{,}4\,pF$

$\Rightarrow \tau = 0{,}64\,ns$

EL POLO DOMINANTE ES EL 4

↳ $f_h = 1{,}36\,MHz$

3) $R_{eq} = 6K \,//\, 8K = 3K4$
$C_{eq} = C_\mu = 1\,pF$ } $\tau = 3{,}4\,ns$

4) $R_{eq} = (r_x + 2K) \,//\, (r_\pi + \beta\, r_{d_{FET}}) = 1K8$

$C_{eq} = C_\mu\left(1 - \frac{-3K4}{58 + r_{d_{TBJ}}}\right) + C_\pi\left(1 - \frac{58}{58 + r_{d_{TBJ}}}\right) = 65\,pF$

$\Rightarrow \tau = 117\,ns$

2) $V_{OFF} = V_{gs1} - V_{gs2}$ 27/07/2016

AHORA BIEN: $I_{D1} = K_1' \frac{W_1}{L_1} (V_{gs1} - V_{T1})^2$

$$\hookrightarrow V_{gs1} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} + V_{T1}$$

$$V_{OFF} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} + V_{T1} - \sqrt{\frac{I_{D2}}{K_2' W_2/L_2}} - V_{T2}.$$

a) $\frac{|V_{T2} - V_{T1}|}{V_{T1}} = \delta$; $\delta \ll 1$

EL ÚNICO DESAPAREAMIENTO ES EN V_T $\Rightarrow \begin{cases} K_1' = K_2' \\ W_1 = W_2 \\ L_1 = L_2 \end{cases}$

AL APLICAR V_{OFF} BUSCO QUE: $I_{D1} = I_{D2}$.

LUEGO: $V_{OFF} = V_{T1} - V_{T2} = \Delta V_T = \delta V_{T1}$??? YA ESTÁ ?

b) EL ÚNICO DESAPAREAMIENTO ES EN W $\Rightarrow \begin{cases} V_{T1} = V_{T2} \\ L_1 = L_2 \\ K_1' = K_2' \end{cases}$

$$V_{OFF} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} - \sqrt{\frac{I_{D2}}{K_2' W_2/L_2}} = \sqrt{\frac{I_{D1}}{K_1'/L_1}} \left\{ \frac{1}{\sqrt{W_1}} - \frac{1}{\sqrt{W_2}} \right\}$$

$$V_{OFF} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \left\{ 1 - \frac{1}{\sqrt{W_2/W_1}} \right\} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \left\{ 1 - \frac{1}{\sqrt{1+\delta}} \right\}$$

PARA $\delta \ll 1 \Rightarrow \sqrt{1+\delta} \approx 1 + \delta/2$.

$$V_{OFF} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \left\{ 1 - \frac{1}{1+\delta/2} \right\} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \left\{ \frac{\delta/2}{1+\delta/2} \right\}$$

$$V_{OFF} = \sqrt{\frac{I_{D1}}{K_1' W_1/L_1}} \frac{\delta}{2}.$$?

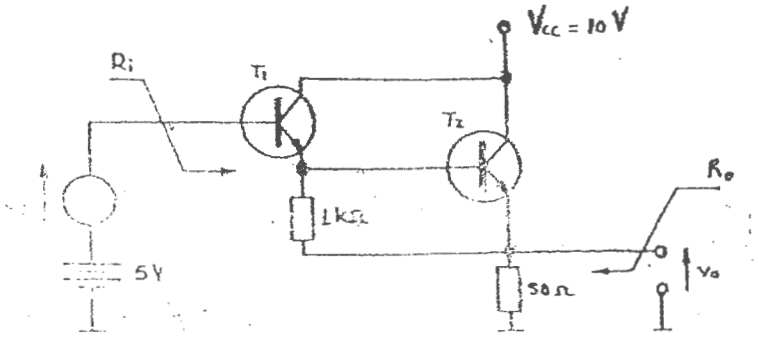
P/Fotocopiar V

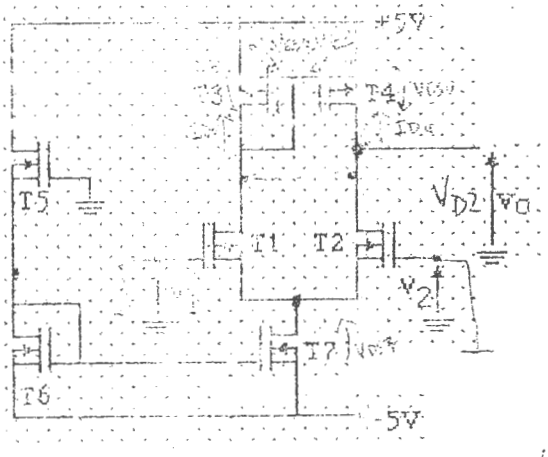
66.08 – 86.03 Eval. integradora – 1/2016 – 3era fecha 20/07/16

APELLIDO	NOMBRE	PADRON	TURNO			N° de HOJAS	Corrección	
				T	N			

1.- Para el siguiente circuito, donde v_i y la fuente de 5V representan la tensión que entrega la etapa anterior a la indicada en la figura (cc + señal):
Justificar en qué valor podría estimarse la frecuencia de corte superior de esta etapa.

$\beta = 200$; $r_x \to 0$; $V_A \to \infty$; $f_T = 300MHz$; $C_\mu \cong 1$ pF





2.- MOSFET inducidos: $V_T = \pm 1{,}5V$; $k' = 100\mu A/V^2$; $\lambda = 0{,}01V^{-1}$; $(W/L)_{1,2,3,4} = 10$; $(W/L)_{5,6,7} = 2$

a) Definir y obtener la RRMC en dB.
b) Definir y obtener los valores del rango de tensión de modo común.

1) $V_{DS2} > V_{DS1}$

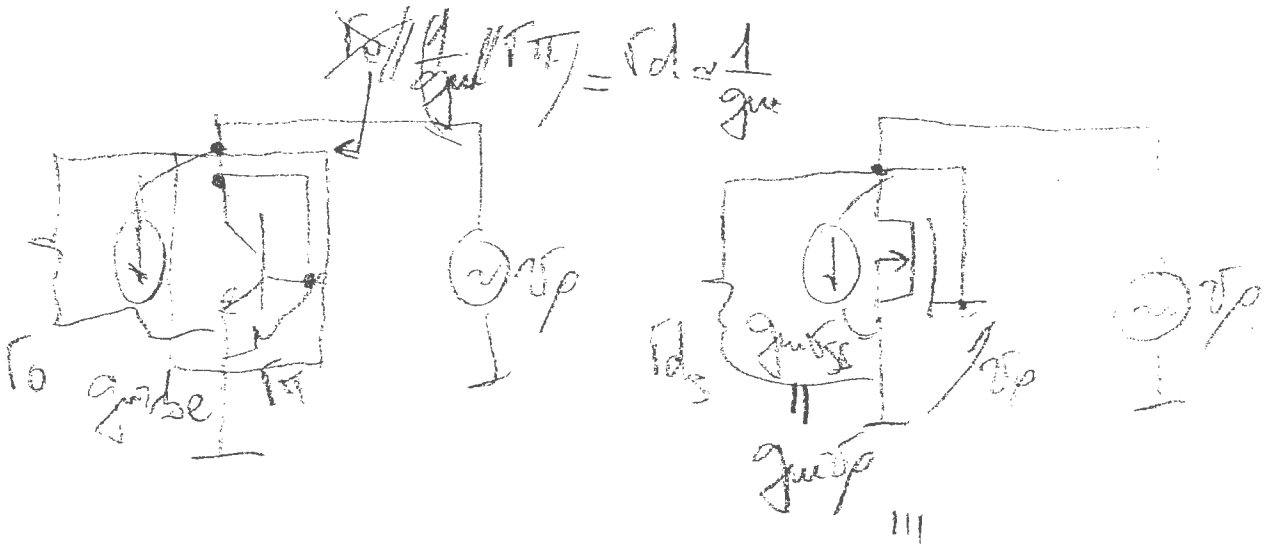
$\left.\begin{array}{l} V_{DS2} > V_{DS1} \\ V_{GS2} = V_{GS1} \end{array}\right\} \xrightarrow{\lambda} I_{D2} > I_{D1}$

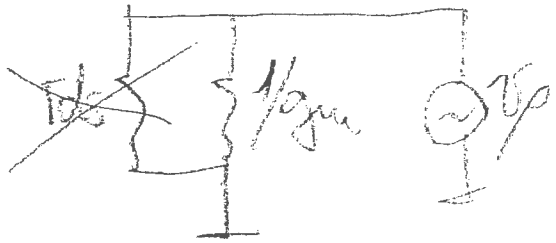
ABS

$\left.\begin{array}{l} V_{DS4} < V_{DS3} \\ V_{GS4} = V_{GS3} \end{array}\right\} \xrightarrow{\lambda} I_{D4} < I_{D3}$

$I_{D2} = I_{D2}$ $I_{D3} = I_{D}$

$\Rightarrow \boxed{V_{DS2} = V_{DS1}}$





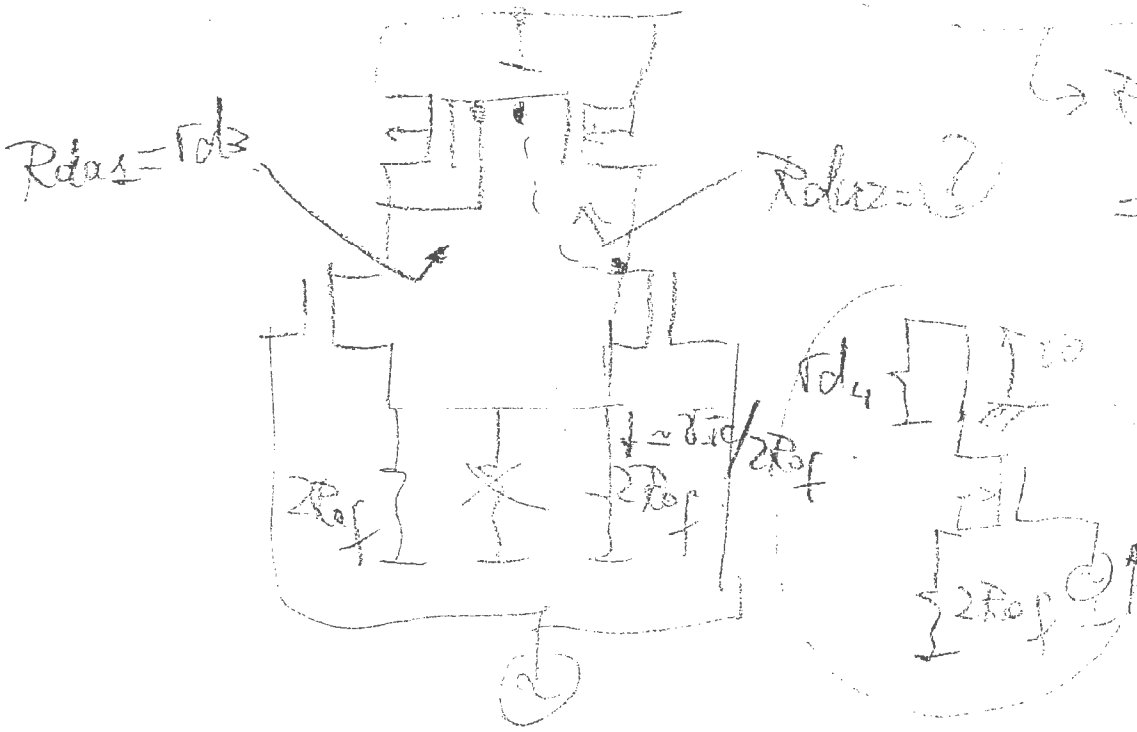
$v_{ic} \Rightarrow$ $v_{GS1} = v_{GS2} \ \forall t$ → extrayendo conclusiones PO...

valores totales

→ $v_{D2}(t) = v_{D1}(t) \ \forall t$ $\qquad i_{D2}(t) = i_{D1}(t)$

$-V_{DQ2} = V_{DQ1}$ $\qquad I_{DQ2} = I_{DQ1}$

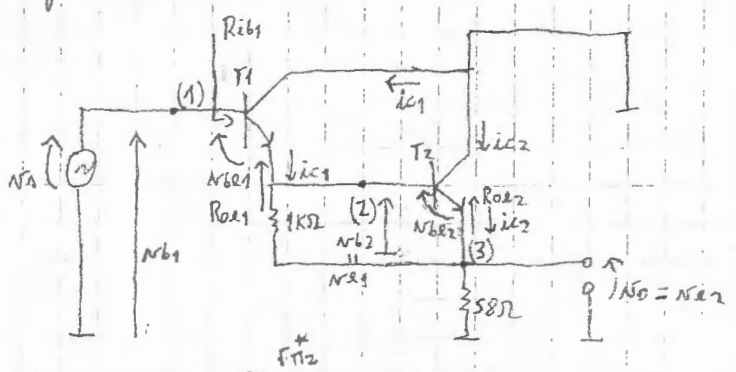
$v_{d2}(t) = v_{d1}(t)$ $\qquad i_{d2}(t) = i_{d1}(t)$



→ $R_{da2} = R_{da1} = r_{d3} = r_{d4} = 1/g_m$

(1) 20/7/16

1) · En frecuencias medias)

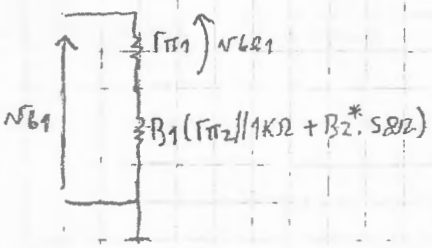


$\beta = 200$
$f_T = 300\,MHz$
$r_x \to 0$
$V_A \to \infty$
$C_\mu \cong 1\,PF$

– En freq. altas afectan las capacidades internas.

(1) $R_{ib1} = r_{\pi1} + \beta_1 (\overbrace{r_{\pi2} // 1K\Omega}^{r^*_{\pi2}} + \beta^*_2 \cdot 58\Omega)$

· Reflejo $C_{1\pi}$ => $A_{v1} = \dfrac{v_{be1}}{v_{b1}} = \dfrac{\overbrace{i_{c1}}^{g_{m1} \cdot v_{be1}} (r_{\pi2} // 1K\Omega + \beta^*_2 \cdot 58\Omega)}{v_{b1}} = \dfrac{\beta_1 (r_{\pi2} // 1K\Omega + \beta^*_2 \cdot 58\Omega)}{r_{\pi1} + \beta_1 (r_{\pi2} // 1K\Omega + \beta^*_2 \cdot 58\Omega)} \leq 1$

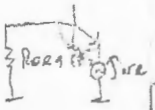


$\therefore C^*_{1\pi 1} = C_{1\pi}(1 - A_{v1})$ => se refleja más chico

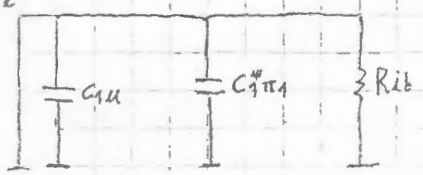
T_2 eq. $\begin{cases} \beta^*_2 = \dfrac{i_{c2}}{i_{b2}} = \dfrac{g_{m2} \cdot v_{be2}}{i_{b2}} = \dfrac{g_{m2} \cdot i_{b2} \cdot (r_{\pi2} // 1K\Omega)}{i_{b2}} = g_{m2}(r_{\pi2} // 1K\Omega) \\ r^*_{\pi2} = r_{\pi2} // 1K\Omega \end{cases}$

parámetros del T_2 equivalente

R-C equivalente:

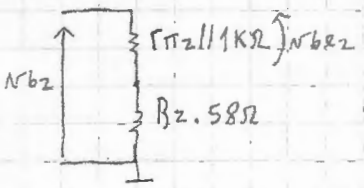


$i_1 \to 0$ (la fuente de señal en corto y $r_x \to 0$)



(2) · Reflejo $C_{1\pi}$ => $A_{v2} = \dfrac{v_{b1}}{v_{be1}} \cong 0$ => se refleja igual (corto en v_s para reflejar)

· Reflejo $C_{2\pi}$ => $A_{v3} = \dfrac{v_{be2}}{v_{b2}} = \dfrac{\overbrace{i_{c2}}^{g_{m2} \cdot v_{be2}} \cdot 58\Omega}{v_{b2}} = \dfrac{\beta^*_2 \cdot 58\Omega}{\underbrace{r_{\pi2} // 1K\Omega}_{r^*_{\pi2}} + \beta^*_2 \cdot 58\Omega} \leq 1$

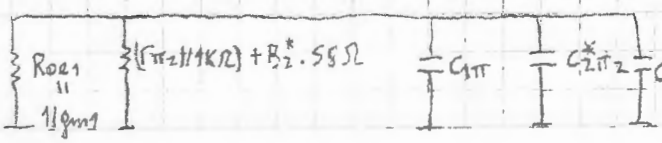


$\therefore C^*_{2\pi 2} = C_{2\pi}(1 - A_{v3})$ => se refleja más chico

· $R_{oe1} = \dfrac{r_{\pi1}}{\beta_1} = \dfrac{1}{g_{m1}}$

R-C equivalente:

$Z_2 = \Big(\underbrace{\dfrac{1}{g_{m1}} // ((r_{\pi2} // 1K\Omega) + \beta^*_2 \cdot 58\Omega)}_{\text{Es chico, } 1/g_{m1} \text{ reduce el paralelo}}\Big) \cdot (C_{1\pi} + \underbrace{C^*_{2\pi 2}}_{< C_{2\pi}} + C_{2\mu})$

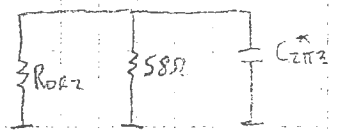


(3) Reflejo $C_{2\pi} \Rightarrow A_{v4} = \frac{v_{e2}}{v_{e2}} = v_{b2} \cdot \frac{R_{o2}}{R_{o2}+r_{\pi 2}^*} \cdot \frac{1}{A_{v2}} = \frac{R_{o2}}{R_{o2}+r_{\pi 2}^*} \Rightarrow C_{2\pi 3}^* = C_{2\pi}(1-A_{v2})$

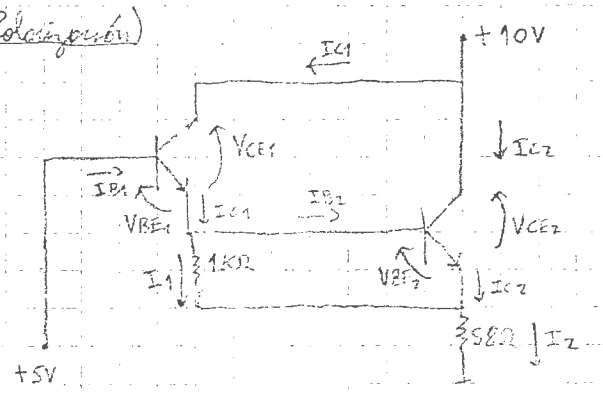
se refleja miller

$$R_{o2} = \frac{R_{o1} + \overbrace{r_{\pi 2} \,//\, (r_{o1})}^{r_{\pi 2}^*}}{\beta_2^*}$$

R-C equivalente: $\tau_3 = (R_{o2} // 58\Omega) \cdot C_{2\pi 3}^*$



· Polarización)



$I_1 = I_{C1} + I_{B2} = 0{,}7\,mA << I_{C2}$ ✓

· $I_{C2} >> I_1 \Rightarrow I_2 \approx I_{C2}$

$5V - 0{,}7V - 0{,}7V - I_{C2} \cdot 58\Omega = 0$

$[I_{C2} = 62\,mA]$

· $5V - 0{,}7V - \left(I_{C1} - \frac{62\,mA}{200}\right) \cdot 1K\Omega - 62\,mA \cdot 58\Omega = 0$

$[I_{C1} = 1{,}014\,mA]$

Parámetros de modelo: $g_{m1} = 40{,}56\,mA/V$ $\quad g_{m2} = 2{,}48\,A/V$

$r_{\pi 1} = 4{,}93K\Omega$ $\quad r_{\pi 2} = 80\Omega$

$f_T = 300MHz = \frac{1}{2\pi r_{\pi 1} C_{\pi 1}}$ $\quad C_{1\pi} = 21{,}51\,PF$ $\quad C_{2\pi} = 1{,}37\,nF$

(1) $Z_1 \Rightarrow 0$

(2) $A_{v3} = \frac{\beta_2^* \cdot 58\Omega}{r_{\pi 2} // 1K\Omega + \beta_2^* \cdot 58\Omega} = 0{,}99 \Rightarrow C_{2\pi 2}^* = 13{,}2\,PF \Rightarrow Z_2 = 24{,}6\Omega \cdot (13{,}2PF + 21{,}51PF + 1PF) = 0{,}88\,mA$

(3) $A_{v4} = \frac{1/g_{m2}}{1/g_{m1} + r_{\pi 2}} = 0{,}335 \Rightarrow C_{2\pi 3}^* = 1\,mF \Rightarrow Z_3 = 0{,}53\Omega \cdot 1mF = 0{,}53\,mA$

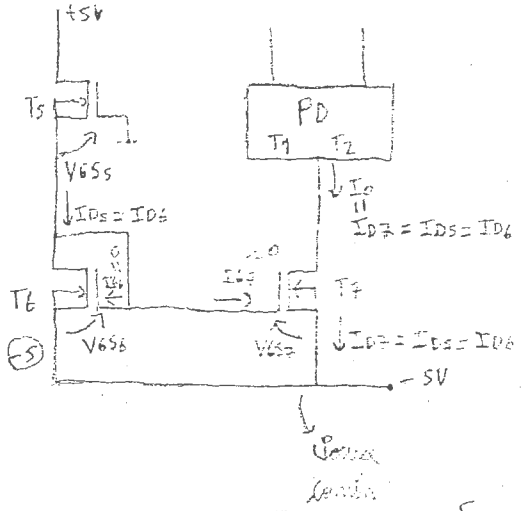
∴ Sumando los Z en serie $\Rightarrow Z_{eq} = 1{,}41\,mA \Rightarrow f_H = 115\,MHz$

la frecuencia

(2)

20/3/16

Polarización:



$-5V + V_{GS6} + V_{GS5} = 0$ $\quad [V_{GS6} = V_{GS7}]$ (a) → tomar idem 1.

$[V_{GS5} = 5V - V_{GS6}]$ (1)

$I_D = K' \frac{W}{L} (V_{GS} - V_T)^2$ (2)

$I_{DS5} = K' \frac{W}{L} (V_{GS5} - V_T)^2$ Usar (1) y (a)

$I_{DS5} = K' \frac{W}{L} (5V - V_{GS7} - V_T)^2 = I_{D7}$

$\left[I_{D7} = K' \frac{W}{L} (3,5V - V_{GS7})^2 \right]$ (b)

$\left[I_{D6} = I_{D7} = K' \frac{W}{L} (V_{GS7} - 1,5V)^2 \right]$ (c)

$R_{OD} = r_{o7}$

$R_{OD} = 1/\lambda . I_{D7}$

$R_{OD} = 500 k\Omega$

$\Rightarrow (b)-(c) \quad 0 = 100 \frac{\mu A}{V^2} . 2 \left((3,5)^2 - 7 . V_{GS7} + V_{GS7}^2 - (V_{GS7}^2 - 3V_{GS7} + (1,5)^2) \right)$

$0 = 10 - 4 . V_{GS7} \Rightarrow [V_{GS7} = 2,5 V] \Rightarrow [I_{D7} = 0,1 mA]$

$T_1 = T_2 \Rightarrow \left[I_{D1} = I_{D2} = \frac{I_0}{2} = 0,1 mA \right] \Rightarrow g_{m1} = g_{m2} = 0,28 mA/V$

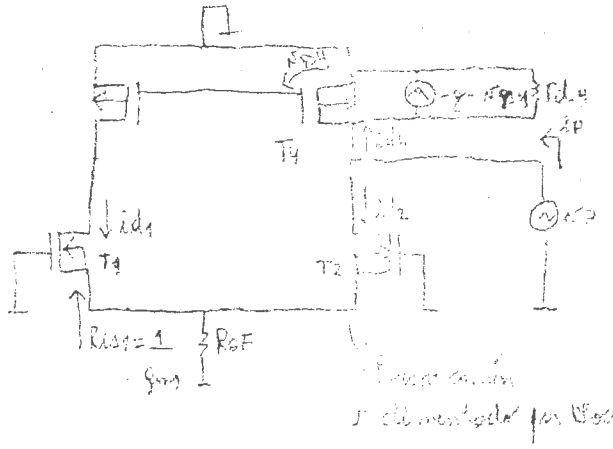
$r_{ds1} = r_{ds2} = 1 M\Omega$

$g_m = 2 (K . I_{DQ})^{1/2}$

$K = K' \frac{W}{L} = 200 \mu A/V$

$r_{ds} = 1/\lambda . I_{DQ}$

a)

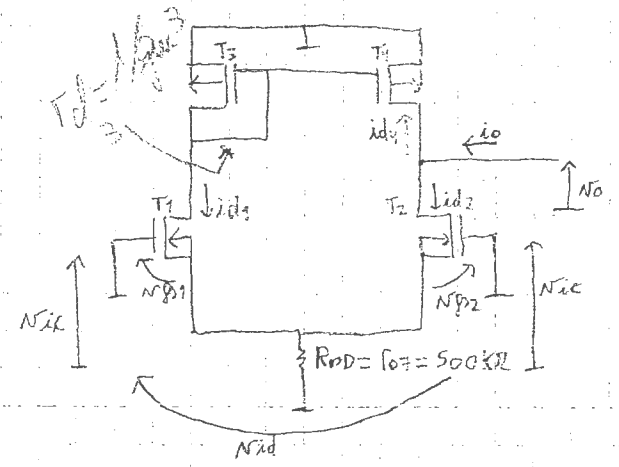


$R_o = \frac{v_p}{i_p}\Big|_{v_{OF}=0} \Rightarrow i_p = i_{d2} + i_{d4}$

$R_{o2} = r_{ds2}(1 + g_{m2} . (R_{OF} // 1/g_{m1})) \cong 2 r_{ds2} = 2 M\Omega$

$R_{o4} = r_{ds4} // R_{o2} = r_{ds4} // 2 r_{ds2}$

$\therefore R_o = R_{o4} // R_{o2} = r_{ds2} // r_{ds4} = 0,5 M\Omega$



• Con entrada diferencial

$N_{gs1} = \frac{N_{id}}{2} \Rightarrow i_{d1} = \frac{N_{id}}{2} g_{m1}$

$i_{d4} = -i_{d1} \rightarrow$ se copia a través de la fuente superior (espejo de corriente)

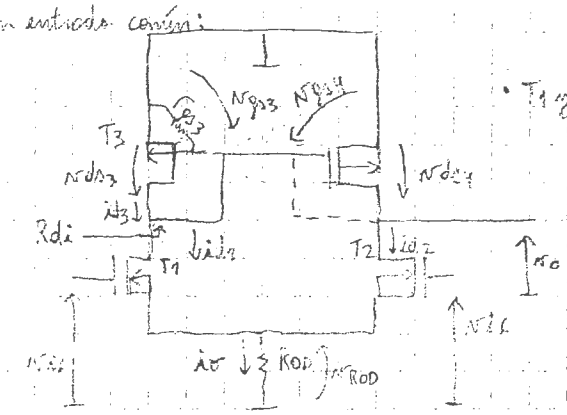
$N_{gs2} = -\frac{N_{id}}{2} \Rightarrow i_{d2} = -g_{m2} \cdot \frac{N_{id}}{2}$

• $i_o = i_{d2} + i_{d4} = -\frac{N_{id}}{2}(g_{m1} + g_{m2})$

$N_o = -i_o \cdot R_o = \frac{N_{id}}{2}(g_{m1} + g_{m2}) \cdot R_o$

$\Rightarrow A_{vd} = \left.\frac{N_o}{N_{id}}\right|_{N_{ic}=0} = \left(\frac{g_{m1} + g_{m2}}{2}\right) \cdot R_o = 140$

• Con entrada común:



• T1 y T2, T3 y T4 presentan apareamiento perfecto:

$A_{vc} = \frac{N_o}{N_{ic}} = \frac{N_{gs2}}{N_{ic}} = \frac{N_{gs3}}{N_{ic}} = \frac{i_{d1} \cdot r_{d3}}{i_{d1} \cdot r_{d1} + \underbrace{i_o \cdot R_{OD}}_{2i_{d1}}} \approx \frac{r_{d3}}{2 \cdot R_{OD}} \cong 3{,}57 \times 10^{-3}$

$N_{ic}\uparrow \Rightarrow N_{ROD}\uparrow \Rightarrow i_o\uparrow \Rightarrow i_{d1}$ & $i_{d2}\uparrow \Rightarrow N_{gs3} = N_{gs4}\uparrow$

$R_{di} = \frac{N_R}{i_P} = \frac{r_{gs3}}{B_{FET}} = \frac{1}{g_{m3}} = r_{d3} \rightarrow$ T3 carga a T1 con esta resistencia, T4 a T2 con $r_{d4} = r_{d3}$ ($I_{D3} = I_{D4}$) ¿?

$\Rightarrow RRMC = \left|\frac{A_{vd}}{A_{vc}}\right| = 39200$

b) El rango de tensión de modo común se define como el rango de valores de tensión de entrada de modo común comprendidos entre un mínimo y un máximo tal que los transistores del circuito sigan en MAD, es decir, que el circuito amplificador siga funcionando como tal. Debido a que A_{vc} es pequeño, se deduce que se mantienen las corrientes de reposo ante señales de entrada de modo común. $\Rightarrow$ Los límites están dados por la saturación del transistor de salida de la fuente de polarización del par diferencial y la saturación de uno o ambos transistores del par diferencial estrangulamiento incipiente por ser FETs.

$-5V + V_{DSE7} + V_{GSS} < V_{ic} < 5V + V_{DS4} + V_T$ ($V_{DSS} = V_{GS3}$, $I_{D3} = I_{D4} \Rightarrow V_{GD4} = 0 \Rightarrow V_{DS4} = V_{GS4}$)

$-5V + (V_{GS7} - V_T) + \sqrt{\frac{I_{D2}}{K' \frac{W}{L}}} + V_T < V_{ic} < 5V + V_{GS3} + V_T$

$-5V + 1V + 1{,}8V < V_{ic} < 5V - 1{,}18V + 1{,}5V$

$-2{,}2V < V_{ic} < 5{,}32V$

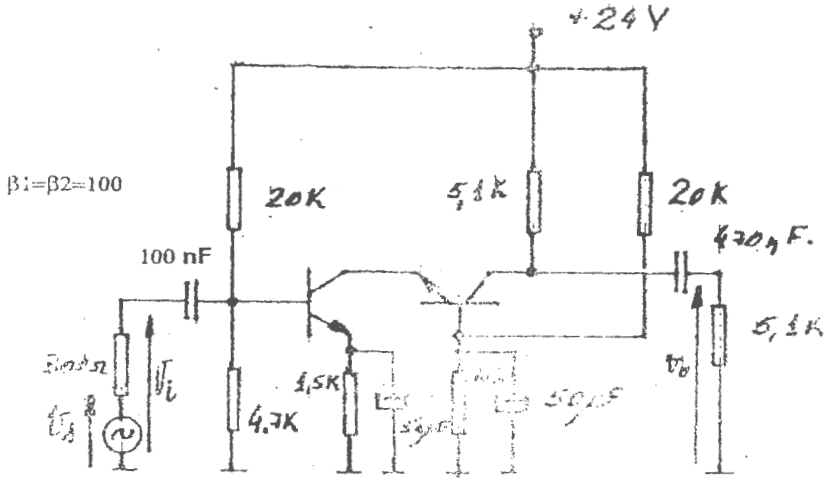
$\frac{V_{gs}}{V_{ic} - (5V - V_{DS})}$

$V_{ic} < 5V + V_{DS}$

66.08 – 86.06 Evaluación Integradora – 1/2016 – 1era fecha – 1/7/16

APELLIDO	NOMBRE	PADRON	TURNO			Nº de HOJAS	Corrección	
				T	N			

1. Obtener el valor garantizable de f_h para A_{vs}.
C_μ = 1 pF ; f_T = 300 MHZ ; r_x = 100 Ω



2.- Dibujar el circuito de un par diferencial NMOS FET (T_1 – T_2) con carga resistiva en ambas ramas R_{D1} = R_{D2} = 10KΩ y polarizado mediante una fuente de corriente cascodada con rama de referencia: R_{ref} = 8KΩ, T_3 y T_4; y rama de salida: T_5 y T_6. Se alimenta todo con un 6V.
Los transistores son idénticos y de características:

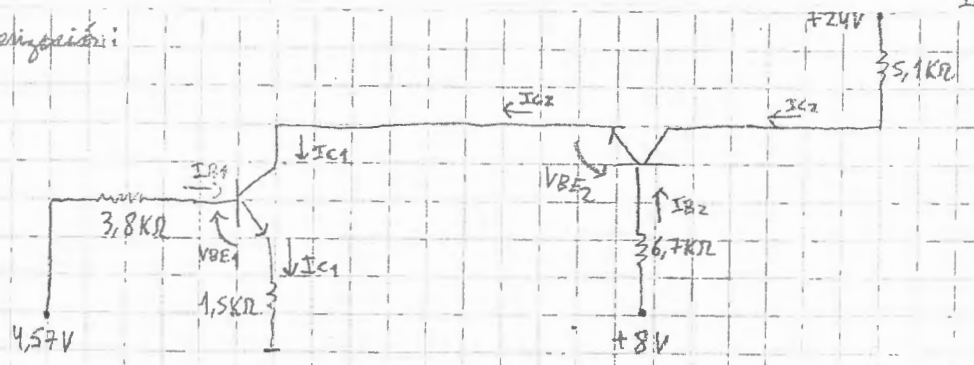
$$V_T = 1\ V;\ k' = 1\ mA/V^2\ ;\ (W/L) = 1,\ \lambda = 0{,}01\ V^{-1}.$$

Hallar las expresiones y el valor de Av_{1d}, Av_{1c}, Av_{2d}, Av_{2c}. Justificar cuál es la más sensible a posibles desapareamientos.

1

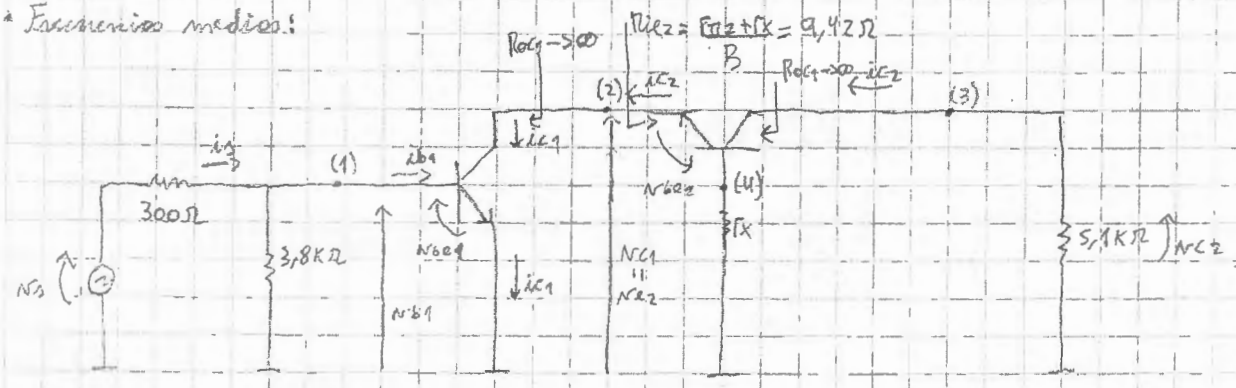
1/7/16

1) • Polarización:



$$4{,}57V = \frac{I_{C1}}{100} \cdot 3{,}8K\Omega - I_{C1} \cdot 1{,}5K\Omega = 0 \Rightarrow I_{C1} = 2{,}97\,mA = I_{C2}$$

• Funcionamiento medio:



Parámetros de señal: $g_{m1} = g_{m2} = 118{,}8\ mA/V$ $\quad r_{o1} = r_{o2} \to \infty$

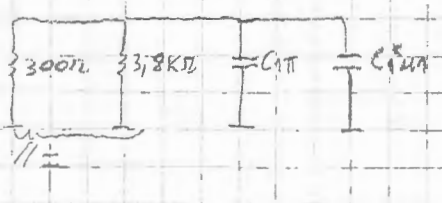
$r_{\pi 1} = r_{\pi 2} = 842\Omega$ $\quad C_{\pi 1} = C_{\pi 2} = 63\,PF$

Altas frecuencias: Afectan las capacidades internas de los capacitores.

(1) Refleja $C_{1\mu}$ $\Rightarrow A_{v1} = \frac{v_{c1}}{v_{b1}} = \frac{-i_{c1} \cdot R_{ie2}}{v_{b1}} = -g_{m1} \cdot R_{ie2} = -1{,}12$, $\quad C^*_{1\mu 1} = C_{1\mu}(1 - A_{v1})$

$v_{b1} \to v_{be1}$ $\quad C^*_{1\mu 1} = 2{,}12\,PF$

R-C equivalente:



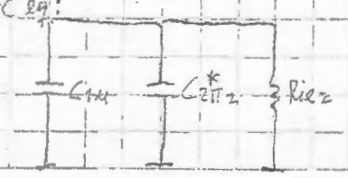
$\tau_1 = 278\Omega \cdot 65{,}12\,PF = 18{,}10\,ns$

$f_1 = 8{,}79\,MHz$

(2) Refleja $C_{1\mu} \Rightarrow A_{v2} = \frac{v_{b1}}{v_{c1}} \to 0 \Rightarrow C^*_{1\mu 2} = C_{1\mu}$

Refleja $C_{2\pi} \Rightarrow A_{v3} = \frac{v_{be2}}{v_{e2}} = \frac{1}{A_{v2}} \cdot A_{v2} \cdot \frac{r_x}{r_x + r_{\pi 2}} = 0{,}11 \Rightarrow C^*_{2\pi 2} = C_{2\pi}(1 - A_{v3}) = 56{,}07\,PF$

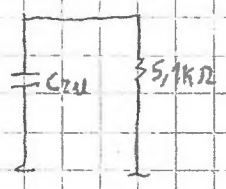
R-C eq:



$\tau_2 = 9{,}42\Omega \cdot 57{,}07\,PF = 0{,}54\,ns$

$f_2 = 294\,MHz$

(3) RC equivalente:

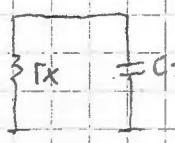


$\tau_3 = 1PF \cdot 5,1k\Omega = 5,1ns$
$f_3 = 31,2\ MHz$

(4) Refleja $C_{2\pi}$ => $A_{vs4} = \frac{v_{e2}}{v_{b2}} = \frac{B_2 R_{o1} // r_{\pi 2}}{r_{\pi 2} + B_2 R_{o1}} \xrightarrow{R_{o1}\to\infty} 1$ => $C_{2\pi}$ no se refleja

Refleja $C_{2\mu}$ => $A_{vs5} = \frac{v_{c2}}{v_{e2}} = \frac{B_2 \cdot 5,1k\Omega}{r_{\pi 2} + B_2 \cdot R_{o1}} \xrightarrow{R_{o1}\to\infty} 0$ => $C_{2\mu}$ se refleja igual

RC equivalente:

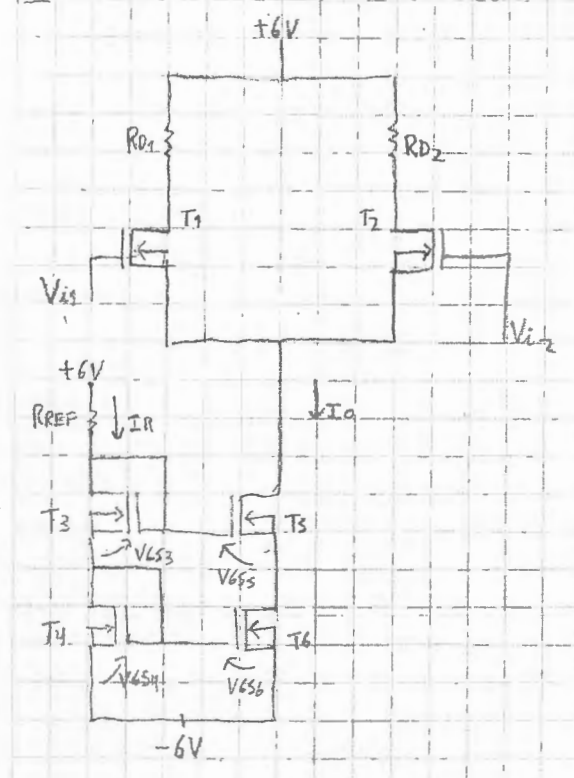


$\tau_4 = 100\Omega \cdot 1PF = 100PS$
$f_4 = 1,6 \times 10^9 Hz$

· Ninguna f 10 veces menor la otra => $\tau = \sum \tau_i = 23,84\ ns$ => $f_H = 6,7\ MHz$

(2) 1/7/16

2)



· Todos los transistores son idénticos:

(1) $-6V + V_{GS4} + V_{GS3} + I_D \cdot 8K\Omega - 6V = 0$

(2) $V_{GS4} = V_{GS3}$ ya que las corrientes de gate son nulas
$\Rightarrow$ Las I_D son idénticas

$\therefore$ (1) $\left[V_{GS} = \frac{12V}{2} - \frac{I_D \cdot 8K\Omega}{2} = 6V - I_D \cdot 4K\Omega \right]$

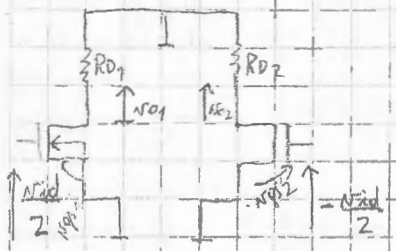
$I_{D1} = K \cdot (V_{GS} - V_T)^2$

$I_{D1} = 1\frac{mA}{V} \cdot 1 \left(6V - I_D \cdot 4K\Omega - 1V\right)^2$

$I_{D1} = 1\frac{mA}{V} \left(5V - I_D \cdot 4K\Omega\right)^2$

$0 = 0{,}025 - 41 \cdot I_D + 0{,}025 \cdot I_D^2$ $\begin{cases} I_D = 0{,}61\,mA \ \checkmark \\ I_D = 1639\,A \ \times \end{cases}$

· Como T_1 y T_2 son idénticos $\Rightarrow$ $\left[g_{m1} = g_{m2} = 1{,}90\frac{mA}{V} \right]$ Propongo repasar en hemicircuitos, T_1 - T_2, $I_{D1} = I_{D2} = 0{,}305\,mA$ es decir, apareados

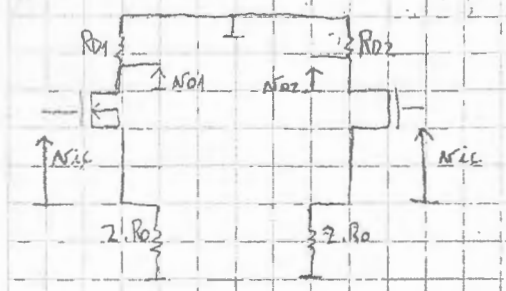


$v_{o1} = -g_m \cdot v_{gs1} \cdot R_{D1} = -g_m \cdot \frac{v_{id}}{2} \cdot R_{D1}$

$v_{o2} = -g_m \cdot v_{gs2} \cdot R_{D2} = g_m \cdot \frac{v_{id}}{2} \cdot R_{D2}$

$v_{od} = v_{o1} - v_{o2} = -g_m \cdot \frac{v_{id}}{2} \cdot (R_{D1} + R_{D2})$

$\left[A_{vcd} = \frac{v_{o1}}{v_{id}} \Big|_{v_{ic}=0} = -\frac{g_m \cdot R_{D1}}{2} = -5{,}5 \right]$ $\left[A_{vdd} = \frac{v_{od}}{v_{id}} \Big|_{v_{ic}=0} = -\frac{g_m}{2} \cdot (R_{D1} + R_{D2}) = -11 \right]$



· Necesito la Ro de la fuente cascode:

$\left[R_o = \frac{v_{pds}}{i_{pds}} \simeq g_m \cdot r_{ds}^2 = 1{,}56\frac{mA}{V} \cdot (164K\Omega)^2 = 42M\Omega \right]$

$v_{o1} = -g_m \cdot v_{gs1} \cdot R_{D1} = -\frac{R_{D1} \cdot v_{ic}}{r_d + 2R_o}$

$v_{o2} = -g_m \cdot v_{gs2} \cdot R_{D2} = -\frac{R_{D2} \cdot v_{ic}}{r_d + 2R_o}$

$v_{od} = v_{o1} - v_{o2} = \left(-\frac{R_{D1}}{r_d + 2R_o} + \frac{R_{D2}}{r_d + 2R_o} \right) \cdot v_{ic}$

$v_{gs} = v_{ic} \cdot \frac{r_{gs}}{r_{gs} + R_{EE} \cdot 2R_o}$

$v_{gs} = v_{ic} \cdot \frac{1/g_m}{1/g_m + 2R_o}$

$$\left[A_{vic} = \frac{v_{o1}}{v_{ic}} \Big|_{v_{id}=0} = \frac{-R_{d1}}{r_d + 2R_e} = -0{,}12\,m \right]$$

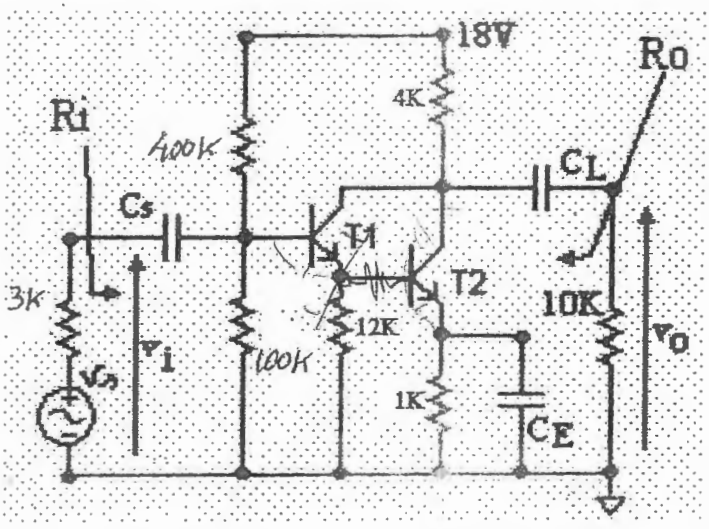
$$\left[A_{vdc} = \frac{v_{od}}{v_{ic}} \Big|_{v_{id}=0} = \frac{-R_{D1}}{r_d + 2R_e} + \frac{R_{D2}}{r_d + 2R_e} = 0 \right]$$

· A_{vdc} es el mas sensible a posibles desparecimientos, ya que un pequeño cambio en R_c o algun tipo de desparecimiento de los transistores ya hacia que no salga 0 (simetrico de construccion).

P/ Fotocopias

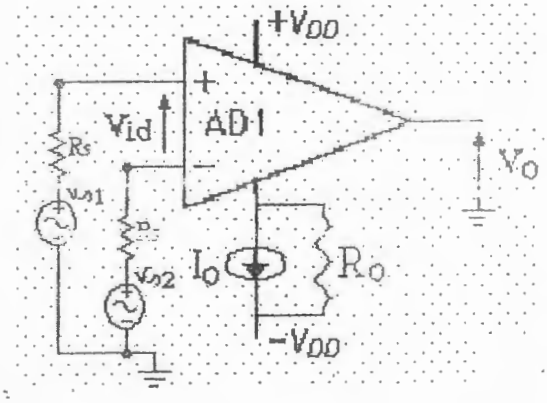
66.08 - Circuitos Electrónicos 1 — Evaluación integradora- 1/2016 quinta fecha 3/8/16

APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
				T	N			



1. $\beta = 100$; $C_\mu = 2$ pF ; $f_T = 300$ MHz.
$r_x = 100\,\Omega$

Justificar *cualitativamente* cuál será el nodo dominante para la respuesta en alta frecuencia de A_{vs}. Calcular el valor aproximado de f_h en base a este nodo.

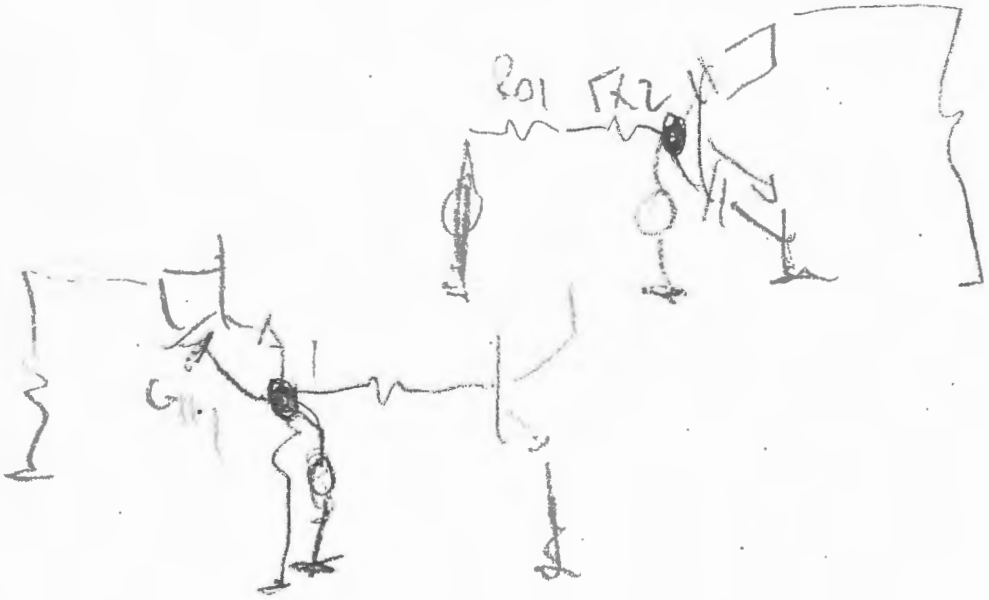


2. AD1 es un par acoplado por emisor de TBJs (T_1 - T_2), con una fuente espejo PMOSFET como carga (T_3 - T_4).

Se admiten transistores con características nominalmente similares ($T_1 = T_2$ y $T_3 = T_4$).

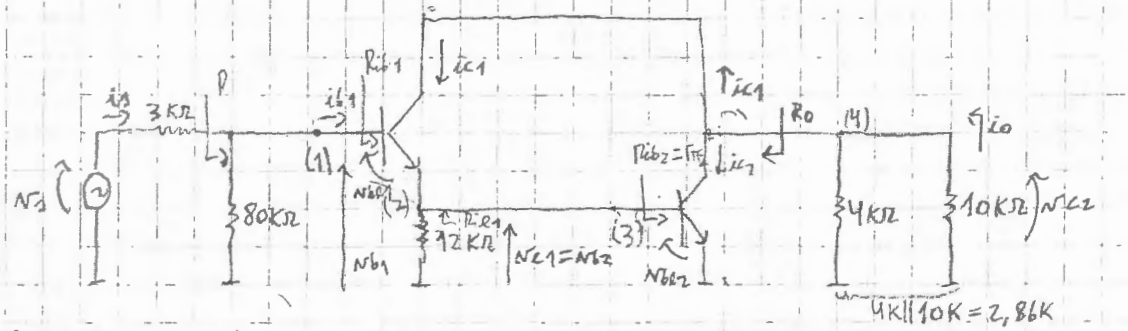
Io = 200 uA ; $k' = 100$ uA/V^2 ; W/L = 1

Definir y hallar el valor de la tensión de offset *total*, si $|I_{S2} - I_{S1}|/I_{S1} < \delta$ y $|W_4 - W_3|/W_3 < \delta$, donde $\delta = 0{,}02$.



(1) 3/8/16

1) A frecuencias medias



(1) Colector común realimentado por emisor

· $R_{ib1} = r_{\pi1} + \beta(12K\Omega \,||\, r_{\pi2} + r_x)$

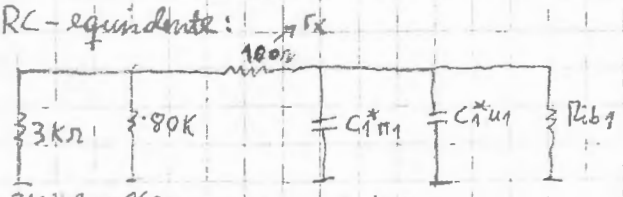
· Reflejo $C_{1\pi}$ a la entrada => $C^*_{\pi1} = C_{1\pi}(1 - A_{v1})$ (considero abiertos los otros capacitores)

$A_{v1} = \frac{v_{e1}}{v_{b1}}$, $A_{v1} < 1$ => C_π se refleja más chico (Av1 de seguidor)

· Reflejo C_μ a la entrada => $C^*_{1\mu1} = C_{1\mu}(1 - A_{v2})$ (abiertos los otros capacitores)

$A_{v2} = \frac{v_{c1}}{v_{b1}} = \frac{v_{e2}}{v_{b1}}$ -> de todo el circuito => es grande y < 0 => se refleja mas grande.

∴ RC-equivalente:

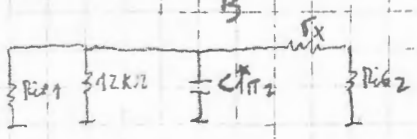


3K || 80K ≅ 3KΩ + 100Ω = 3,1KΩ

$Z_1 = \underbrace{(3,1K \,||\, R_{ib1})}_{\leq 3,1K\Omega} \cdot (\underbrace{C^*_{1\pi1}}_{<C_{1\pi}} + \underbrace{C^*_{1\mu1}}_{>C_{1\mu}})$ pero no tanto.

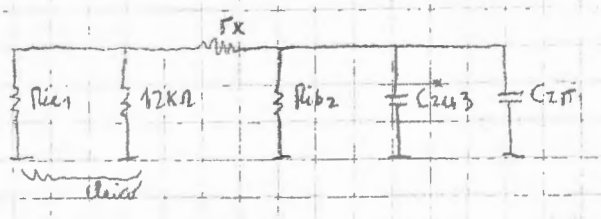
(2) Reflejo $C_{1\pi}$ => $A_{v3} = \frac{v_{b1}}{v_{e1}}$ -> chico => $C^*_{1\pi2} = C_{1\pi}(1 - A_{v3})$ se refleja mas chico

$R_{ie1} = \frac{r_{\pi1} + r_x + (3K \,||\, 80K)}{\beta}$ chico



$Z_2 = (\underbrace{R_{ie1} \,||\, 12K\Omega \,||\, (r_x + R_{ib2})}_{\text{menor a (1), } R_{ie1} \text{ lo achica}}) \cdot \underbrace{C_{1\pi2}}_{<C_{1\pi}}$ } divisor entre nodo

(3)



$C^*_{2\mu3} = C_{2\mu}(1 + \underbrace{A_{v3}}_{\frac{v_{c2}}{v_{b2}}})$ -> se refleja mas grande

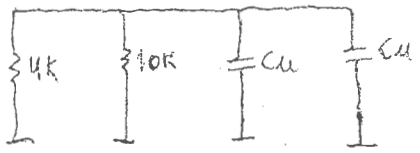
$Z_3 = \underbrace{\{(R_{ie1} \,||\, 12K\Omega + 100\Omega) \,||\, R_{ib2}\}}_{\text{menor a R de (2)}} \{\underbrace{\underbrace{C^*_{2\mu3}}_{>C_{1\mu}} + C_{2\pi}}_{>C^*_{1\mu1}}\}$

(menor a la de (1) y (4))

(4) $R_o = \frac{2}{3} r_{o2} \to \infty$ (considero $V_A \to \infty$)

· Los C_μ se reflejan en la salida igualados, ya que en los TBJ, $A_v = \frac{g_m}{N_2} \approx 0$

∴ RC eq:



$$Z_4 = \underbrace{(4K \| 10K)}_{2,86K} \cdot \underbrace{(C_\mu + C_\mu)}_{4pF}$$

· El nodo (2) lo descarto R y C chicas, y el nodo (4) también, C muy chica => me quedo con los nodo (1) y (3).

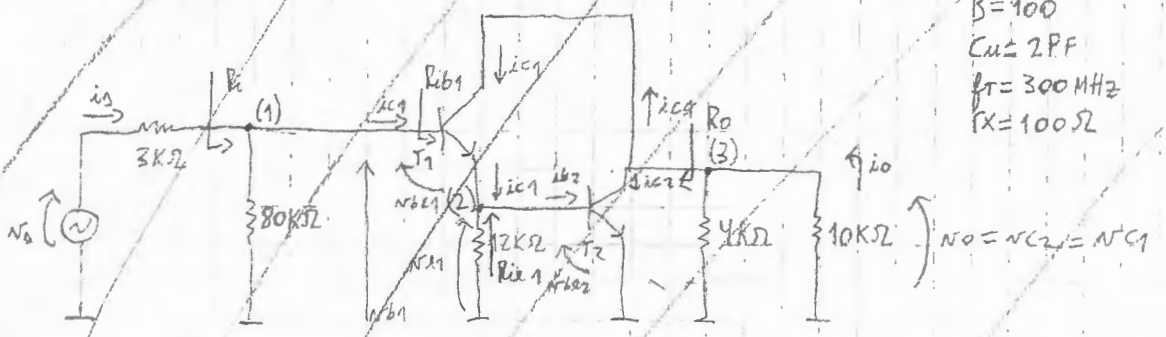
(2)

3/8/16

1) Dibujo el circuito en frecuencias medias:

$\beta = 100$
$C_\mu \simeq 2PF$
$f_T = 300 MHz$
$r_x = 100\Omega$

$f_T = \frac{1}{2\pi C_\pi r_d}$ $\quad 11 k\Omega$



ESTO NO HECHO SOLO POLARIZACIÓN Y LO QUE SIGUE

(1) Colector común realimentado por emisor

- $R_{ib1} = r_{\pi1} + \beta(12K\Omega // r_{\pi2} + r_x)$
- Reflejo C_π a la entrada $\Rightarrow C^*_{\pi1} = C_\pi(1 - A_{v1})$ (considero abiertos los otros capacitores)

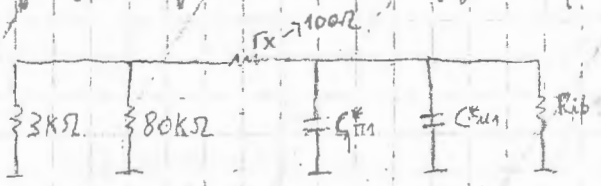
$A_{v1} = \frac{v_{e1}}{v_{b1}}$, $A_v \leq 1 \Rightarrow C_\pi$ se refleja menos chico, A_v chico en el seguidor es menor a 1

seguidor por emisor

- Reflejo C_μ a la entrada $\Rightarrow C^*_{\mu1} = C_\mu(1 - A_{v2})$ (abiertos los otros capacitores)

$A_{v2} = \frac{v_{c1}}{v_{b1}}$, emisor común $\Rightarrow A_v$ es negativa pero no tan grande debido a que T_1 está realimentado por emisor y baja la ganancia $\Rightarrow$ se refleja menos grande

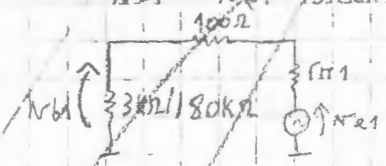
$\therefore$ La red RC equivalente será:



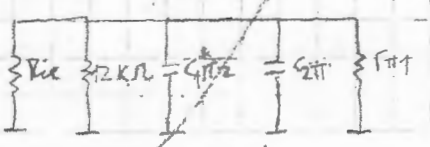
$$\Rightarrow Z_1 = \left\{ \left[\underbrace{(3K\Omega // 80K\Omega)}_{\sim 3K\Omega} + 100\Omega \right] // R_{ib1} \right\} \cdot \left(\underbrace{C^*_{\pi1}}_{\gg C_\pi} + \underbrace{C^*_{\mu1}}_{> C_\mu} \right)$$

(2) Reflejo C_π del $T_1 \Rightarrow A_{v3} = \frac{v_{b1}}{v_{e1}} = \frac{v_{e1}}{v_{e1}} \cdot \frac{3K\Omega // 80K\Omega + 100\Omega}{3K\Omega // 80K\Omega + 100\Omega + r_{\pi1}} \Rightarrow C^*_{\pi2} = C_\pi(1 - A_{v3})$

Se refleja casi idéntico



$R_{i1} = \frac{3K\Omega // 80K\Omega + 100\Omega + r_{\pi1}}{100}$ $\therefore$ La red equivalente RC será:



C_π del T_2

$Z_2 = (\underbrace{r_{\pi1} // 12K\Omega // R_{i1}}_{\text{menor que R de (1)}}) \cdot (C_{2\pi} + \underbrace{C^*_{\pi2}}_{\gg C_{2\pi}})$

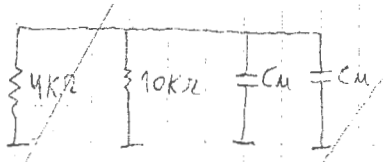
chico

$v_3 \simeq 0{,}21$
$r_{\pi1} = 11K\Omega$
$R_{i1} = 139\Omega$
$C_{2\pi} = 4{,}6PF$
$C_{1\pi} = 4{,}88PF$
$C^*_{\pi2} = 3{,}79 PF$
$\tau_2 = 128\Omega \cdot 49{,}79PF = 6{,}37ns$

③ $R_o = \underset{3}{\mathcal{Z}}\, r_{o2} \to \infty$ (considero $V_A \to \infty$)

• Los C_μ se reflejan a la salida igualmente, ya que en los TBJ, $A_v = \frac{v_c}{v_b} = 0$

∴ La red RC equivalente será

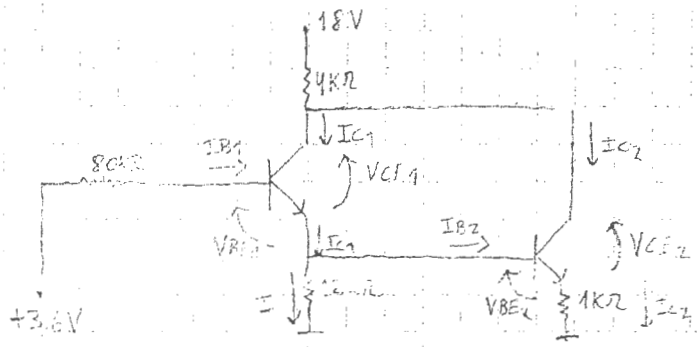


$$\tau_3 = \underbrace{(4K\Omega // 10K\Omega)}_{2{,}9K\Omega}\cdot\underbrace{(C_\mu + C_\mu)}_{4PF} = 11{,}6\,ns$$

↳ similar a la de (1)

• La R de (2) es menor a la de (1) y (3), pero, al ser R_3 y R_1 por similares, C_π suele ser mayor a C_μ y en (1) C_μ se refleja como mucho grande => el de (1) dominará

POLARIZACIÓN



- Considero $I_{C1} >> I_{B2}$ => $I \approx I_{C1}$

• $3{,}6V - \frac{I_{B1}}{100}\cdot 80K\Omega - 0{,}7V - I_{C1}\cdot 12K\Omega = 0$

$[I_{C1} = 0{,}23\,mA]$

• $3{,}6V - \frac{0{,}23\,mA}{100}\cdot 80K\Omega - 0{,}7V - 0{,}7V - I_{C2}\cdot 1K\Omega = 0$

$[I_{C2} = 2{,}2\,mA]$

$I_{B2} = 22\,\mu A << I_{C1} = 0{,}23\,mA$

$g_{m1} = 9{,}2\,\frac{mA}{V}$, $r_{\pi1} = 11K\Omega$, $C_{1\pi} = 4{,}88\,PF$

$g_{m2} = 88\,\frac{mA}{V}$; $r_{\pi2} = 1{,}14K\Omega$; $C_{2\pi} = 46\,PF$

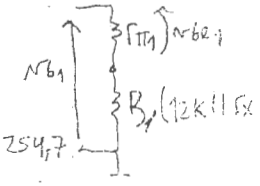
• ALTAS FRECUENCIAS: Ver valores de nodos (1) y (3)

(1) $R_{ib1} = \underbrace{r_{\pi1}}_{11K\Omega} + \underbrace{\beta_1}_{100}\,\underbrace{(12K // (r_{\pi2} + r_x))}_{1{,}12K\Omega} = 123K\Omega$ $\qquad \tau_1 = 3{,}1K\Omega\cdot(511{,}4PF + 0{,}44PF) = 1{,}59\,\mu s \to f = 100KHz$

$$A_{v1} = \frac{v_{b1}}{v_{b1}} = \frac{\overbrace{i_{c1}}^{g_{m1}v_{b1}}\cdot\overbrace{(12K\Omega // (r_x + r_{\pi2}))}^{1{,}12K\Omega}}{v_{b1}} = \frac{\beta_1\cdot 1{,}12K\Omega}{\underbrace{r_{\pi1}}_{11K\Omega} + \beta_1\cdot 1{,}12K\Omega} = 0{,}91 \Rightarrow C^*_{\pi1} = 0{,}44PF$$

$$A_{v2} = \frac{v_{c2}}{v_{b1}} = \frac{\overbrace{i_o}^{i_{c1}+i_{c2}}\cdot 2{,}86K\Omega}{v_{b1}} = \frac{-g_{m1}v_{b1}\cdot 2{,}86K\Omega}{v_{b1}} - \frac{g_{m2}v_{b2}\cdot 2{,}86K\Omega}{v_{b1}}$$

$$A_{v2} = \frac{-\beta_1\cdot 2{,}86K\Omega}{r_{\pi1} + \beta_1\cdot\underbrace{(12K\Omega // r_x + r_{\pi2})}_{1{,}12K\Omega}} - \frac{g_{m2}\beta_1\cdot\overbrace{(12K // r_x + r_{\pi2})}^{1{,}12K\Omega}\cdot 2{,}86K\Omega}{r_{\pi1} + \beta_1\underbrace{(12K // r_x + r_{\pi2})}_{1{,}12K\Omega}} = -25{,}7 - 229 = -254{,}7$$



$\Rightarrow C^*_{\mu1} = 511{,}4\,PF$

(3) $A_{v3} = \frac{v_{c2}}{v_{b2}} = \frac{-i_o\cdot 2{,}86K\Omega}{v_{b2}} = \frac{-g_{m1}v_{b1}\cdot 2{,}86K}{v_{b2}} - \frac{g_{m2}v_{b2}\cdot 2{,}86K}{v_{b2}} = -\frac{\overbrace{g_{m1}}^{9{,}2mA/V}\,\overbrace{\beta_1}^{100}\,\overbrace{(12K\Omega // r_x + r_{\pi2})}^{1{,}12K\Omega}}{r_{\pi1} + \beta_1(12K\Omega // r_x + r_{\pi2})} - \overbrace{g_{m2}}^{88mA/V}\cdot 2{,}86K\Omega$

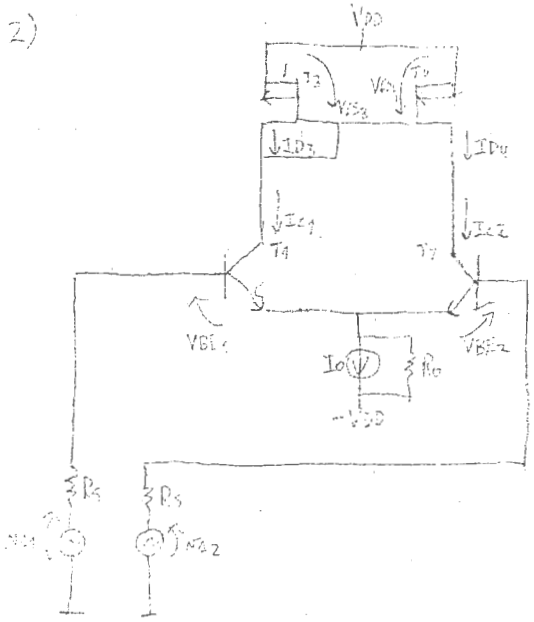
$v_{b2} = v_{b1}$

$A_{v3} = -8{,}37m - 251{,}7 \cong -251{,}7 \Rightarrow C^*_{\mu3} = 505{,}4\,PF$

$\tau_3 = 177\Omega\cdot 551{,}4PF = 97{,}6\,ns \to f = 1{,}63\,MHz$ => el modo dominante sería el 1 y $f_H = 100KHz$

3)

2)



$I_o = 200\,\mu A$

$K' = 100\,\frac{\mu A}{V^2}$

$\frac{W}{L} = 1$

- La tensión de offset, es la tensión de entrada diferencial necesaria para anular la tensión de salida.

Dependiendo de offset total, $I_C = I_S \cdot e^{\frac{V_{BE}}{V_T}}$ / ... $\frac{I_C}{I_S}$ ...

- Para los MOSFET: $I_D = K' \frac{W}{L} (V_{GS} - V_{TH})^2$ (2)

$I_{C1} = I_{D3}$ con factor de capacidad 1 $\Rightarrow$ $I_{D3} = K' \frac{W_3}{L} (V_{GS} - V_{TH})^2$, $I_{D4} = K' \frac{W_4}{L} (V_{GS} - V_{TH})^2$ $\Big\}$ $\frac{I_{D3}}{I_{D4}} = \frac{W_3}{W_4} \Rightarrow \frac{I_{D3}}{W_3} = \frac{I_{D4}}{W_4}$

- $I_C = I_S \cdot e^{\frac{V_{BE}}{V_T}} \Rightarrow \frac{I_C}{I_S} = e^{\frac{V_{BE}}{V_T}} \Rightarrow V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right)$

$V_{OFF} = V_{BE1} - V_{BE2} = V_T \ln\left(\frac{I_{C1}}{I_{S1}}\right) - V_T \ln\left(\frac{I_{C2}}{I_{S2}}\right) = V_T \left(\ln\left(\frac{I_{D3}}{I_{S1}} \cdot \frac{W_3}{L}(V_{GS} - V_{TH})^2\right) - \ln\left(\frac{I_{D4}}{I_{S2}} \cdot \frac{W_4}{L}(V_{GS} - V_{TH})^2\right)\right)$

$V_{OFF} = V_{BE1} - V_{BE2} = V_T \ln\left(\frac{W_3}{I_{S1}} \cdot \frac{I_{S2}}{W_4}\right) = V_T \left(\ln\left(\frac{W_3}{W_4}\right) + \ln\left(\frac{I_{S2}}{I_{S1}}\right)\right)$

- Si $I_{S1} = I_{S2} \Rightarrow V_{OFF} = V_T \ln\left(\frac{W_3 - W_4}{W_4} + 1\right) \cong V_T \cdot \frac{\Delta W}{W_4} = V_T \cdot \delta$

- Si $W_3 = W_4 \Rightarrow V_{OFF} = V_T \ln\left(\frac{I_{S2} - I_{S1}}{I_{S1}} + 1\right) \cong V_T \cdot \frac{\Delta I_S}{I_S} = V_T \cdot \delta$

$\Big\} \Rightarrow V_{OFF} = 2 V_T \delta$

$\searrow$ la ... [illegible]

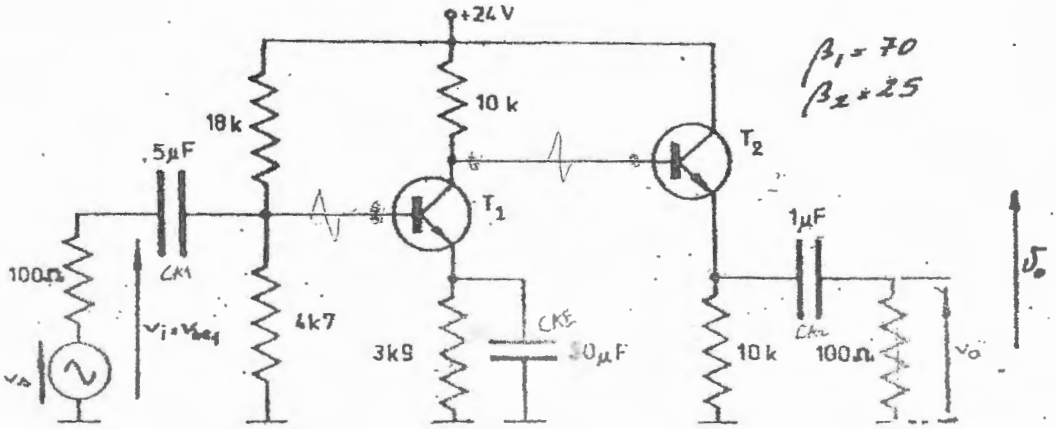
P/ fotocopiar

66.08 – 86.06 Evaluación integradora – 1/2016 - segunda fecha 13/07/16

APELLIDO	NOMBRE	PADRON	TURNO			Nº de HOJAS	Corrección	
				T	N			

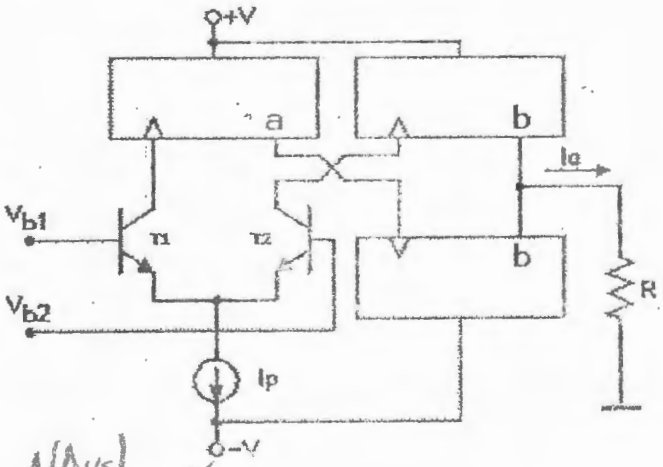
1.-

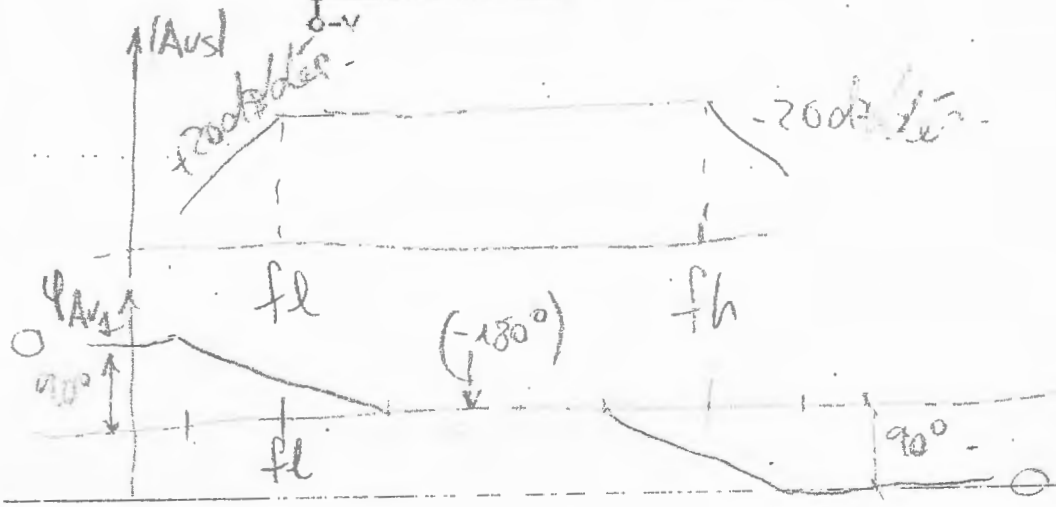
$f_T = 300$ MHz ; $C_\mu = 1$ pF ; $r_x = 100\ \Omega$; $V_A \to \infty$



Obtener los valores aproximados de f_l y f_h. Trazar un diagrama de Bode aproximado de módulo y argumento de A_{vs}.

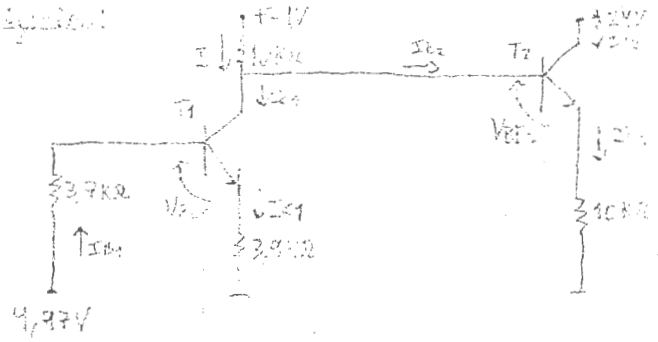
2.- Los bloques representan fuentes espejo de copia "a" y "b", respectivamente. ¿Cuál es el valor de I_{OQ}, si $a = b = 1$?. Obtener la expresión de la transconductancia del circuito $G_{md} = i_o/v_{Id}$ en función de Ip.





① 13/3/16

Polarización:



$f_T = 300\ MHz$
$C_\mu = 1\ pF$
$r_x = 100\ \Omega$
$V_A \to \infty$
$\beta_1 = 70$
$\beta_2 = 25$

(1) $4{,}97V - \frac{I_{C1}}{70} \cdot 3{,}7K\Omega - I_{C1} \cdot 3{,}9K\Omega = 0 \Rightarrow [I_{C1} = 1{,}26\ mA]$

(2) $24V - \left(I_{C1} + \frac{I_{C1}}{\beta_1}\right) \cdot 1{,}5K\Omega - 0{,}7V - I_{C2} \cdot 10K\Omega = 0$

$24V - 12{,}4V - I_{C2} \cdot 1500\Omega - 0{,}7V - I_{C2} \cdot 10K\Omega = 0 \Rightarrow [I_{C2} = 1{,}01\ mA]$

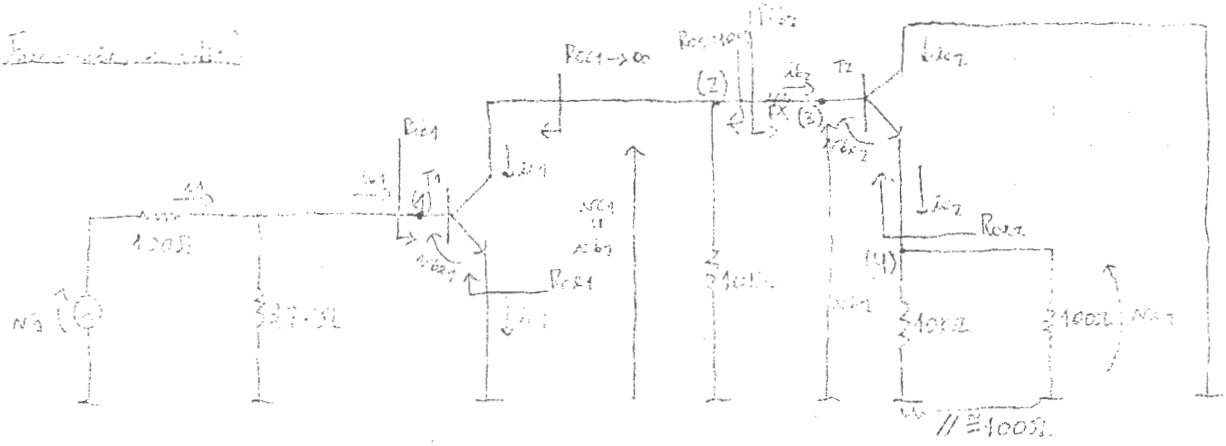
$\Rightarrow$ Parámetros de 1 y 2: $g_{m1} = 50{,}4\ mA/V$ $\quad g_{m2} = 40{,}8\ mA/V$

$\beta_1 = 70$ $\quad r_{\pi1} = 1{,}4K\Omega$ $\quad r_{\pi2} = 617\ \Omega$

$\beta_2 = 25$ $\quad r_{o1} \to \infty$ $\quad r_{o2} \to \infty$

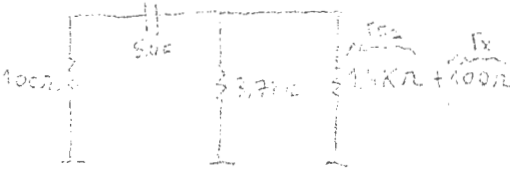
$C_{\pi1} = 28{,}9\ pF$ $\quad C_{\pi2} = 24{,}1\ pF$

Incremental:



Bajas frecuencias: Definir los capacitores C_{A1} y C_{A2}

C_{A1}: R-C equivalente: (Poner CE cortocircuito)



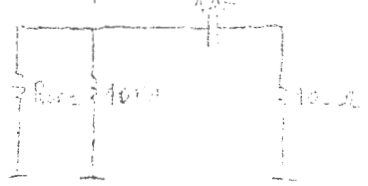
$R_{i1} = r_{\pi1} = 1{,}4K\Omega$

$\therefore Z_{C_{A1}} = 5\mu F\ ((3{,}7K\Omega // 1{,}5K\Omega) + 100\Omega)$

$Z_{C_{A1}} = 5{,}83\ m\Omega$

$f_{C_{A1}} = 27{,}29\ Hz$

C_{A2}: R-C equivalente: (Poner C_{A1} y CE cortocircuito)



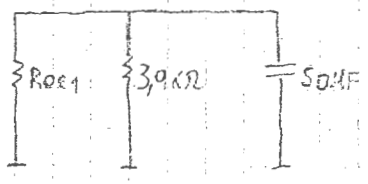
$R_{o2} = \frac{r_{\pi2} + (r_x + R_{o2}//10K\Omega)}{\beta_2} + r_x = 428\ \Omega$

$\therefore Z_{C_{A2}} = 1\mu F\ (428\Omega // 10K\Omega + 100\Omega)$

$Z_{C_{A2}} = 0{,}51\ m\Omega$

$f_{C_{A2}} = 312\ Hz$

(AE) R-C equivalente: (Quito $C_{\mu 1}$ como cada)



$$R_{oe1} = \frac{(100\Omega // 3{,}7K\Omega) + \overbrace{1{,}4K\Omega}^{r_\pi} + \overbrace{100}^{r_x}}{70} = 22{,}81\Omega$$

$\tau_{CAE} = (22{,}81\Omega // 3{,}9K\Omega) \cdot 50\mu F = 1{,}13 ms$

$f_{CAE} = 140 Hz$

• Ninguna f es 10 veces mayor a otra $\Rightarrow \frac{1}{\tau} = \sum_{\forall i} \frac{1}{\tau_i} \Rightarrow \left[f_L = \frac{1}{2\pi\tau} = 480 Hz \right]$

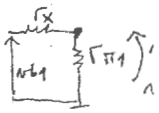
se aproxima

· Altas frecuencias) Influyen las capacidades internas de los dispositivos.

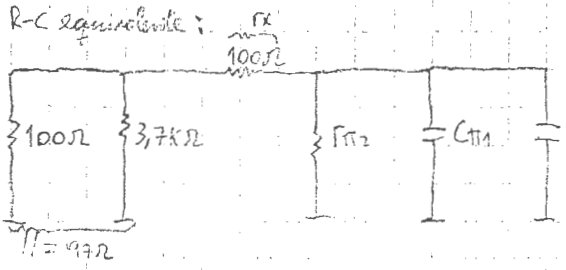
(1) · Reflejo $C_{\mu 1} \Rightarrow A_{v1} = \frac{v_{c1}}{v_{b1}} = -\frac{i_{c1} \cdot (3{,}19K\Omega // 10K\Omega)}{v_{b1}} = -g_{m1} \cdot 2{,}42K\Omega = -122 \Rightarrow C^*_{\mu 1} = C_{\mu 1}(1 - A_{v1})$

(de los otros capacitores)

$R_{ib2} = r_x + r_{\pi 2} + \beta_2 (10K\Omega // 100\Omega) = 3{,}19K\Omega$



R-C equivalente:

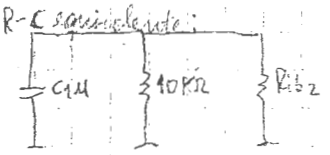


$\tau_1 = (197\Omega // 612\Omega) \cdot (26{,}7pF + 123pF)$

$\tau_1 = 22 ms$

$f_1 = 7{,}23 MHz$

(2) R-C equivalente:

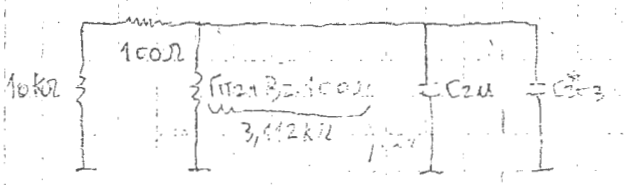


$R_{ib2} = r_{x2} + r_{\pi 2} + \beta_2 \cdot 100\Omega = 3{,}21K\Omega$

$\tau_2 = 2{,}43K\Omega \cdot 1pF = 2{,}43 ns$

$f_2 = 65 MHz$

(3) RC equivalente:



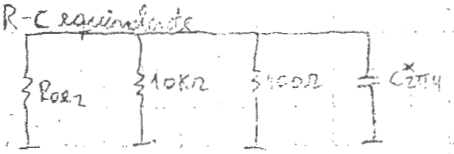
· Reflejo $C_{2\pi} \Rightarrow A_{v2} = \frac{v_{e2}}{v_{b2}} = \frac{\beta_2 \cdot 100\Omega}{r_{\pi 2} + \beta_2 \cdot 100\Omega} = 0{,}8$

$C^*_{2\pi 3} = C_{2\pi}(1 - A_{v2}) = 4{,}32 pF$

$\tau_3 = 2{,}38K\Omega \cdot 5{,}32pF = 12{,}66 ns$

$f_3 = 13 MHz$

(4) R-C equivalente



· Reflejo $C_{2\pi} \Rightarrow A_{v3} = \frac{v_{e2}}{v_{b2}} = \frac{1}{\beta_2} \cdot \frac{\beta_2 \cdot 10K\Omega}{r_{x2} + 10K\Omega + r_{\pi 2}} = 0{,}94$

$C^*_{2\pi 4} = C_{2\pi}(1 - A_{v3}) = 1{,}296 pF$

$R_{oe2} = \frac{10K\Omega + r_{x2} + r_{\pi 2}}{\beta_2} = 428\Omega$

$\tau_4 = 428\Omega \cdot 1{,}296pF = 103{,}7 ps$

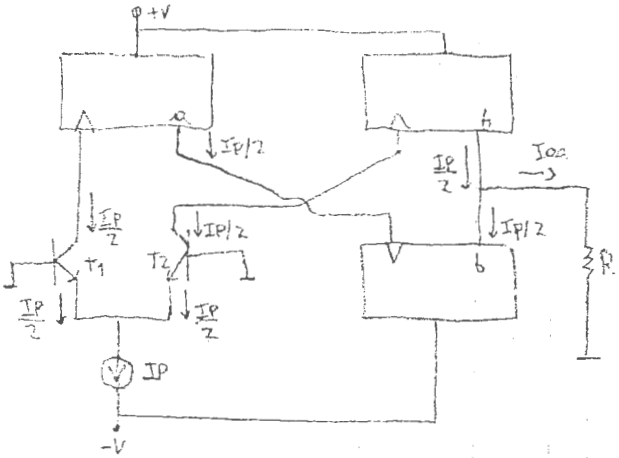
$f_4 = 1{,}54 \times 10^{9} Hz$

· Ninguna f menor 10 veces a las otras $\Rightarrow \tau = \sum \tau_i = 1{,}154 ns \Rightarrow f_H \approx 0{,}5 MHz$

3)

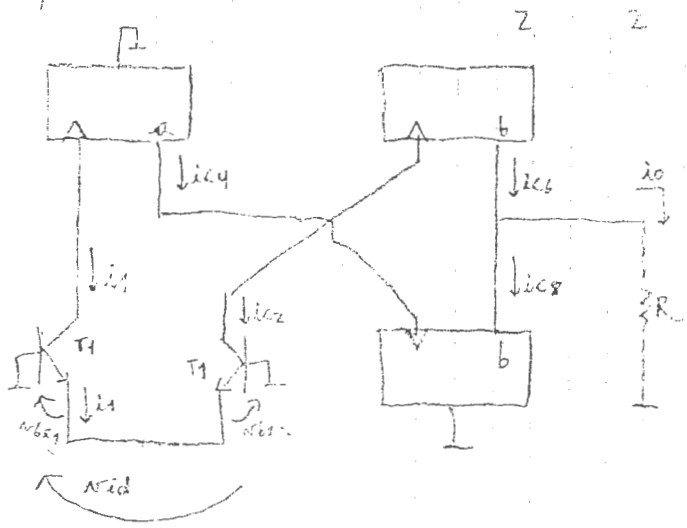
2)

12/7/16



$a = b = 1$

· T_1 y T_2 apareados, $T_1 = T_2 \Rightarrow I_{C1} = I_{C2} = \frac{I_P}{2} \Rightarrow \frac{I_P}{2} + I_{oo} = \frac{I_P}{2} \Rightarrow I_{oo} = 0$ $\left(\underset{g_m}{\underset{\shortparallel}{g_{m1}}} = g_{m2} = \frac{I_P}{2V_T} \right)$



· $v_{be1} = \frac{v_{id}}{2} \Rightarrow i_1 = g_{m1} \cdot v_{be1} = g_{m1} \cdot \frac{v_{id}}{2} \Rightarrow i_{C4} = i_{C1} \Rightarrow i_{C8} = i_{C1} = g_{m1} \cdot \frac{v_{id}}{2}$

· $v_{be2} = -\frac{v_{id}}{2} \Rightarrow i_2 = g_{m2} \cdot v_{be2} = -g_{m2} \cdot \frac{v_{id}}{2} \Rightarrow i_{C2} = i_{C1} = -g_{m2} \cdot \frac{v_{id}}{2}$

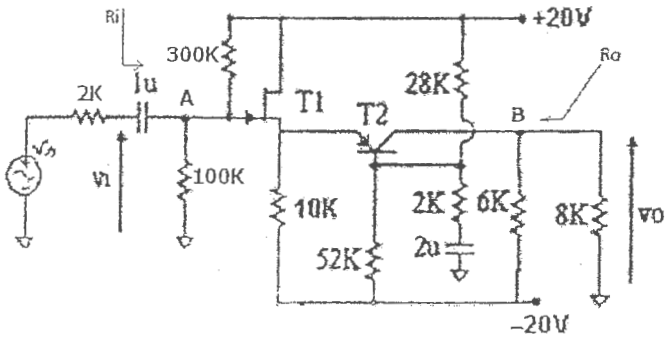
· $i_{C8} + i_o = i_{C4} \Rightarrow i_o = i_{C4} - i_{C8} = \frac{v_{id}}{2} \left(g_{m1} + g_{m2} \right) \overset{\uparrow \sigma(A)}{=} v_{id} \cdot g_m = v_{id} \cdot \frac{I_P}{2V_T}$

$\therefore G_{md} = \frac{i_o}{v_{id}} = \frac{I_P}{2V_T}$

APELLIDO	NOMBRE	PADRON	TURNO		N° de hojas	Corrección	
			T	N			

1.- $\beta = 200$; $V_A \to \infty$; $r_x = 100\Omega$; $I_{DSS} = 12mA$; $V_P = -6V$; r_{gs} y $r_{ds} \to \infty$. $f_T = 200MHz$ $C_d = 1pF$ $C_{gs} = 5pF$ $C_{gd} = 1$

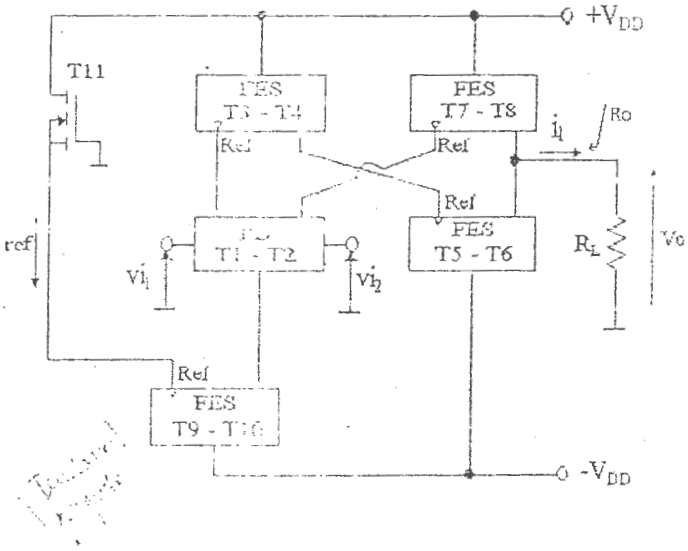
a) Obtener los puntos de reposo de los transistores, indicando las tensiones de sus terminales contra común.



b) Dibujar el circuito de señal sin reemplazar los transistores por su modelo circuital. Obtener *por inspección Ri, Ro,* $Av = v_o/v_i$ y $Av_s = v_o/v_s$.

c) Obtener el valor de la f_l aproximada. Analizar *cualitativamente* cuál podría considerarse el nodo dominante que determine el valor de f_h. Obtener f_h.

d) Se realimenta el circuito conectando una $R = 1M\Omega$ entre A y B. ¿Qué se muestrea y qué suma? ¿La realimentación es positiva o negativa? *Justificar.*



2 - a) Para $v_{i1} = v_{i2} = 0$, hallar todas las tensiones y corrientes de reposo del circuito. Detallar la corrección de I_{DQ} por el T11.

b) Hallar las expresiones y valores de:

$Gm_d = i_l / v_{id} \,|_{vo=0}$

$Gm_c = i_l / v_{ic} \,|_{vo=0}$.

Definir y hallar los valores de R_{id}, R_{ic} y R_o. Obtener $Av_d = v_o/v_{id}$ y $Av_c = v_o/v_{ic}$.

c) Analizar cualitativamente cómo se modifican todos los valores calculados si se reemplaza T9-T10 por una fuente Widlar con $R_E = 100\Omega$.

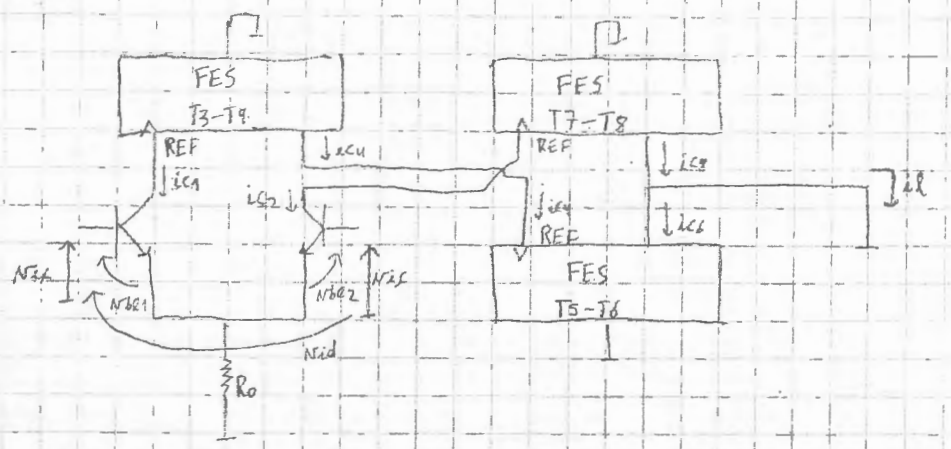
FES: Fuente Espejo Simple – **PD:** Par Diferencial. Todos TBJs (NPN ó PNP, según corresponda)

$\pm V_{DD} = \pm 6V$; $R_L = 1K\Omega$; $\beta = 100$; $V_A = 100V$; $V_T = 2V$; $K' = 100\mu A/V^2$; $W/L = 2$; $\lambda = 0{,}01\ V^{-1}$

②

29/02/16

b)



$g_{m1} = g_{m2} = g_m = 42,8\ mA/V$

$r_{\pi 1} = r_{\pi 2} = r_\pi = 2,34\ K\Omega$

• T_1 y T_2 operando => fuente ceptor bucinicitor.

- Entrada diferencial:

$v_{be1} = \frac{v_{id}}{2} \Rightarrow i_{c1} = g_{m1} \cdot \frac{v_{id}}{2} \Rightarrow i_{c4} = \alpha \cdot i_{c1} = \frac{g_{m1} \cdot \alpha}{2} \cdot v_{id} \Rightarrow i_{c6} = \alpha \cdot i_{c4} = \frac{g_{m1} \cdot \alpha^2}{2} \cdot v_{id}$

$v_{be2} = -\frac{v_{id}}{2} \Rightarrow i_{c2} = -g_{m2} \cdot \frac{v_{id}}{2} \Rightarrow i_{c8} = \alpha \cdot i_{c2} = -\frac{g_{m2} \cdot \alpha}{2} \cdot v_{id}$

$T_1 = T_2 \Rightarrow I_{c1} = I_{c2} \Rightarrow g_{m1} = g_{m2}$

$i_{c8} = i_l + i_{c6} \Rightarrow i_l = i_{c8} - i_{c6} \Rightarrow i_l = -v_{id} \cdot \frac{g_m}{2}(\alpha + \alpha^2)$; $G_{md} = \left.\frac{i_l}{v_{id}}\right|_{v_o=0} = -\frac{g_m}{2}(\alpha + \alpha^2)$

- Entrada común:

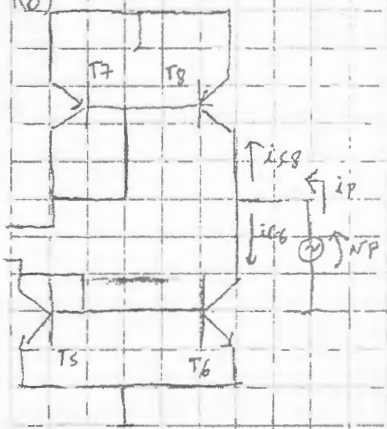
$v_{be1} = v_{ic} \cdot \frac{r_\pi}{r_\pi + B_2 R_e}$ (0,5m) $\Rightarrow i_{c1} = v_{ic} \cdot 0,5m \cdot g_m \Rightarrow i_{c4} = i_{c1} \cdot \alpha \Rightarrow i_{c6} = i_{c4} \cdot \alpha = i_{c1} \cdot \alpha^2 = v_{ic} \cdot 0,5m \cdot \alpha^2 g_m$

$v_{be2} = v_{be1} \Rightarrow i_{c2} = v_{ic} \cdot 0,5m \cdot g_m \Rightarrow i_{c8} = \alpha \cdot i_{c2} = v_{ic} \cdot 0,5m \cdot \alpha \cdot g_m$

$i_l = v_{ic} \cdot 0,5m \cdot g_m(\alpha - \alpha^2) \Rightarrow G_{mc} = \left.\frac{i_l}{v_{ic}}\right|_{v_o=0} = 0,5m \cdot g_m(\alpha - \alpha^2)$

Rid) $R_{id} = \frac{v_{id}}{i_b} = 2r_\pi$ Ric) $R_{ic} = \frac{v_{ic}}{i_b} = r_\pi + B_2 R_e$

Ro)



$R_o = \frac{v_p}{i_p} = \frac{v_p}{i_{c8} + i_{c6}} = R_{oc8} // R_{oc6} = 48\ K\Omega >> R_L \Rightarrow$ Considero toda la corriente por R_L

$\frac{1}{R_o} = \frac{i_{c8}}{v_p} + \frac{i_{c6}}{v_p} = \frac{1}{R_{oc8}} + \frac{1}{R_{oc6}}$

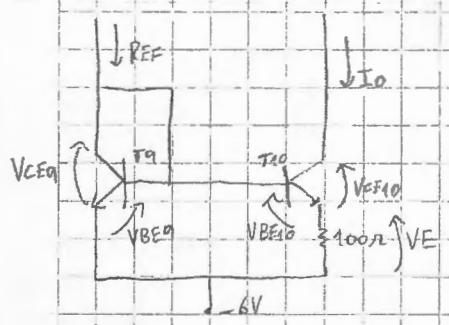
$R_{oc8} = r_{o8} = 95\ K\Omega$
$R_{oc6} = r_{o6} = 97\ K\Omega$ } T6 y T8 emisores comunes sin realimentar

$r_{o8} = \frac{V_A}{I_{c8}} = 95\ K\Omega$ $r_{o6} = \frac{V_A}{I_{c6}} = 97\ K\Omega$

$$A_{vd} = \frac{v_o}{v_{id}}\Big|_{v_{ic}=0} = \frac{1}{v_{id}}\Big(\overbrace{-v_{id}\cdot\frac{g_m}{2}(a+a^2)}^{i_l \text{ con } v_{id}}\Big).R_L = -\frac{\overset{g_{m1}=g_{m2}=42{,}8\,mA/V}{g_m}}{2}\,(\overset{0{,}98}{a}+a^2).\,1K\Omega = -41{,}5\,\Omega$$

$$A_{vc} = \frac{v_o}{v_{ic}}\Big|_{v_{id}=0} = \frac{1}{v_{ic}}\cdot\Big(\overbrace{v_{ic}\cdot 0{,}5\,m(a-a^2)\cdot g_m}^{i_l \text{ con } v_{ic}}\Big).\,1K\Omega = 4{,}19\times10^{-7}$$

C) FUENTE WIDLAR:



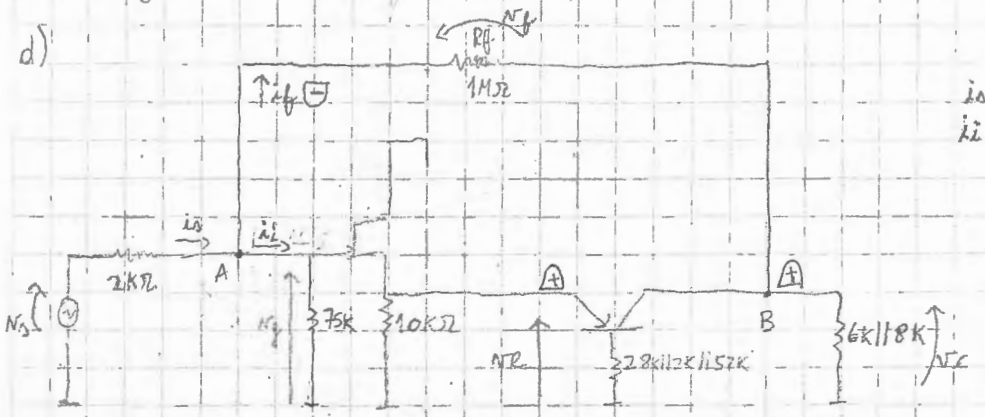
· Al tener una resistencia RE de 100Ω, hay una caída VE que produce una disminución en VBE10, disminuyendo Io, teniendo Io << IR. Por ende IC1 disminuye (por ende IC2), disminuyendo gm1=gm2. Esto hace que tanto Rid aumente y que Avd disminuya.

(1)

29/02/16

1) a), b), c) [illegible] 25/02/15

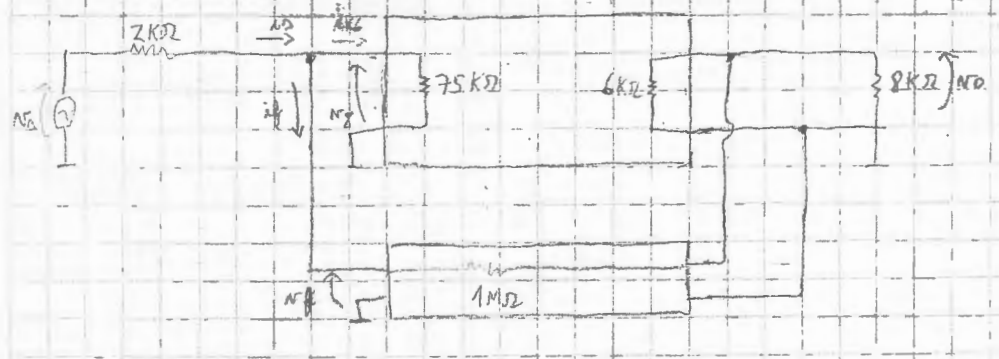
d)



$i_s = i_f + i_i$

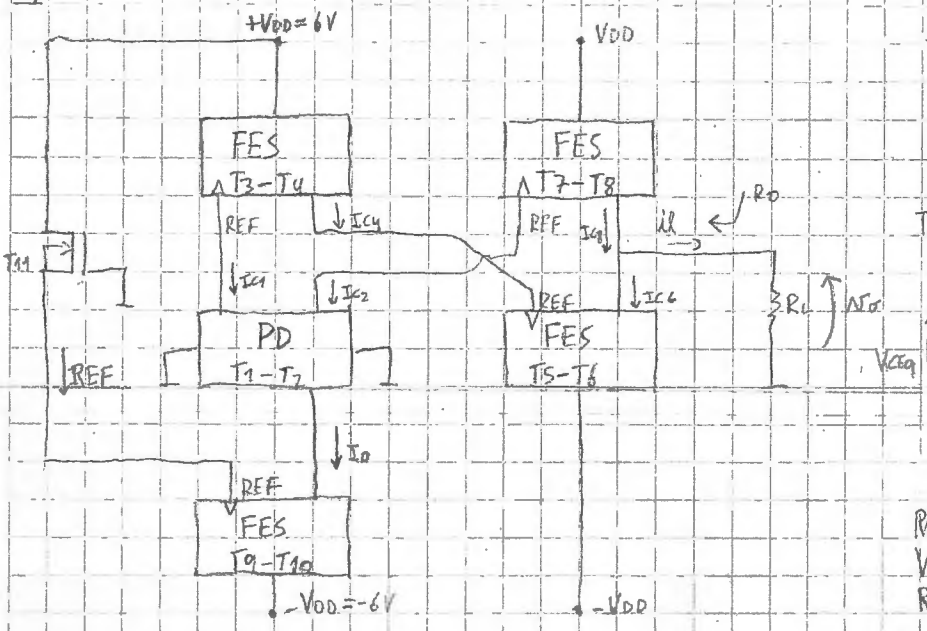
$i_i = i_s - i_f$

$V_g \oplus \Rightarrow V_b \oplus \Rightarrow V_c \oplus \Rightarrow V_c - V_g > 0 \Rightarrow i_f \oplus \Rightarrow i_i = i_s - i_f > i_s \Rightarrow$ [illegible] positiva.



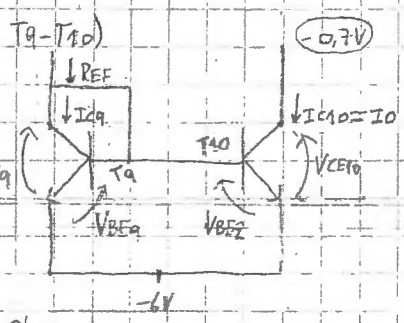
MVSI

2)



a) Se consideran todos los transistores iguales con

$a = \frac{I_C}{I_R} = \frac{\beta}{\beta+2} = 0{,}98$



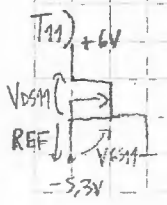
$V_{CE9} \neq V_{CE}$

$I_{REF} = 2{,}18\ mA \Rightarrow I_O = a \cdot I_{REF} = I_{C9} = I_{C10} = 2{,}14\ mA$

$V_{CE9} = 0{,}7V$

$R_O = r_o = \frac{V_A}{I_{CA}} = 47\ K\Omega$

$V_{CE10} = 5{,}3\ V$

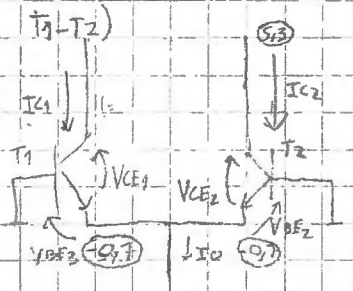


$I_{REF} = 100\ \mu A \cdot 2\,(5{,}3V - 2V)^2 / V^2$

$I_{REF} = 2{,}18\ mA$

$V_{GS11} = 5{,}3V$

$V_{DS11} = 11{,}3V$



$T_1 = T_2 \Rightarrow I_{C1} = I_{C2} = \frac{I_O}{2}$

$I_{C1} = I_{C2} = 1{,}07\ mA$

$V_{CE1} = 6V$

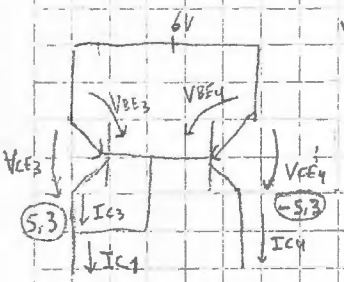
$V_{CE2} = 6V$

T3 - T4)

$I_{C4} = a \cdot I_{C1} = I_{C3} = 1{,}05\ mA$

$V_{CE3} = -0{,}7V$

$V_{CE4} = -11{,}3V$

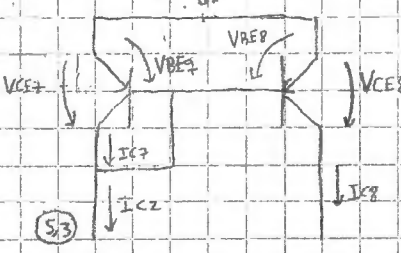


T7 - T8)

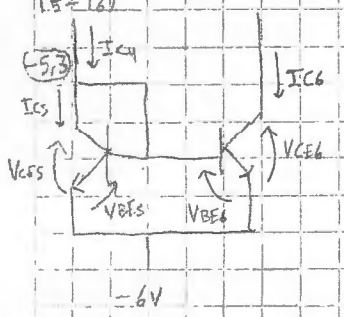
$I_{C7} = I_{C8} = a \cdot I_{C2} = 1{,}05\ mA$

$V_{CE7} = -0{,}7V$

$V_{CE8} \cong -6V$



T5 - T6)



$I_{C6} = I_{C5} = I_{C4} \cdot a = 1{,}03\ mA$

$V_{CE5} = 0{,}7V$

$V_{CE6} \cong 6V$

$I_{C8} = 1{,}05\ mA$

$I_{C6} = 1{,}03\ mA$

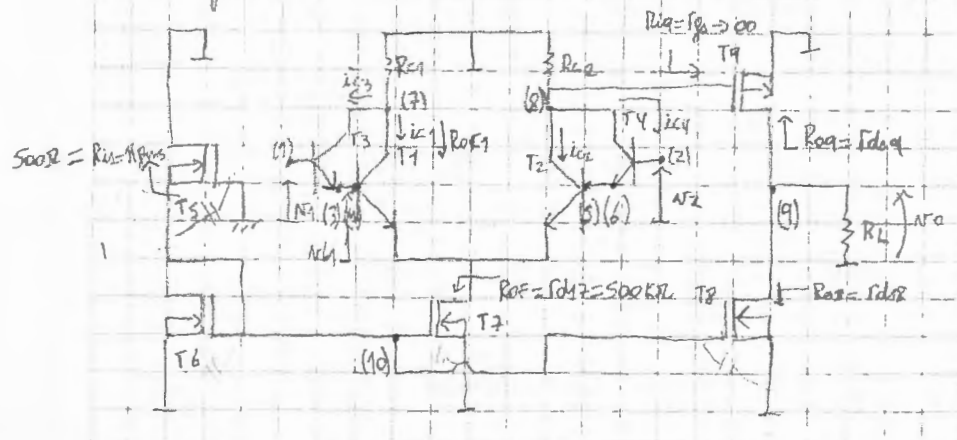
$I_L = I_{C8} - I_{C6} = 0{,}2\ \mu A$

$\Rightarrow V_O = 0{,}2\ mV$

②

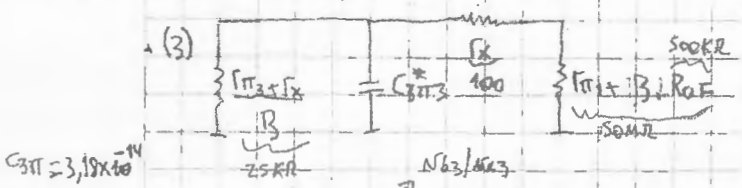
21/12/16

c) Dibujo el circuito en señal



· Los nodos (1) y (2) están a tierra al poner las fuentes => los denuncio.

(3)

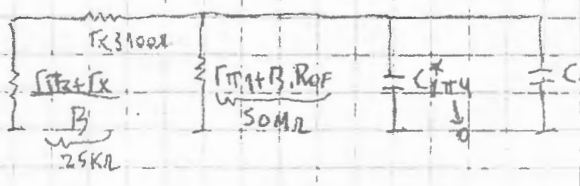


$Z_3 = Z_6 = 3{,}18\times10^{-14}\cdot 25K\Omega = 0{,}795\ ns$

$f_3 = f_6 = 200\ MHz$

$$C^*_{3\pi3} = C_{3\pi}\left(1 - A_{N1}\right) = C_{3\pi}\left(1 - \frac{r_x}{r_x + r_{\pi3}}\right) = 3{,}18\times10^{-14}$$

(4)



$Z_4 = 25K\Omega \cdot 1{,}06\ pF = 0{,}265\ ns = Z_5$

$f_4 = f_5 = 600\ MHz$

· Refleja $C_{1\pi}$ => $A_N = \frac{N_{b1}}{N_{b1}} = \frac{\beta . R_{OF}}{r_{\pi1} + \beta . R_{OF}} = 0{,}99$ => $C_{1\pi}$ casi no se refleja

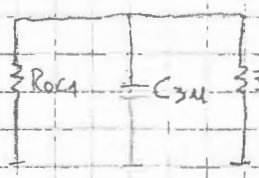
· Refleja $C_{1\mu}$ => $A_N = \frac{N_{c1}}{N_{b1}} = \frac{-(i_{c1}+i_{c3}).30K\Omega}{N_{b1}} \simeq \frac{-g_{m1}v_{be1}.30K\Omega}{N_{b1}} = -\frac{g_{m1}.r_{\pi1}.30K\Omega}{r_{\pi1}+\beta.R_{OF}} = -0{,}06$

$\therefore C^*_{1\mu4} = C_{1\mu}(1 - A_N) = 1{,}06\ pF$

(7) $R_{oc1} = r_{o1}\left(1 + \frac{\beta . R_{OF}}{R_{OF} + r_x + r_{\pi1} + \frac{r_x + r_{\pi3}}{\beta}}\right) = 92\ M\Omega$ (mirar cómo redondeado por arriba)

r_{o1} = 1MΩ, β = 100, R_{OF} = 500K, r_x = 100, $r_{\pi1}$ = 5K, $\frac{r_x + r_{\pi3}}{\beta}$ = 25K

$R_{oc1} >> r_{u3} \times \beta . R_{o3}$



$Z_7 = 1\ pF . 30K\Omega = 0{,}3\ ns$

$f_7 = 5{,}3\ MHz$

(8) Idem (7) pero se nunca la capacidad C_{gd9} y se refleja C_{gd9}

$Z_8 = 30K\Omega\,(3pF + 5pF + 1pF)$

$Z_8 = 0{,}27\ \mu s$

$f_8 = 589\ KHz$

· Refleja C_{gd9} => $A_N = \frac{N_d}{N_g} = -g_{m9}.1K\Omega = -2$ => $C^*_{gd9} = 3pF$

(9)

Por Cgd se refiere, para la ganancia idéntica $A_v = v_d / v_g \to 0$

$Z_9 = 2\,PF \cdot 480\Omega = 1{,}96\,ms$

$f_9 = 81\,MHz$

(10) Se refiere $C_{7gd} \Rightarrow A_v = \frac{v_{d7}}{v_{g7}} = -\underbrace{g_{m7}}_{0{,}89\,mA/V} \cdot \left(\frac{r_{ce}}{R_{eq.2}}\right) = -[illegible] \Rightarrow C^*_{7gd10} = 1{,}22\,PF$

$R_{eq.2} = 250$

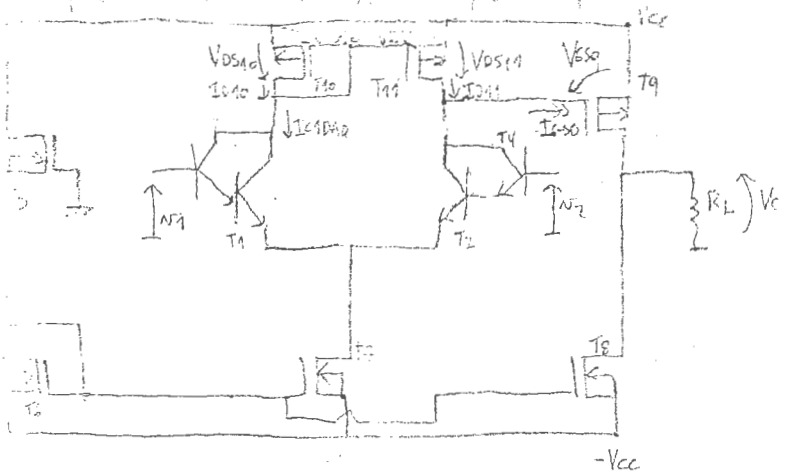
Se refiere $C_{8gd} \Rightarrow A_v = \frac{v_{d8}}{v_{g8}} = -\underbrace{g_{m8}}_{2\,mA/V} \cdot (1K\Omega \,//\, \underbrace{r_{ds8}}_{100K\Omega}) = -1{,}98 \Rightarrow C^*_{8gd10} = 2{,}98\,PF$

$\therefore Z_{10} = \underbrace{\left(\frac{1}{g_{m5}} \,//\, r_{g6} \,//\, r_{g7} \,//\, r_{g8}\right)}_{500\Omega} \cdot \underbrace{\left(C_{g15} + C_{g16} + C_{g17} + C_{g18} + C^*_{7gd10} + C^*_{8gd10}\right)}_{24{,}2\,PF} = 12{,}1\,ms$

$f_{10} = 13\,MHz$

$\therefore f_{H} = 589\,KHz$

d) Se refiere R_{e1} y R_{e2} por fuente seguidor simple PMOSFET



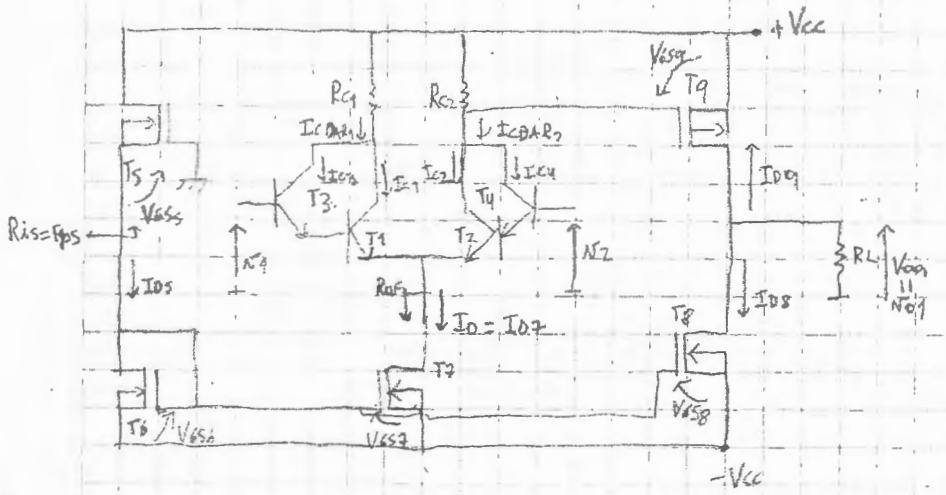
①

21/12/16

$V_{CC}=6V$, $R_{C1}=R_{C2}=30K$, $R_L=10K$

$\beta=100$, $r_x=100$, $V_A=100V$, $f_T=200MHz$
$C_\mu=1PF$

$V_T=\pm 2V$, $k'=1mA/V^2$, $\lambda=0{,}01V^{-1}$
$(W/L)_{5,6}=1$, $(W/L)_7=0{,}2$
$C_{gs}=5PF$, $C_{gd}=1PF$



a) (W/L)9 para Voa = 0V

(1) $-6V+V_{GS6}+V_{GS5}=0$, $I_{D5}=I_{D6} \Rightarrow V_{GS5}=V_{GS6} \Rightarrow V_{GS5}=V_{GS6}=3V \Rightarrow V_{G7}=-3V=V_{G8}$

$\Rightarrow V_{GS8}=3V \Rightarrow I_{D8}=1\frac{mA}{V}\cdot 1(3V-2V)^2=1mA$, para que $V_{oa}=0V \Rightarrow I_{D9}=-I_{D8}$ (A)

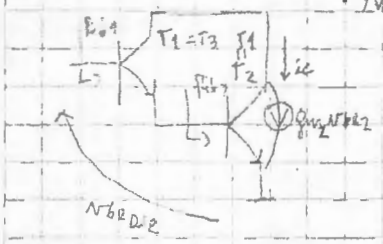
· Veo que se sale I_D, ya que tengo $V_{GS7}=3V \Rightarrow I_{D7}=1\frac{mA}{V}\cdot 0{,}2(3V-2V)^2=0{,}2mA$

· Considerando dos ramas Darlington idénticas $\Rightarrow I_{CDAR1}=I_{CDAR2}=0{,}1mA \Rightarrow V_{G9}=3V \Rightarrow V_{GS9}=-3V$

· Tengo que cumplir (A) $\Rightarrow -1mA=-1\frac{mA}{V^2}\cdot\left(\frac{W}{L}\right)^9(-3V+2V)^2 \Rightarrow \left(\frac{W}{L}\right)^9=1$

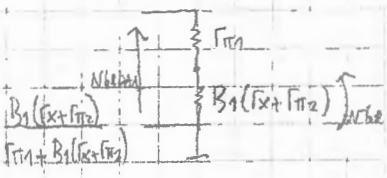
b) Rid, Ric y RRMC en dB

· Armar un Darlington equivalente:



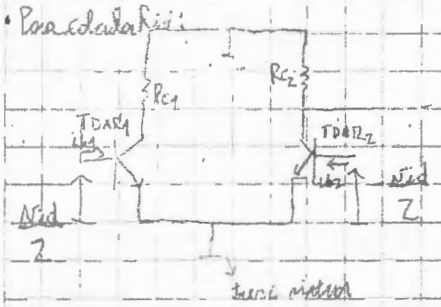
$$\left[r_{\pi eq}=\overset{2}{r_{\pi1}}+\overset{3}{\beta_1}(r_x+\overset{1}{r_{\pi2}})\right]$$

$$g_{m2eq}=\frac{i_c}{v_{be\,DAR}}=\frac{g_{m2}\,v_{be2}}{v_{be\,DAR}}=g_{m2}\cdot\frac{v_{be2}}{v_{be\,DAR}}\cdot\frac{\beta_1(r_x+r_{\pi2})}{r_{\pi1}+\beta_1(r_x+r_{\pi2})}$$



$$\left[g_{meq}=g_{m2}\cdot\frac{\beta_1(r_x+r_{\pi2})}{r_{\pi1}+\beta_1(r_x+r_{\pi2})}\right]\quad\left[\beta_{eq}=g_{meq}\cdot r_{\pi eq}\right]$$

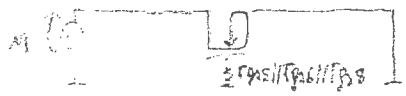
· Para calcular Rid:



$$\left[R_{id}=\frac{v_{id}}{i_{b1}}=2\left(\frac{v_{id}/2}{i_{b1}}\right)=2\,r_{\pi eq}\right]$$

· Ambos Darlington son idénticos

• Para calcular R_{ic}, necesito R_{OF}: $R_{OF} = \frac{v_P}{i_P} = r_{ds7} = \frac{1}{\lambda \cdot I_{D7}}$



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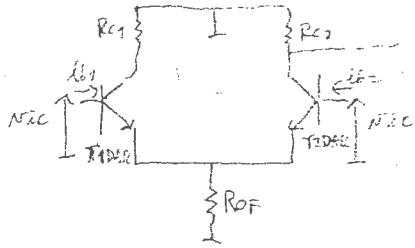
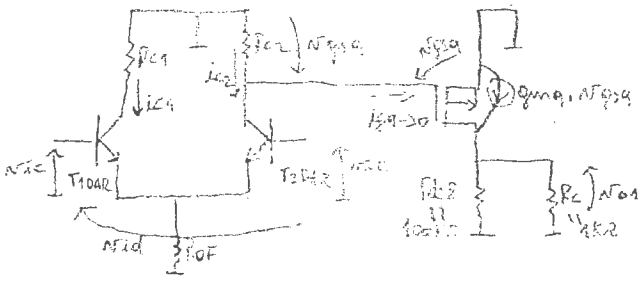


$$R_{ic} = \frac{v_{ic}}{i_{b1}} = r_{\pi eq} + \beta_{eq} \cdot 2R_{OF} \qquad r_{ds7} = 500\,k\Omega$$

• Para calcular la RRMC: $\left[RRMC = \left| \frac{A_{vd}}{A_{vc}} \right| = \frac{g_{m1} \cdot g_{meq} \cdot R_{c2} \cdot 1k\Omega}{2} \cdot \frac{r_{\pi eq} + \beta_{eq} \cdot 2R_{OF}}{g_{m1} \cdot g_{meq} \cdot r_{\pi eq} \cdot R_{c2} \cdot 1k\Omega} = \frac{r_{\pi eq} + \beta_{eq} \cdot 2R_{OF}}{2 r_{\pi eq}} \right]$

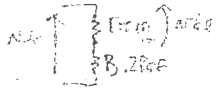
• En vd:



$$A_{vd} = \frac{v_{o1}}{v_{id}}\Big|_{v_{ic}=0} = \frac{g_{m1} \cdot v_{p1a} \cdot 1k\Omega}{v_{id}} = \frac{-g_{m1} \cdot i_{c2} \cdot R_{c2} \cdot 1k\Omega}{v_{id}} = \frac{-g_{m1} \cdot g_{meq} \cdot v_{id} \cdot R_{c2} \cdot 1k\Omega}{2 \cdot v_{id}}$$

$$\left[A_{vd} = \frac{g_{m1} \cdot g_{meq} \cdot R_{c2} \cdot 1k\Omega}{2} \right]$$

$$A_{vc} = \frac{v_{o1}}{v_{ic}}\Big|_{v_{id}=0} = \frac{g_{m1} \cdot v_{p1a} \cdot 1k\Omega}{v_{ic}} = \frac{-g_{m1} \cdot i_{c2} \cdot R_{c2} \cdot 1k\Omega}{v_{ic}} = \frac{-g_{m1} \cdot g_{meq} \cdot v_{b32} R_{c2} \cdot 1k\Omega}{v_{ic}}$$



$$A_{vc} = \frac{1}{v_{ic}} \cdot -g_{m1} \cdot g_{meq} \cdot v_{ic} \cdot \frac{r_{\pi eq}}{r_{\pi eq} + \beta_{eq} \cdot 2R_{OF}} \cdot R_{c2} \cdot 1k\Omega$$

$$v_{b32} = v_{ic} \cdot \frac{r_{\pi eq}}{r_{\pi eq} + \beta_{eq} \cdot 2R_{OF}}$$

$$\left[A_{vc} = -g_{m1} \cdot g_{meq} \cdot \frac{r_{\pi eq}}{r_{\pi eq} + \beta_{eq} \cdot 2R_{OF}} \cdot R_{c2} \cdot 1k\Omega \right]$$

• VALORES NUMERICOS: Como $I_{C1} = I_{C2} = I_{CQAR1} = I_{CQAR2} = 0{,}1\,mA \Rightarrow g_{m1} = g_{m2} = 4\,mA/V \Rightarrow r_{\pi1} = r_{\pi2} = 25\,k\Omega$

$I_{B3} = I_{B4} = 1\,\mu A \Rightarrow g_{m3} = g_{m4} = 40\,\mu A/V \Rightarrow r_{\pi3} = r_{\pi4} = 2{,}5\,M\Omega$

• Darlington equivalente: $r_{\pi eq\,DAR1} = r_{\pi eq\,DAR2} = r_{\pi3} + \beta_3 (r_x + r_{\pi1}) = 5{,}01\,M\Omega = r_{\pi eq}$

$$g_{meq\,DAR1} = g_{meq\,DAR2} = g_{m1} \cdot \frac{\beta_3 (r_x + r_{\pi1})}{r_{\pi3} + \beta_3 (r_x + r_{\pi1})} = 2\,\frac{\mu A}{V} = g_{meq}$$

$$\beta_{eq} = r_{\pi eq} \cdot g_{meq} = 10020$$

$g_{m1} = 2\,mA/V$

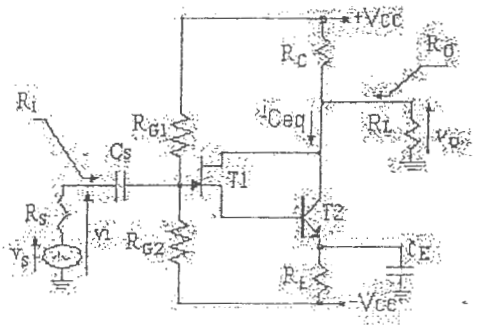
• $\left[R_{id} = 2 \cdot r_{\pi eq} = 10{,}02\,M\Omega \right]$ $\left[R_{ic} = r_{\pi eq} + \beta_{eq} \cdot 2R_{OF} = 1{,}01 \times 10^{11}\,\Omega \right]$ $\left[A_{vd} = 60 \right]$ $\left[A_{vc} = 0{,}06 \right]$ $\left[RRMC = 1000 \right] \rightarrow$ en dB, RRMC = 60 dB

Para Fotocopiar

66.08 - 86.06 Evaluación integradora 2014/2- cuarta fecha - 18/02/15

APELLIDO	NOMBRE	PADRON	TURNO			N° de hojas	Corrección	
			M	T	N			

1.- Admitiendo que ambos transistores (de bajo nivel de potencia) se encuentran en modo activo, se conocen todos sus parámetros (de valores típicos), los valores de los resistores y capacitores y V_{CC}:

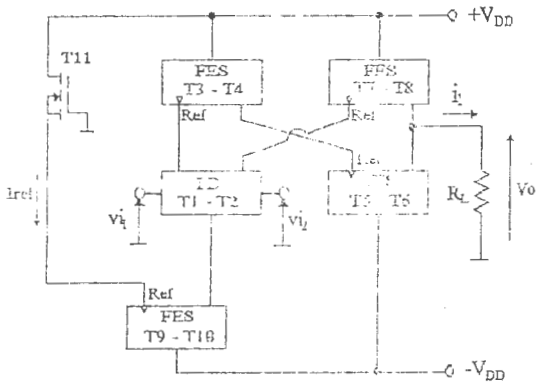


a) Si V_{CC} es del orden de 10 V, R_C y R_L de algunos KΩ y R_E de cientos de Ω, ¿podría estimarse un valor ***aproximado*** de V_{GSQ} sin cálculo previo?. ***Justificar.*** Si V_{OQ} = 0V, justificar qué relación deberían tener entre sí los resistores del divisor de gate para funcionamiento en modo activo (cuál es mayor)

b) Hallar la expresión por inspección, justificando el procedimiento de la relación de pequeña señal $i_{ceq}/v_i|_{Vce(eq)=0}$ a frecuencias medias.

c) Explicar por qué el uso del modelo equivalente del darlington no resulta válido para el cálculo de la respuesta en alta frecuencia de este circuito. Justificar por qué sí resulta válido para el cálculo de la respuesta en baja frecuencia.

2 - a) Para $v_{i1} = v_{i2} = 0$, hallar todas las tensiones y corrientes de reposo del circuito, incluyendo I_{CQ}. Despreciar la corrección de I_{DQ} por el λ.



b) Hallar las expresiones y valor de:

$Gm_d = i_l/v_{id}\ |_{vo=0}$

$Gm_c = i_l/v_{ic}\ |_{vo=0}$

Definir y hallar la expresión de la R_o vista por la carga. Obtener su valor. Definir y obtener $A_{vd} = v_o/v_{id}$.

c) Definir y hallar el rango de tensión de modo común.

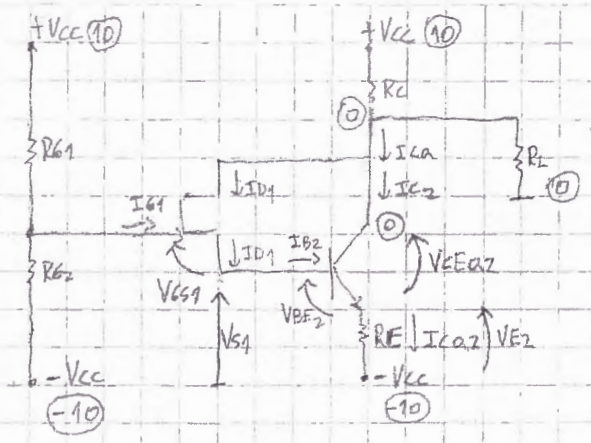
FES: Fuente Espejo Simple – **PD:** Par Diferencial. Todos los MOSFET son iguales (canal N ó P según corresponde)

$\pm V_{DD} = \pm 6V$, $|V_T| = 2V$; $|K'| = 100\mu A/V^2$; $W/L = 2$; $\lambda = 0{,}01\ 1/V$; $\gamma \cong 0$; $R_L = 10K\Omega$.

①

18/02/15

1) a)



· Debe conocer la relación entre R_{G1} y R_{G2} para dar un valor aprox. de V_{GS1}

· Si $V_{GS1} = 0 \Rightarrow I_{CQ} = \frac{V_{CC}}{R_C} \sim 30 \text{ a } 5\,mA$

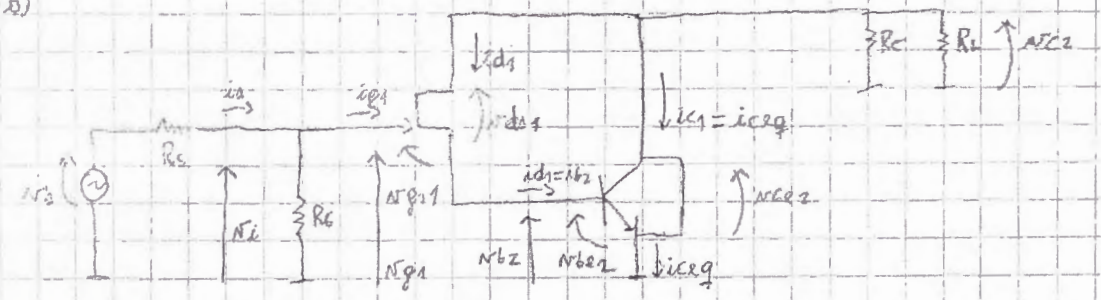
$I_{C2} >> I_{D1}$, $I_{C2} = \beta \cdot I_{D1}$ $\therefore I_{CQ} \approx I_{C2}$

$\Rightarrow |V_{E2}| = I_{CQ} \cdot \underset{\sim 100\Omega}{R_E} \Rightarrow \sim 0{,}3V \text{ a } 0{,}5V$

$\therefore V_{S1} \sim -9V \text{ a } -8{,}8V$

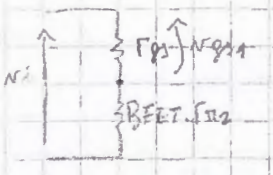
· $V_{GG} = -10V + \frac{20V}{R_{G1}+R_{G2}} \cdot R_{G2}$, R_{G1} debe ser mayor ya que por ser canal N, $V_T < 0$ y como $V_{S1} \sim -9V \Rightarrow V_G$ debe ser más negativo $\therefore R_{G1} > R_{G2}$

b)



$i_{cxq} = g_{m2} \cdot v_{be2}$

$v_{be2} = i_{d1} \cdot r_{\pi 2} = g_{m1} \cdot v_{gs1} \cdot r_{\pi 2} = \frac{g_{m1} \cdot r_{\pi 2}}{1 + g_{m1} \cdot r_{\pi 2}}$



$v_{gs1} = \frac{v_i \cdot r_{gs}}{r_{gs} + R_{FET} \cdot r_{\pi 2}} = \frac{v_i}{1 + g_{m1} \cdot r_{\pi 2}}$

$\cancel{i_{cxq} = \frac{g_{m2} \cdot g_{m1} \cdot r_{\pi 2} \cdot v_{gs1}}{1 + g_{m1} \cdot r_{\pi 2} \cdot r_{\pi 2}} \Rightarrow \frac{i_{cxq}}{v_i} = \frac{g_{m2} \cdot g_{m1} \cdot r_{\pi 2} \cdot r_{\pi 2}}{1 + g_{m1} \cdot r_{\pi 2} \cdot r_{\pi 2}}}$

$\frac{i_{cxq}}{v_i} = \frac{g_{m2} \cdot g_{m1} \cdot r_{\pi 2} \cdot r_{\pi 2}}{1 + g_{m1} \cdot r_{\pi 2} \cdot r_{\pi 2}}$

c) c)

2) Hecho en 29/02/16; menos el punto d) (ver enunciado de esa fecha para leerlo)

c) El rango de tensiones para que los transistores sigan en MAD es lo que se denomina rango de modo común

$$\underbrace{-6V + V_{CE10(sat)} + V_{BE2}}_{\text{satura } T_{10}} \leq V_{ic} < \underbrace{6V + V_{CE7a}}_{\text{satura } T_2}$$

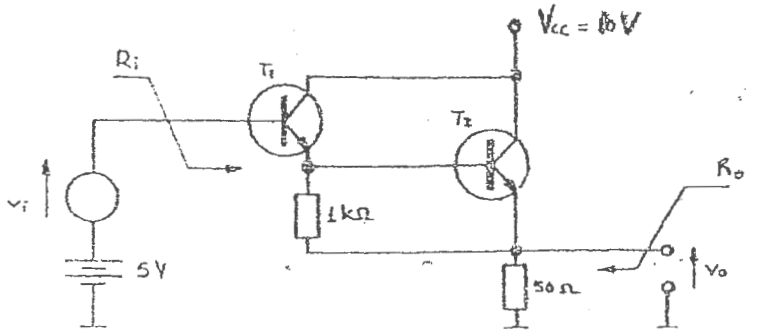
66.08 – 3606 **Evaluación Integradora 2014/2 - tercera fecha – 11/02/15**

APELLIDO	NOMBRE	PADRON	TURNO			Nro. de HOJAS	Corrección	
			M	T	N			

1.- Para el siguiente circuito, donde v_i y la fuente de 5V representan la tensión que entrega la etapa anterior a la indicada en la figura (cc + señal), calcular (suponiendo $\beta = 200$; $r_x \to 0$; $V_A \to \infty$; $f_T = 300MHz$; $C_\mu \cong 1$ pF):

a) Los puntos de reposo. Las expresiones ***por inspección*** y sus valores, de las resistencias de entrada y salida, y la amplificación de tensión $A_v = v_o/v_i$.

b) Justificar en qué valor podría estimarse la frecuencia de corte superior de esta etapa. ¿Qué utilidad tiene esta etapa?.



2.- Dibujar el circuito de un par acoplado por source con NMOSFET inducidos (T_1-T_2), polarizado mediante una fuente cascode con MOSFET (T_5-T_6 y T_7-T_8), de R_{ref} = 20 KΩ conocida y carga activa espejo simple, también con MOSFET (T_3-T_4), alimentado todo entre $\pm V_{DD} = \pm 12$ V. **Los transistores son idénticos** y se conocen todos sus parámetros ($|V_T| = 1$ V ; $|k'| = 1$ mA/V^2 ; W/L = 1 ; $\lambda = 0{,}01$ V^{-1})

a) Obtener los puntos de reposo, justificando por inspección el valor de la tensión de salida V_{OQ}.

b) Obtener *por inspección*, justificando el procedimiento, el valor de las amplificaciones de tensión para modo diferencial y común para la salida simple convencional. Definir y obtener la RRMC en veces y en dB. ¿Cómo influyen los desapareamientos en su valor?.

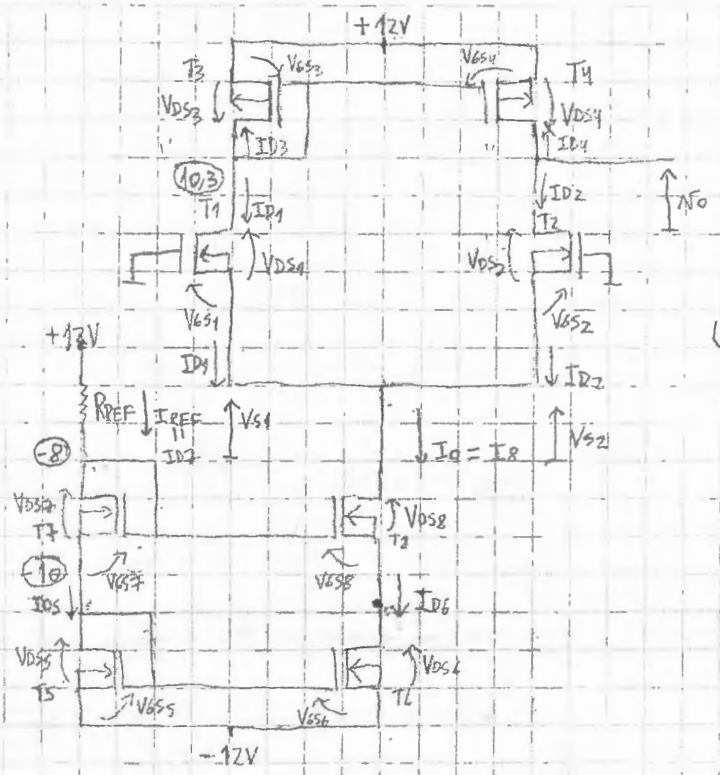
c) Obtener el rango de tensión de modo común. ¿Cuál es su utilidad?.

d) Definir y obtener la tensión de Offset para un desapareamiento entre $W_{(T1)}$ y $W_{(T2)}$ del 2%.

①

2)

a)



11/02/15

Fuente de corriente cargada:

$V_{GS5} = V_{GS7}$ (idem I)

(1) $-12V + V_{GS5} + V_{GS7} + I_{D7} \cdot R_{REF} - 12V = 0$

$2V_{GS7} - 24V + I_{D7} \cdot R_{REF} = 0$

$V_{GS7} = 12V - I_{D7} \cdot 10K\Omega$

(2) $I_{D7} = K' \frac{W}{L} (V_{GS7} - V_T)^2$

$I_{D7} = 1m\,(11V - I_{D7} \cdot 10K\Omega)^2$

$0 = 0{,}121 - I_D \cdot 22 + I_D^2 \cdot 100K$

$I_{D7} = 1mA \Rightarrow V_{GS7} = 2V > V_T$

$I_{D7} = 1{,}21mA$ X

PUNTO a) $I_{DS} = I_{D6} = I_{D7} = I_{D8} = 1mA$ (fuente de corriente ideal)

$V_{GS7} = 2V = V_{GS5} = V_{GS6} = V_{GS5}$

$V_{DS7} = V_{DS5} = V_{DS6} = 2V$

$V_{DS8} = 8{,}3V$

fuente ideal

· Por T1 y T2 la mitad de $I_8 \Rightarrow I_{D1} = I_{D2} = 0{,}5mA \Rightarrow$ hay el V_{GS} que permite esta corriente

$I_D = 0{,}5mA = 1\frac{mA}{V} \cdot 1 \cdot (V_{GS} - 1V)^2 \Rightarrow V_{GS1} = V_{GS2} \cong 1{,}7V \Rightarrow V_{S1} = V_{S2} = -1{,}7V$

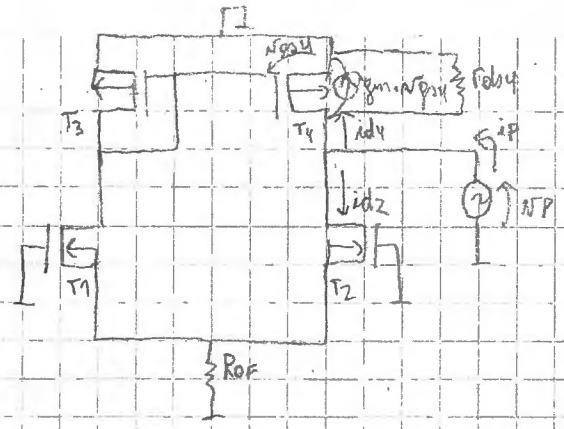
· Por T3 y T4 misma corriente $\Rightarrow -0{,}5mA = -1\frac{mA}{V} \cdot 1\,(V_{GS} + 1V)^2 \Rightarrow V_{GS3} = V_{GS4} \cong -1{,}7V$

· $V_{D1} = V_{D2}$, idem, se llega a un absurdo $\Rightarrow V_{DS3} = V_{DS4} = -1{,}7V$

$V_{DS1} = V_{DS2} = 12V$

$\therefore V_{Oa} = 10{,}3V$

b)



$$R_o = \frac{v_P}{i_P} = \frac{v_P}{i_{d2}+i_{d4}} \Rightarrow \frac{1}{R_o} = \frac{i_{d2}}{v_P} + \frac{i_{d4}}{v_P} = \frac{1}{R_{o2}} + \frac{1}{R_{o4}}$$

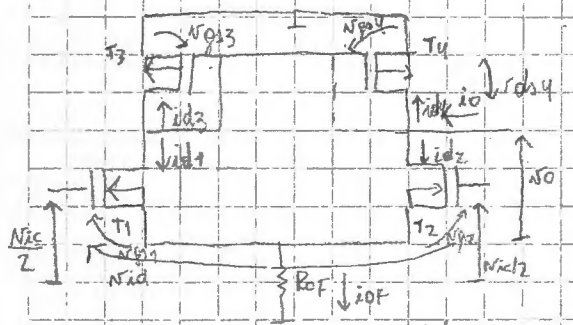
$\therefore R_o = R_{o2} // R_{o4}$

$$R_{o2} = r_{ds2}\left(1 + g_{m2}\left(R_{OF} // \underbrace{1/g_{m2}}_{=g_{m2}}\right)\right) = 2 \cdot r_{ds2}$$

$$R_{o4} = r_{ds4} // \left(\overbrace{\frac{v_P}{i_{d2}}}^{R_{o2}}\right) = r_{ds4} // 2 r_{ds2}$$

$$r_{ds2} = r_{ds4} = \frac{1}{\lambda \cdot I_{DQ}}$$

$$\therefore R_o = 2r_{ds2} // 2r_{ds2} // r_{ds4} = r_{ds2} // r_{ds4} \approx \frac{r_{ds}}{2}$$



Entrada diferencial:

$$v_{gs1} = \frac{v_{id}}{2} \Rightarrow i_{d1} = g_{m1} \cdot \frac{v_{id}}{2} = -i_{d3} = -i_{d4} \Rightarrow i_{d4} = -g_{m1}\frac{v_{id}}{2}$$

$$v_{gs2} = -\frac{v_{id}}{2} \Rightarrow i_{d2} = -g_{m2} \cdot \frac{v_{id}}{2}$$

$$i_o = -\frac{v_{id}}{2}(g_{m1} + g_{m2}) \Rightarrow v_o = +\frac{v_{id}}{2}(g_{m1} + g_{m2}) \cdot R_o$$

Bajia unitaria => corto circuito en V_{GD4}

$$A_{vd} = \left.\frac{v_o}{v_{id}}\right|_{v_{ic}=0} = \frac{g_{m1} + g_{m2}}{2} \cdot R_o = g_m \cdot R_o$$

$g_m = g_{m1} = g_{m2}$

$I_D = K(V_G$

$\sqrt{\frac{I_D}{K}} + V_T =$

Entrada común:

$$A_{vc} = \left.\frac{v_o}{v_{ic}}\right|_{v_{id}=0} = \frac{v_{gs3}}{v_{ic}} = \frac{i_{d1} \cdot r_{d3}}{i_{d1} \cdot r_{d1} + \underbrace{i_{OF}}_{i_{d1}+i_{d2}} \cdot \underbrace{R_{OF}}_{\gg r_{d1}}} \approx \frac{r_{d3}}{2R_{OF}}$$

T_3 carga con r_{d3} a T_1

$$RRMC = \left|\frac{A_{vd}}{A_{vc}}\right| = \frac{2R_{OF} \cdot g_m \cdot R_o}{r_{d3}}, \quad 20\log(RRMC) = 20\log\left(\frac{2 \cdot R_{OF} \cdot g_m \cdot R_o}{r_{d3}}\right)$$

c) Saturan los transistores de la fuente de corriente: $-12V + V_{DSE6} + V_{DSE8} + V_{ic} = 0$

$V_{ic} = 12V - V_{DSE6} - V_{DSE8}$

· Saturan $T_2 \Rightarrow V_{GD} < V_T \Rightarrow V_{ic} - (V_{DD} + V_{DS4}) < V_T$

$V_{ic} < V_T + V_{DD} + V_{DS4}$

$\therefore 12V - V_{DSE6} - V_{DSE8} < V_{ic} < V_T + V_{DD} + V_{DS4}$ => Rango de tensiones que se pueden aplicar para que todos los transistores sigan en MAD, se supone que no salen los valores de regreso.

d) $$V_{OFF} = V_{GS1} - V_{GS2} = \sqrt{\frac{I_D \cdot L}{K' W_1}} - \sqrt{\frac{I_D \cdot L}{K' W_2}} = \sqrt{\frac{I_D \cdot L}{K'}}\left(\frac{1}{\sqrt{W_1}} - \frac{1}{\sqrt{W_2}}\right) = \sqrt{\frac{I_D \cdot L}{K' W_1}}\left(1 - \sqrt{\frac{W_1}{W_2}}\right)$$

$$= \sqrt{\frac{I_D \cdot L}{K' W_1}}\left(1 - \sqrt{\underbrace{\frac{W_1 - W_2}{W_2} + 1}_{\text{pequeño } \alpha}}\right) = \sqrt{\frac{I_D \cdot L}{K' W_1}}\left(\cancel{1} - \cancel{1} - \frac{\alpha}{2}\right) \Rightarrow V_{OFF} = -\sqrt{\frac{I_D \cdot L}{K' W_1}} \cdot \frac{\alpha}{2}$$

$\sqrt{1+\alpha} \approx 1 + \frac{\alpha}{2}$

65.08 - 86-06

Evaluación integradora - 1/2014 - quinta fecha 01/08/14

APELLIDO	NOMBRE	PADRON	TURNO			Nº de HOJAS	Corrección
			M	T	N		

1.-

$$\beta = 100 \; ; \; f_T = 300 \text{ MHz} \; ; \; C_\mu = 2 \text{ pF} \; ; \; r_x = 100\,\Omega \; ; \; V_A = 100\text{V}$$

$$(W/L)_{1,2} = 1 \; ; \; k' = 0{,}1 \text{ mA/V}^2 \; ; \; V_{Th} = 1 \text{ V} \; ; \; \lambda = 0{,}01 \text{ V}^{-1} \; ; \; C_{gs} = 5 \text{ pF} \; ; \; C_{gd} = 2 \text{ pF}$$

$$V_{CC} = 5\text{V} \; ; \; R_{ref} = 1 \text{ K}\Omega \; ; \; R_E = 470\,\Omega \; ; \; R_L = 1 \text{ K}\Omega$$

a) Obtener los puntos de reposo, implementando los bloques de fuentes espejo con MOSFETs de canal inducido cuyas características son:

$(W/L)_{3,4,5,7} = 1$; $(W/L)_{6,8} = 50$

$|k'| = 0{,}1 \text{ mA/V}^2$; $|V_{Th}| = 1\text{V}$; $\lambda = 0{,}01 \text{ V}^{-1}$; $C_{gs} = 5\text{pF}$; $C_{gd} = 1\text{pF}$

¿Qué utilidad y características posee la fuente T9-T10 frente a una espejo?.

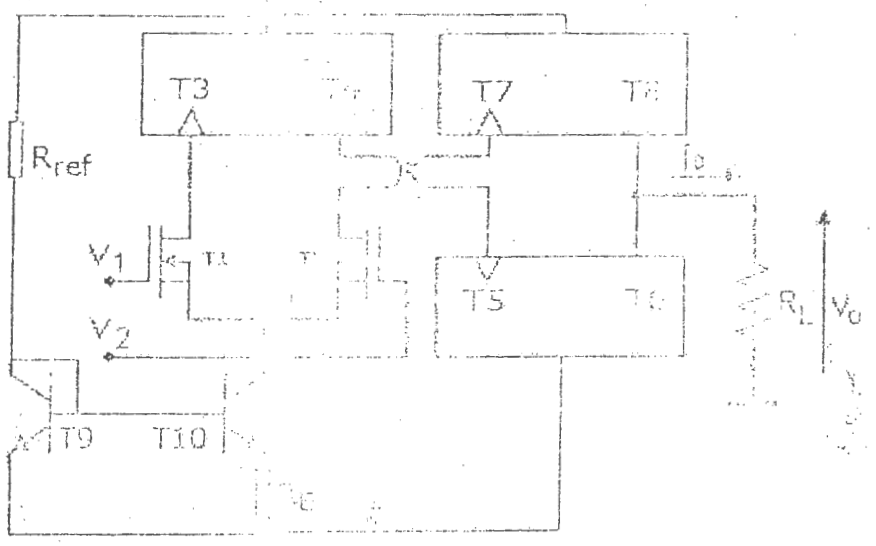
b) Dibujar el circuito de señal, sin reemplazar los transistores por su modelo. Definir y obtener el valor de R_{Id}, R_o y la transconductancia del circuito para modo diferencial. Obtener A_{vd}. ¿Cuál es el valor aproximado de la transconductancia de modo común? ¿Por qué su valor depende fuertemente de los desapareamientos de componentes en cada bloque (par diferencial o fuente espejo)?

c) Obtener el valor aproximado de f_h para A_{vd}.

d) Obtener la frecuencia de corte impuesto por la fuente T9-T10 para modo común. ¿Cuál es la importancia de esta frecuencia?

e) Obtener el valor de la tensión de offset si: $(W/L)_1 = 0{,}93.(W/L)_2$

f) Definir y obtener el rango de tensión de modo común.



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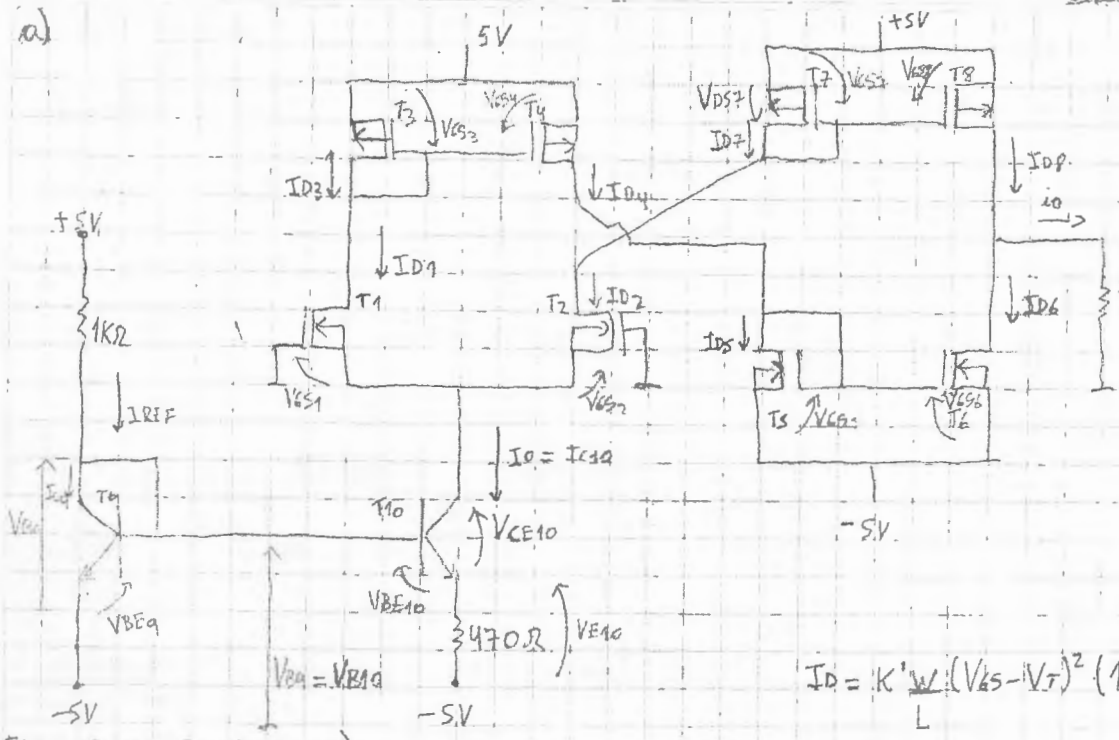
01/08/14

a)



$I_o = I_{D8} - I_{D6} = 0$

$V_o = 0V$

$$I_D = K'\frac{W}{L}(V_{GS}-V_T)^2(1+\lambda V_{DS})$$

FUENTE DE CORRIENTE)

Malla IREF: $-5V + 0{,}7V + I_{REF}\cdot 1K\Omega - 5V = 0 \Rightarrow I_{REF} = 9{,}3mA$, es una fuente de corriente

Malla $\Rightarrow$ $I_o \cdot R_E = V_T \ln(I_R/I_o) \Rightarrow I_o \cdot 470\Omega = 25mV \cdot \ln(9{,}3mA/I_o)$

$[I_o = 203\mu A] \Rightarrow 0{,}095 \cong 0{,}095$

PUNTO Q: $V_{C9} = -4{,}3V = V_{B9}$ $\quad V_{B10} = -4{,}3V$ $\quad V_{C10} = V_{S4} = V_{S3} = -2V$

$V_{E9} = -5V$ $\quad V_{E10} \cong -4{,}9V$

$I_{C9} \approx I_{REF} = 9{,}3mA$ $\quad I_b = I_{C10} = 203\mu A$

PAR DIFERENCIAL) T1 y T2 idénticos $\Rightarrow$ por cada rama circula $I_o/2 = 101{,}5\mu A = I_{D1} = I_{D2}$

$I_D = K'\frac{W}{L}(V_{GS}-V_T)^2 \Rightarrow \sqrt{\frac{I_D}{K'\frac{W}{L}}} + V_T = V_{GS}$; $I_{D1} = I_{D2} \Rightarrow V_{GS1} = V_{GS2} = 2V$, $V_{G1} = V_{G2} = 0$

$V_{DS1} = 5V$ $\quad V_{S1} = V_{S2} = +2V$

$V_{DS2} = 5V$ $\quad V_{D1} = V_{D3} = 3V$

$V_{D2} = V_{D7} = 3V$

T3-T4) Los transistores son idénticos, T6 despreciable $\Rightarrow$ el factor de copia es unitario.

$I_{D3} = I_{D4} = 101{,}5\mu A \Rightarrow V_{GS3} = V_{GS4} = -2V$ $\quad V_{S3} = V_{S4} = 5V$, $V_{G3} = V_{G4} = 3V$ $\quad V_{DS3} = -2V$

$V_{D3} = 3V$, $V_{D4} = V_{D5} = -3V$ $\quad V_{DS4} = -8V$

T7-T8) $I_{D7} = 101{,}5\mu A \Rightarrow V_{GS7} = -2V$ $\quad V_{S7} = V_{S8} = 5V$ $\quad V_{D8} = 0V$ $\quad V_{DS7} = -2V$

$a = \frac{I_{D8}}{I_{D7}} = 50 \Rightarrow I_{D8} = 5{,}075mA \Rightarrow V_{GS8} = -2V$ $\quad V_{D7} = 3V$ $\quad V_{DS8} = -5V$

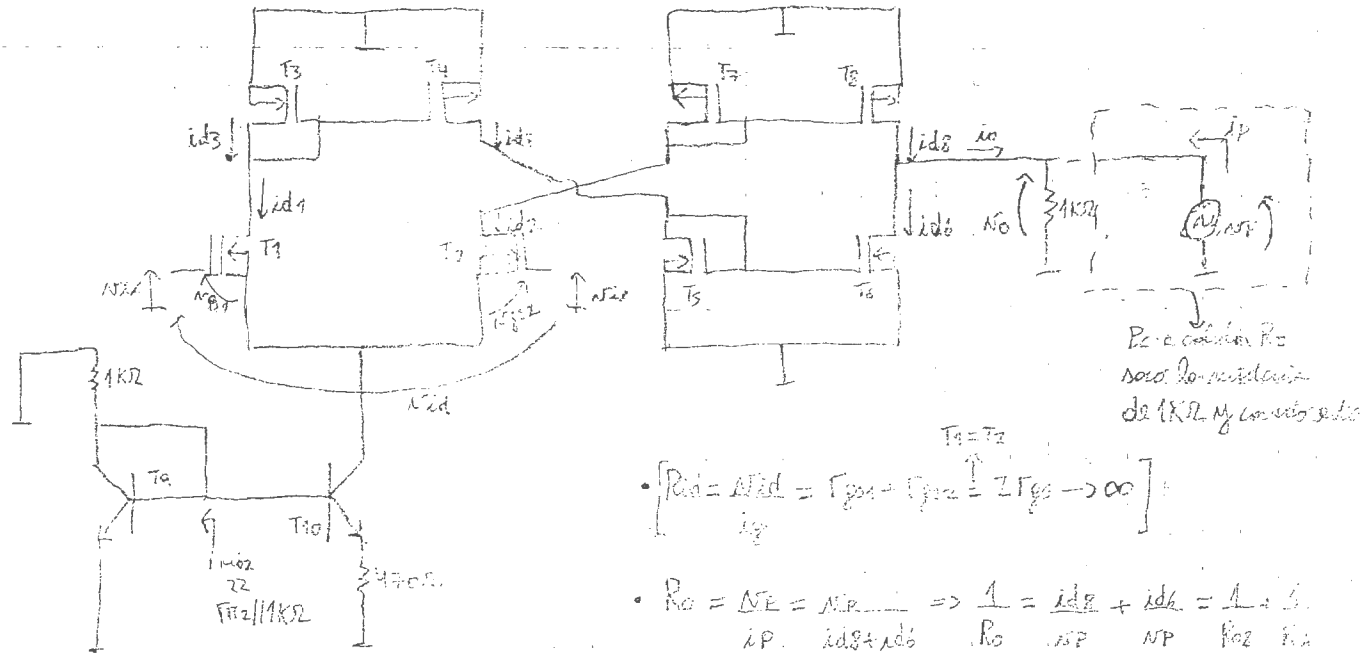
factor de copia

T5-T6) $I_{D5} = 101{,}5\mu A \overset{N}{\Rightarrow} V_{GS5} = 2V$, $V_{S5} = -5V$, $V_{D5} = -3V$ $\quad V_{DG5} = 2V$

$a = \frac{I_{D6}}{I_{D5}} = 50 \Rightarrow I_{D6} = 5{,}075mA$, $V_{GS6} = 2V$, $V_{S6} = -5V$, $V_{D6} = 0V$ $\quad V_{DS6} = 5V$

· La fuente $T_9 - T_{10}$ para la entrada de tensión I_0 del domo de un con 2B del orden del mA, ya que en una fuente espejo sería necesario integrar una R_{REF} grande. Además convierte la R_{id} del amplificador al dominio g_m y el mango con iones dicen disminuye el nivel de ruido que aportan los semiconductores.

b)



$$\cdot \left[R_{id} = \frac{N_{id}}{i_g} = r_{gs1} + r_{gs2} \overset{T_1 = T_2}{=} 2 r_{gs} \to \infty \right]$$

$$\cdot \; R_o = \frac{N_P}{i_P} = \frac{N_P}{i_{d8} + i_{d6}} \Rightarrow \frac{1}{R_o} = \frac{i_{d8}}{N_P} + \frac{i_{d6}}{N_P} = \frac{1}{R_{o2}} + \frac{1}{R_{o6}}$$

$$\therefore \left[R_o = R_{o6} // R_{o8} \underset{r_{ds} = R_{oi}}{=} \frac{r_{o6}}{2} = \frac{r_{o8}}{2} \right]$$

$$R_{o6} = \frac{N_P}{i_{d6}} = r_{o6} \quad (\text{nota con más rendimiento})$$

$$R_{o8} = \frac{N_P}{i_{d8}} = r_{o8} \quad (\;\; '' \;\; '' \;\; '' \;\; '' \;\;)$$

· Entrada diferencial:

$$N_{gs1} = \frac{N_{id}}{2} \Rightarrow i_{d1} = g_{m1} \cdot \frac{N_{id}}{2} = i_{d2} = i_{d4} = i_{d5} \Rightarrow i_{d6} = a \cdot i_{d1}$$

$$N_{gs2} = -\frac{N_{id}}{2} \Rightarrow i_{d2} = -g_{m2} \cdot \frac{N_{id}}{2} = i_{d7} \Rightarrow i_{d8} = a \cdot i_{d1}$$

$$i_o + i_{d6} = i_{d8}$$

$$i_o = i_{d8} - i_{d6} = -\frac{N_{id}}{2} (g_{m2} + g_{m1}) \cdot S$$

$$\cdot \left[G_{mc} = \frac{i_o}{N_{id}} \Big|_{N_{ic}=0} = -\frac{(g_{m2} + g_{m1})}{2} \cdot S \right]$$

$$\cdot \left[A_{vd} = \frac{N_o}{N_{id}} \Big|_{N_{ic}=0} = \frac{i_o (R_o // R_L)}{N_{id}} = -S \cdot \frac{(g_{m1} + g_{m2})}{2} \cdot (R_o // R_L) \right]$$

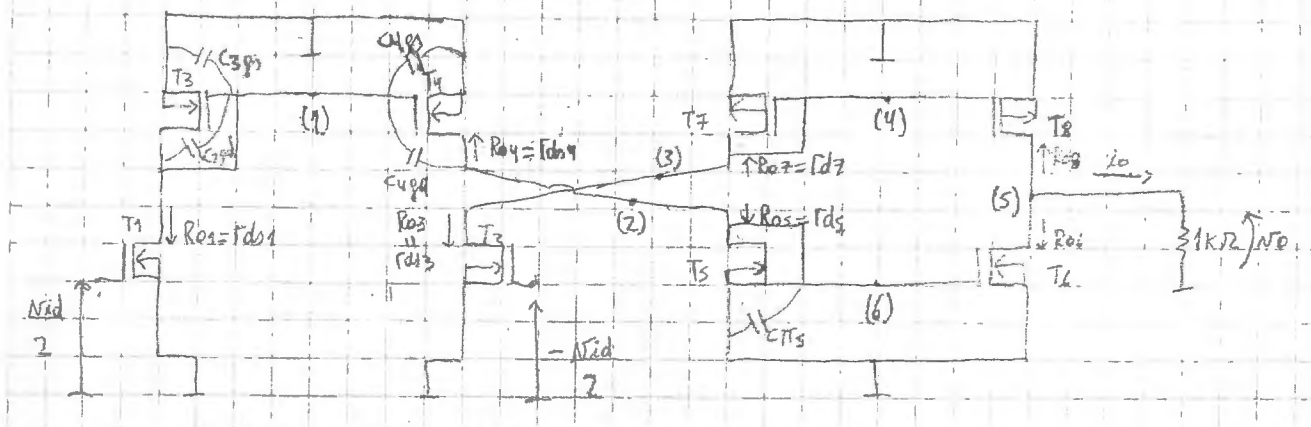
$$\cdot \left[G_{mc} = \frac{i_o}{N_{ic}} \Big|_{N_{id}=0} \longrightarrow 0 \right]$$

→ no varía dependiendo fuertemente de los desapareamientos ya que están cubiertos por los comunes por las normas del PD, haciendo que no se pasen por los zeros como son G_{mc}. Los desapareamientos en los fuentes espejo también pueden ser los dichos anteriormente.

②

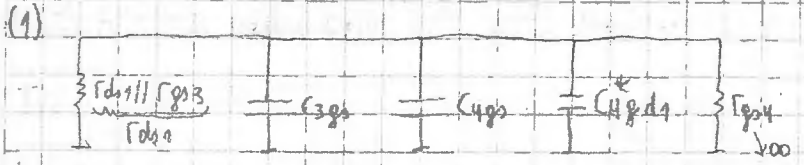
01/08/14

c) T_1 y T_2 apareados => utilizo semicircuitos



Los nodos de las entradas no los considero porque son a tierra

(1)

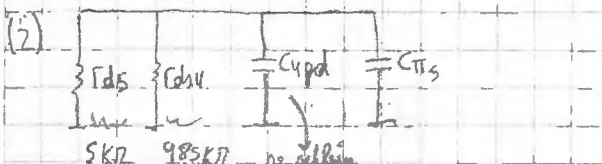


$$Z_1 = \underbrace{r_{ds1}}_{985K\Omega} \cdot (\underbrace{C_{3gs}}_{5PF} + \underbrace{C_{4gs}}_{5PF} + \underbrace{C^*_{4gd1}}_{2PF})$$

$Z_1 = 11,82\ \mu s \Rightarrow f_1 = 13,5\ KHz$

• Reflejo $C_{4gd} \Rightarrow A_{v1} = \frac{v_{d4}}{v_{g4}} = -g_{m4} \cdot r_{ds} \Rightarrow C^*_{4gd1} = C_{4gd}(1 + \underbrace{g_{m4}}_{701\mu A/V} \cdot \underbrace{r_{ds}}_{1/g_{m4}})$

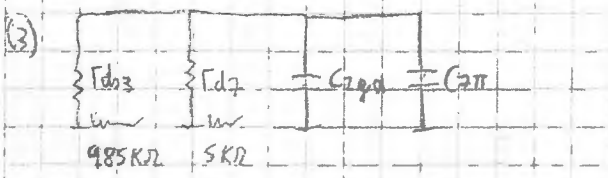
(2)



$Z_2 \approx 5K\Omega \cdot (1PF + 5PF) = 30\ ns$

$f_2 = 5,3\ MHz$

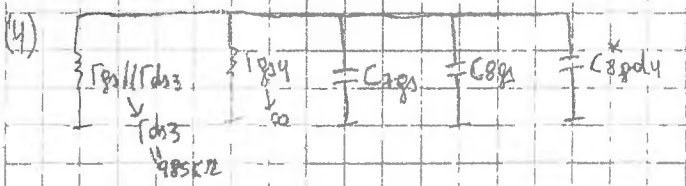
(3)



$Z_3 \approx 5K\Omega \cdot (5PF + 1PF) = 30\ ns$

$f_3 = 5,3\ MHz$

(4)



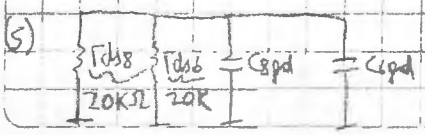
• Para reflejo uso $A_{v2} = \frac{v_{d8}}{v_{g8}} = -\underbrace{g_{m8}}_{1,42mA/V} \cdot (\underbrace{1K\Omega}_{1K\Omega} // r_{ds6})$

$C^*_{8gd4} = C_{8gd}(1 + g_{m8} \cdot 1K\Omega) = 2,42\ PF$

$Z_4 = 985K\Omega(5PF + 5PF + 2,42PF) = 12,23\ ns$

$f_4 = 13\ kHz$

(5)



$A_v = \frac{v_g}{v_d} \to 0$

$Z_5 = 10K\Omega \cdot (1PF + 1PF) = 20\ ns$

$f_5 = 8\ MHz$

e) $I_D = K'\frac{W}{L}(V_{GS}-V_T)^2 \Rightarrow \sqrt{\frac{I_D}{K'\frac{W}{L}}} + V_T = V_{GS}$

$$V_{OFF} = V_{GS1} - V_{GS2} = \sqrt{\frac{I_D}{K'}}\left(\frac{1}{\sqrt{(W/L)_1}} - \frac{1}{\sqrt{(W/L)_2}}\right) = \sqrt{\frac{I_D}{K'(W/L)_1}}\left(1 - \sqrt{\frac{(W/L)_1}{(W/L)_2}}\right)$$

$$V_{OFF} = \sqrt{\frac{I_D}{K'(W/L)_1}}\left(1 - \underbrace{\sqrt{\frac{(W/L)_1 - (W/L)_2 + 1}{(W/L)_2}}}_{\text{Binómica}}\right) = \sqrt{1+x} \underset{\text{Binómica}}{\approx} 1 + \frac{x}{2}$$

$$V_{OFF} = \sqrt{\frac{I_D}{K'(W/L)_1}}\left(\cancel{1} - \cancel{1} + \frac{\overbrace{(W/L)_1 - (W/L)_2}^{0{,}98(W/L)_2}}{2.(W/L)_2}\right) = -\underbrace{\sqrt{\frac{I_D}{K'(W/L)_1}}}_{V_{GS1}-V_T} \cdot 0{,}01 = -0{,}01\,V$$

f) El rango de modo común, es el rango de tensiones de modo común que se puede aplicar sin sacar de los transistores del modo activo. Considero que no contiene la tensión de modo común.

$$\underbrace{-5V + \overbrace{I_D \cdot R_{D1}}^{20\,mA} + \overbrace{V_{GS1}}^{0{,}7V}}_{\text{Malla } T1} < V_i < \underbrace{5V + \overbrace{V_{DS7}}^{1V} + V_{T2}}_{\text{Malla } T2}$$

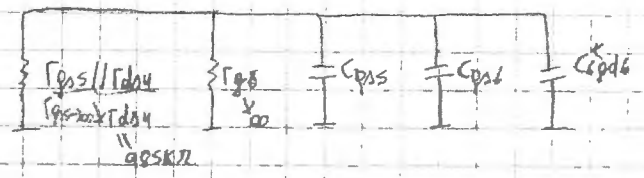
Aux: $V_{SD} \leq V_{T2}$ $\quad V_i - (5V + V_{DS7}) < V_{T2}$

$$V_i < V_{T2} + 5V + V_{DS7}$$

(2.5) 01/08/14

(Sigo con el c)

(6)



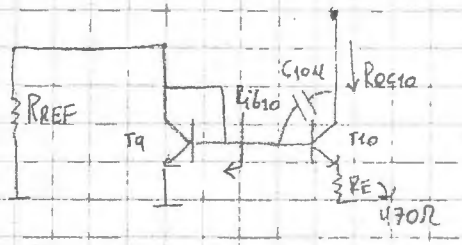
$\tau_6 = 985K\Omega (5PF + 5PF + 2,42PF) = 12,23\mu s$

$f_6 = 13KHz$

$C'_{pgd6} = \underbrace{C_{pgd}}_{1PF} \left(1 + \underbrace{g_{m6}}_{1,42 m\mho} \cdot (\overbrace{r_{ds8} // 1K\Omega}^{20K\Omega})\right) = 2,42PF$

· Ninguna f_i 10 veces menor => $\tau = \sum \tau_i = 36,36\mu s$ => $f_H = 4,4KHz$

d) En modo común la salida soldada O si $R_{EF} \to \infty$ => resonancia



$R_{ib10} = r_{i9} // R_{REF} = 269\Omega // 1K\Omega = 212\Omega$

· $R_{oc10} = r_{o10} \left(1 + \frac{R_E \cdot R_i}{R_E + r_{i1} + r_x + R_{ib10}}\right) = \overbrace{r_{o10}}^{492K\Omega} \cdot 4,68 = 2,3M\Omega$

· $A_v = \underbrace{N_6}_{NC} \to 0$ => C_{10u} se refleja prácticamente idéntico

$r_{i10} = 12K\Omega$

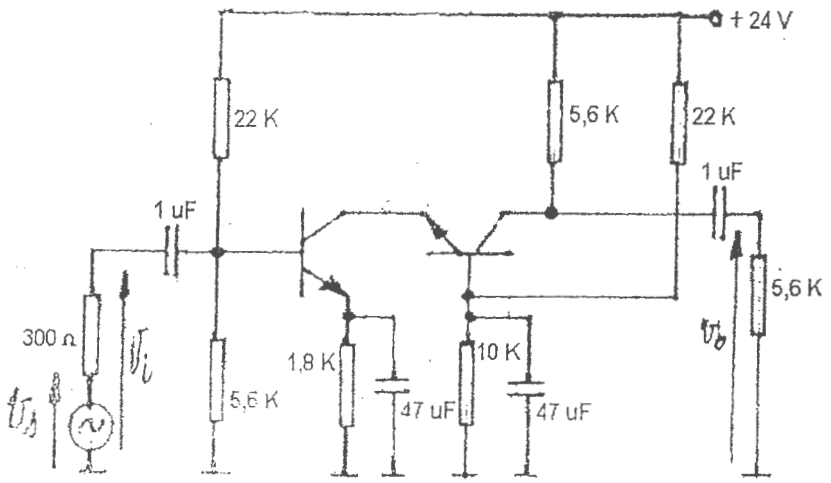
$\therefore \tau = R \cdot C = R_{oc10} \cdot C_{10u} = 4,6\mu s \to f_i = 34KHz$

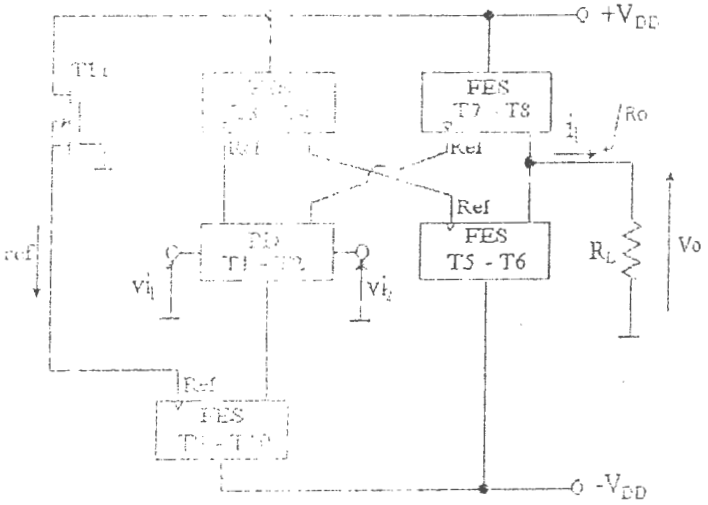
P/Fotocopias

APELLIDO	NOMBRE	PADRON	TURNO		N° de hojas	Corrección	
			T	N			

1.- $\beta = 200$; $r_x = 200\ \Omega$; $f_T = 200$ MHz ; $C_\mu = 2$ pF

Justificar mediante un análisis cualitativo cuál o cuales serán los nodos potencialmente dominantes en la respuesta en alta frecuencia Obtener el valor de f_h aproximado.





2 - Hallar los valores de:

$Gm_d = i_l / v_{id}$

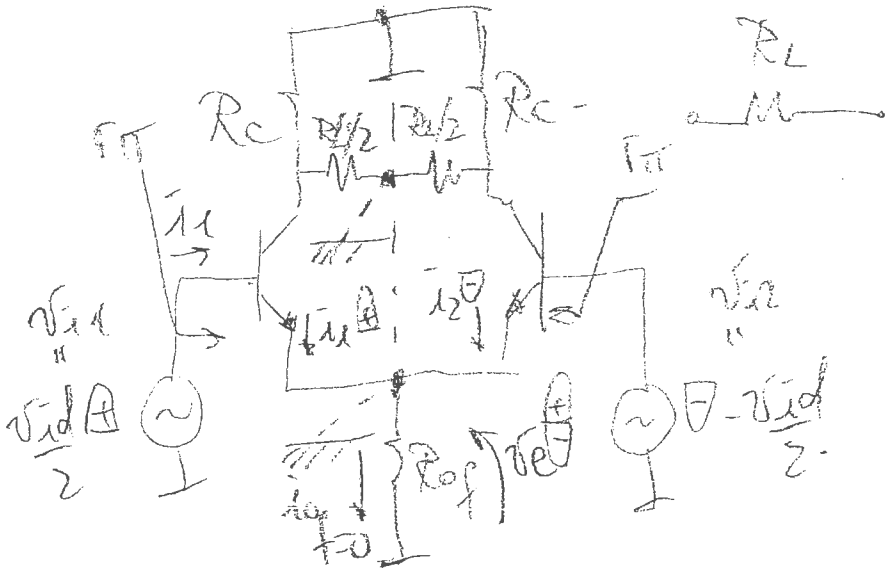
$Gm_c = i_l / v_{ic}$

(considerar la copia de las fuentes espejo)

FES: Fuente Espejo Simple – **PD:** Par Diferencial. Todos TBJs (NPN ó PNP, según corresponda)

$V_{DD} = \pm 6V$; $R_L = 1K\Omega$; $\beta = 100$, $V_A = 100V$

$V_T = 2V$; $k' = 100\mu A/V^2$; $W/L = 1$

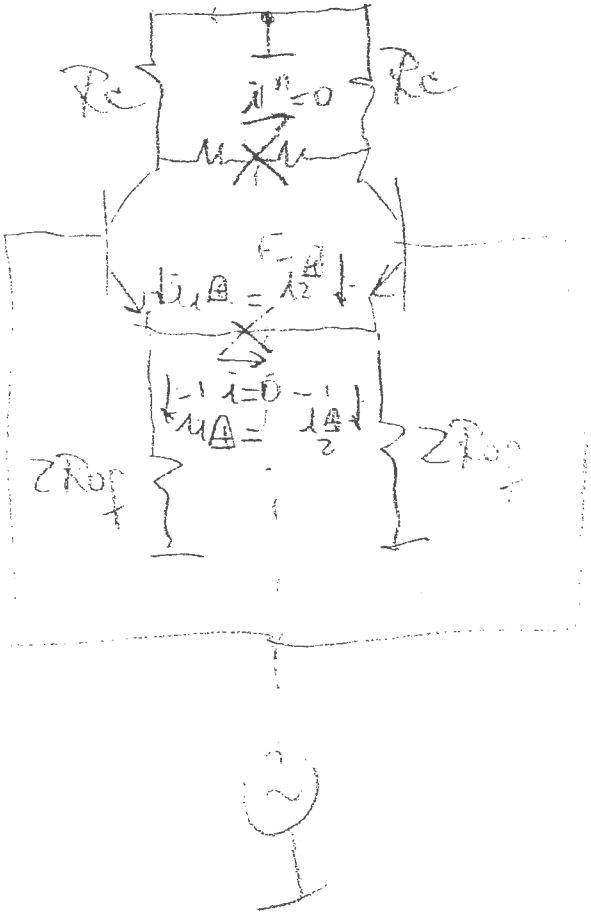


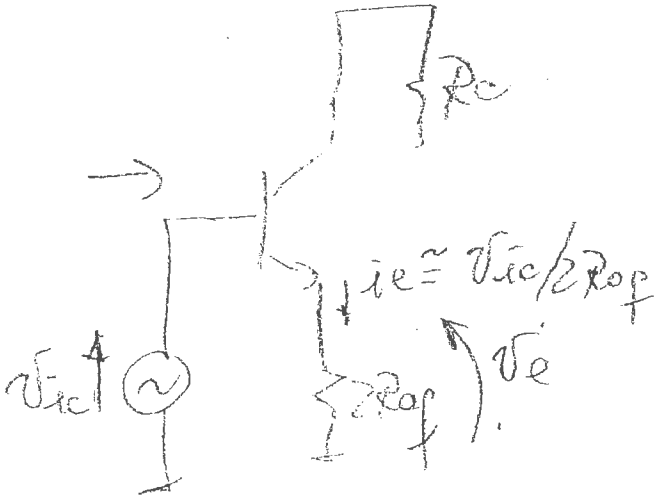
$$R_{id} = \frac{v_{id}}{i_1} = 2\left(\frac{v_{id}/2}{i_1}\right) = 2 r_\pi$$

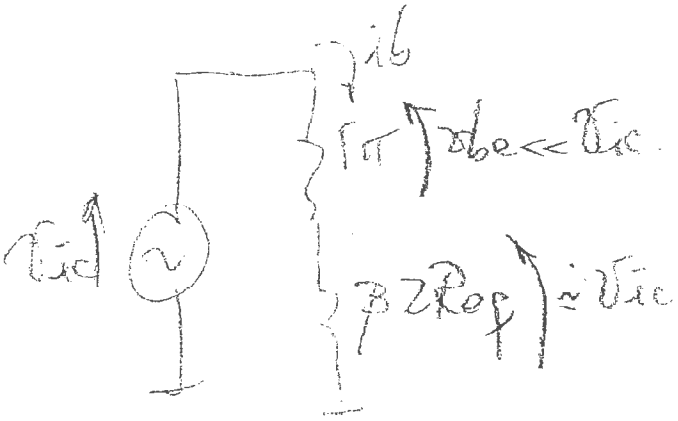
si $R_{of} \to \infty$.

Sup $\underbrace{v_e\big|_{v_{i1}} = -v_e\big|_{v_{i2}}}$

$$\boxed{v_e = 0}$$

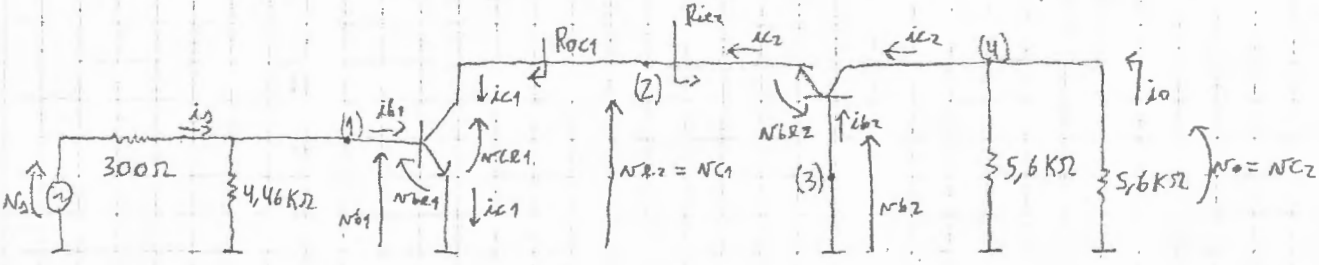






(1) 8/8/16

1) FRECUENCIAS MEDIAS: En frecuencias altas deben tener en cuenta los condensadores internos

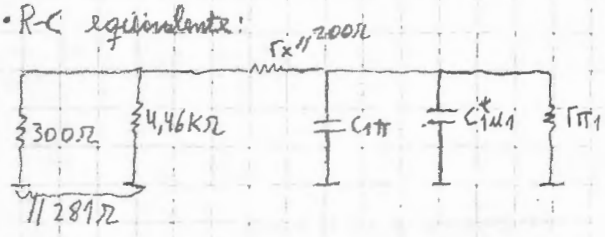


(1) Refleja $C_{1\mu}$ => $A_{v1} = \frac{v_{c1}}{v_{b1}} = \frac{-i_{c1}\cdot R_{ie2}}{v_{b1}} = \frac{-g_{m1}\cdot v_{be1}\cdot R_{ie}}{v_{be1}} = -g_{m1}\cdot R_{ie}$, $R_{ie2} = \frac{r_x + r_{\pi 2}}{\beta}$

$v_{b1} = v_{be1}$

ganancia común, Av puede ser grande, pero Rie es pequeña, es decir, la carga es chica => $C^*_{1\mu 1} = C_{1\mu}(1 - A_{v1})$ no se refleja tan grande

• R-C equivalente:



$Z_1 = \underbrace{(481\Omega // r_{\pi 1})}_{<481\Omega} \cdot (C_{1\pi} + \underbrace{C^*_{1\mu 1}}_{>C_{1\mu} = 2PF})$

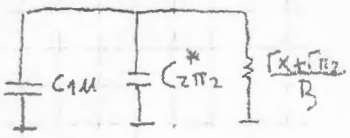
(2) Refleja $C_{1\mu}$ => $A_{v2} = \frac{v_{b1}}{v_{c1}} \overset{r_\mu \to \infty}{\approx} 0$ => $C^*_{1\mu 2} = C_{1\mu}$

Refleja $C_{2\pi}$ => $A_{v3} = \frac{v_{b2}}{v_{b2}} = v_{b2}\frac{r_x}{r_x + r_{\pi 2}}\frac{1}{v_{b2}} = \frac{r_x}{r_x + r_{\pi 2}}$ => $C^*_{2\pi 2} = C_{2\pi}(1 - A_{v2})$

Se refleja mas chico

$R_{o1} = r_{o1} \to \infty$

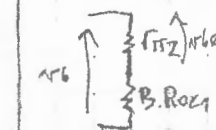
• R-C equivalente:



$Z_2 = \underbrace{\left(\frac{r_x + r_{\pi 2}}{\beta}\right)}_{<R\ de\ (1)} \cdot (\underbrace{C_{1\mu}}_{2PF} + \underbrace{C^*_{2\pi 2}}_{<C_{2\pi}})$

(3)- Refleja $C_{2\mu}$

$A_v = \frac{v_{c2}}{v_{b2}} = \frac{-g_{m2}\, v_{be2}\, 2{,}8K}{v_{b2}}$

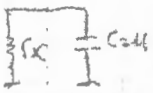


$\frac{-\beta\cdot 2{,}8K}{r_{\pi 2} + \beta R_{oc1}}$ —>

$C_{2\mu}$ se refleja idéntico

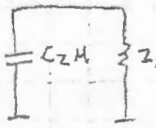
• Refleja $C_{2\pi}$, $A_v = \frac{v_{be2}}{v_{b2}} = \frac{\beta R_{oc1}}{r_{\pi 2} + \beta R_{oc1}}$

∴ $C_{2\pi}$ no se refleja

RC-eq: 

$Z_2 = r_x \cdot C_{2\mu} = 0{,}4ms$ -> la de

(4) • R-C equivalente:

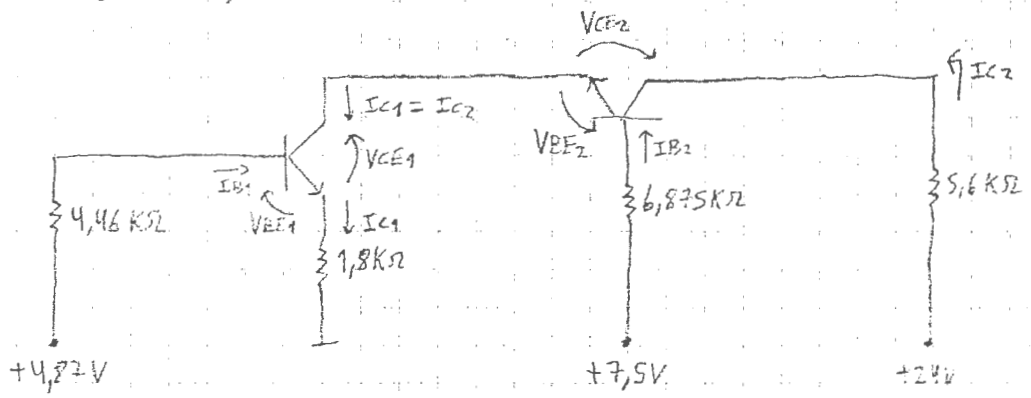


$Z_3 = 2{,}8K\Omega \cdot \underbrace{C_{2\mu}}_{2PF}$

• R de (4) es mayor a la de (1) y mucho mayor a la de (2). Las corrientes Ic1a e Ic2a son muy similares => $r_{\pi 1} = r_{\pi 2}$, $g_{m1} = g_{m2}$ y $C_{1\pi} = C_{2\pi}$, por ello la mayor C es la de (1). Esto hará que (iguales dependiendo I_B)

(1) dominan, ya que la capacidad vale mas grande que 5 veces su R ($R_3/R_1 \geq 5$).

POLARIZACIÓN)



(1) $4,87V - 0,7V - I_{C1} \cdot 1,87K\Omega = 0 \Rightarrow [I_{C2} = I_{C1} = 2,23\,mA]$

$g_{m1} = g_{m2} = 89,2\ \frac{mA}{V}$

$r_{\pi 1} = r_{\pi 2} = 2,24K\Omega$

$C_{\pi 1} = C_{\pi 2} = 71\,PF$

} Parámetros de señal

(1) $R_1 = 396\,\Omega$ $\quad [\tau_1 = 28,9\,ns]$ $\quad$ (3) $\tau_3 = r_x \cdot C_\mu = 0,4\,ns$

$A_{w1} = -0,0504$ $\quad f_1 = 5,5\,MHz$

$C_1 = 7\,PF + 2,1\,PF$

(2) $R_2 = 12,2\,\Omega$ $\quad \tau_2 = 0,82\,ns$

$A_{w2} = 0,081$

$C_2 = 2\,PF + 65,24\,PF$

(4) $\tau_4 = 5,6\,ns$

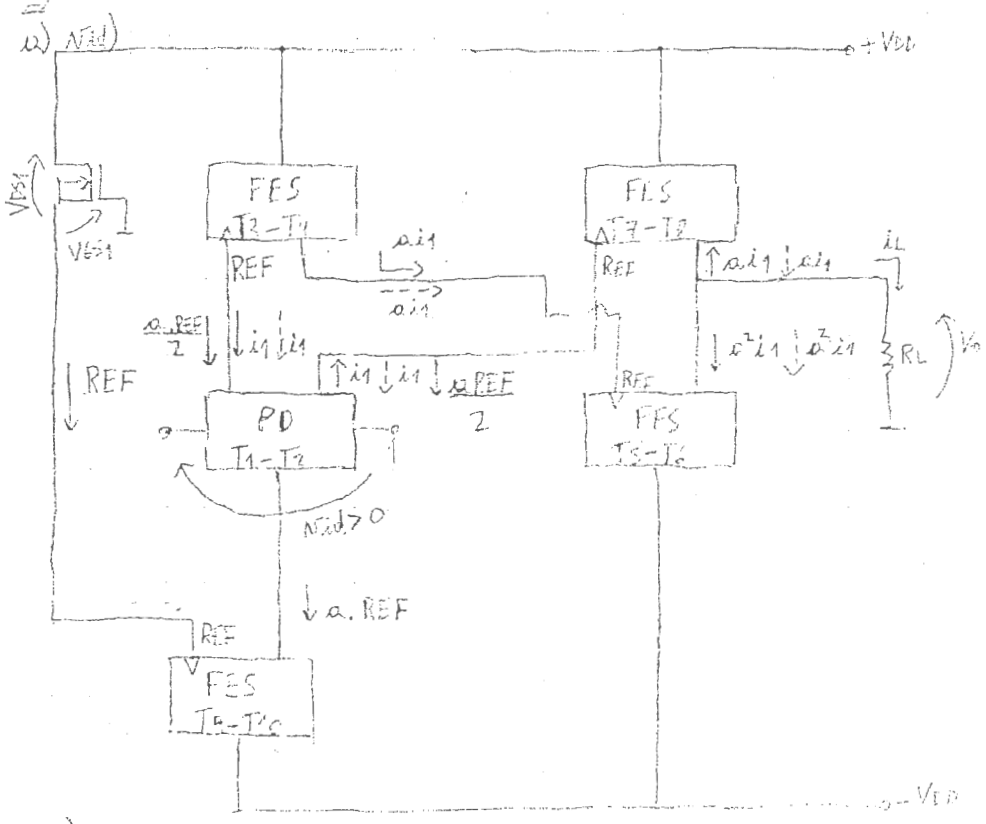
$f_4 = 61\,MHz$

f_1, 10 veces menor que los otros $\Rightarrow f_H = 5,5\,MHz$

②

8/8/16

a) v_{id})



• $a = \frac{R}{R+2}$ → ganancia de corriente

$a = 0,98$

• Bombeo PD como NPN acoplada por emisor

v_{id}) —

• $i_1 = g_{m1} \frac{v_{id}}{2}$, $i_L = -(a i_1 + a^2 i_1) = -\left(a g_{m1} \frac{v_{id}}{2} + a^2 g_{m1} \frac{v_{id}}{2}\right)$

$$\left[G_{md} = \frac{i_L}{v_{id}} = -\left(\frac{a g_{m1}}{2} + \frac{a^2 g_{m1}}{2}\right) \right] \Rightarrow G_{md} = -20,48 \frac{mA}{V}$$

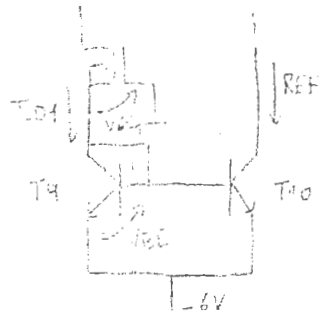
b) v_{ic}) ---

$i_L + a^2 i_1 = a i_1 \Rightarrow i_L = a i_1 - a^2 i_1 = v_{ic}(a g_{m1} - a^2 g_{m1})$

→ $i_1 = g_{m1} v_{ic}$ ≃ [illegible] → [illegible]

$$\left[G_{mc} = \frac{i_L}{v_{ic}} = a g_{m1} - a^2 g_{m1} \right] \Rightarrow G_{mc} = 0,42 \frac{mA}{V}$$

POLARIZACIÓN) [illegible] REF ⇒



$V_{B9} = -5,3V = V_S$
$V_G = 0V$ } ⇒ $V_{GS} = 5,3V$ ⇒ $I_D = K' \frac{W}{L} (V_{GS} - V_T)^2$

$I_D = 1,089 mA = REF$

• $a.REF = a.I_{D1} = 1,067 mA$

• [illegible] T1-T2 apareados ⇒ $I_{C1} = I_{C2} = \frac{a.REF}{2} = 0,533 mA$

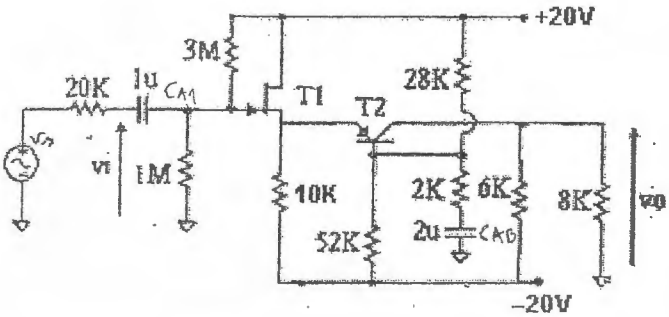
⇒ $g_{m1} = 21,32 \frac{mA}{V}$

9 fotocopias

66.08 – 86.06 Evaluación integradora 2014/2- quinta fecha - 25/02/15

APELLIDO	NOMBRE	PADRON	TURNO			Nº de hojas	Corrección	
			M	T	N			

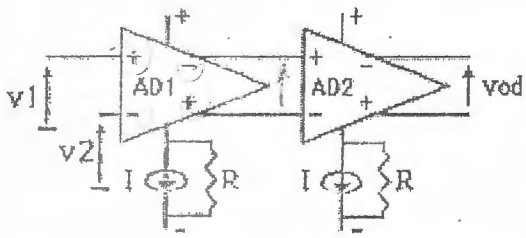
1.- $\beta = 200$; $V_A \to \infty$; $r_x = 100\Omega$; $I_{DSS} = 12mA$; $V_P = -6V$; r_{gs} y $r_{ds} \to \infty$.



a) Obtener los puntos de reposo de los transistores, indicando las tensiones de los tres terminales de cada uno contra común (V_Q).

b) Dibujar el circuito de señal sin reemplazar los transistores por su modelo circuital. Definir, obtener *por inspección* las resistencias de entrada, de salida y de carga de cada etapa; la amplificación de tensión de cada una y la total $Av = v_o/v_i$. Obtener $Av_s = v_o/v_s$.

c) Obtener por inspección el valor de la frecuencia de corte inferior aproximada. Analizar *cualitativamente* cuál podría considerarse del nodo dominante que determine el valor de f_h.



2.- Se tiene el circuito de la figura formado por dos pares NMOSFET T_1-T_2 , T_3-T_4, acoplados por source, polarizados mediante fuente de alimentación $\pm V_{DD}$ y una fuente de corriente I - R. Se admiten en principio transistores cuasi-apareados, con carga $R_{D\,(AD1)}$ y $R_{D\,(AD2)}$, admitiéndose para ambos pares: $I.R_D < V_{DD}$. *¿Qué significa esta condición?* ->ATRAS

a) Dibujar el circuito correspondiente de acuerdo con los signos de los terminales inversor y no inversor. Si en el AD1, existe un desapareamiento tal que $100(R_{D2} - R_{D1}) / R_{D1} = \alpha$, donde $|\alpha| < 3\%$, obtener las expresiones de $Av_d = (v_{od} / v_{id})|_{vic=0}$ y $Av_c = (v_{od} / v_{ic})|_{vid=0}$ totales y de su cociente para la salida v_{od} indicada, en función de α. *¿Por qué estas expresiones son válidas sólo si se ajusta previamente la tensión de offset?*. ¿valores?

b) Repetir a) si en el AD2, $100(R_{D4} - R_{D3}) / R_{D3} = \alpha$. Analizar cualitativamente a cuál de los dos juegos de expresiones obtenidas se acercarán más los valores de la RRMC si existieran ambos desapareamientos a la vez. *(Considerar valores típicos si fuese necesario).*

$AD1 \to \exists\ Avdd_1 = \frac{v_{od1}}{v_{id1}}$ $\quad \exists\ Avcc_1 = \frac{v_{oc1}}{v_{ic1}}$

$\exists\ \boxed{Avdc_1 = \frac{v_{od1}}{v_{ic1}}}$

a) $I = 0$

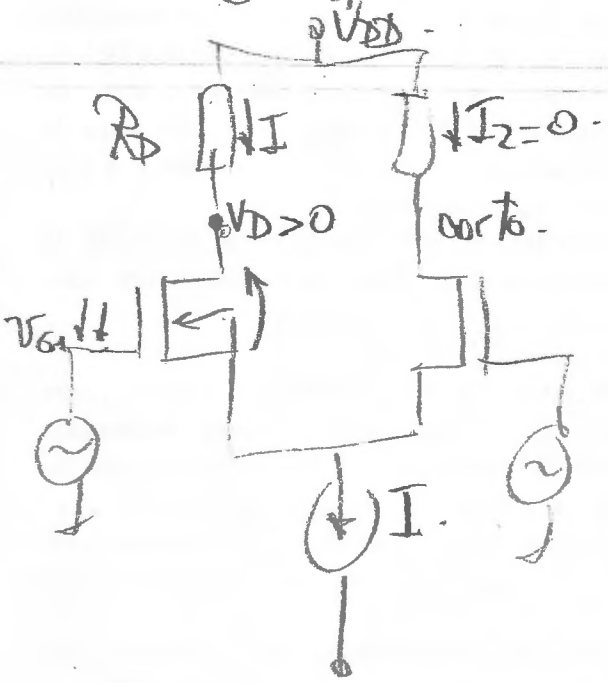
$\boxed{v_{od\,TOT} = Avdd_2 \cdot v_{id2} +}$ $\quad + Avdc_2 \cdot v_{ic2}$.

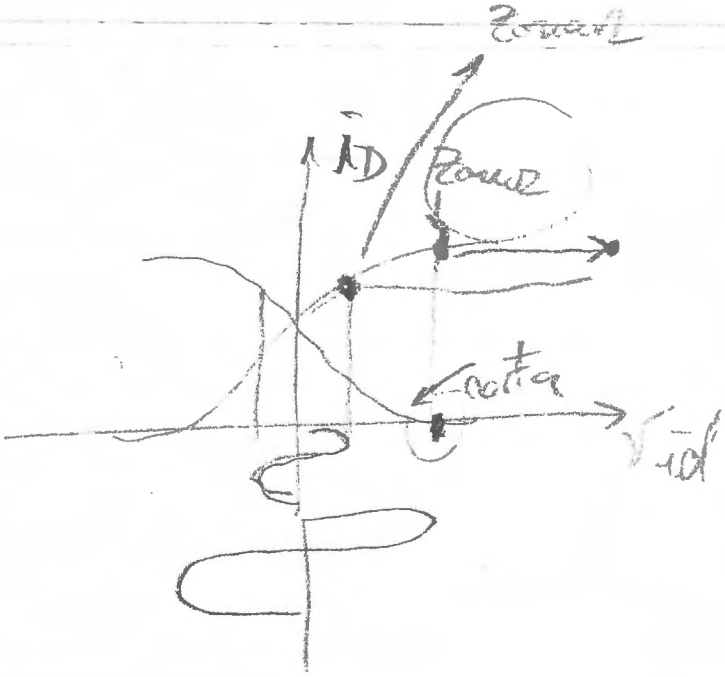
$v_{id2} = v_{od1} = Avdd_1 \cdot v_{id1} + Avdc_1 \cdot v_{ic1}$

$v_{od\,TOT} = Avdd_1 Avdd_2 \cdot v_{id1} + Avdc_1 Avdd_2 v_{ic1}$

$$A_{vdc1} = \left.\frac{v_{od1}}{v_{icc1}}\right|_{v_{id1}=0} = -\frac{g_{m1}\cdot R_{c1}}{1+2g_{m1}R_{of}} - \left(-\frac{g_{m2}R_{c2}}{1+2g_{m1}R_{of}}\right) =$$

$$= -\frac{g_m}{1+2g_{m1}R_{of}}\left(R_{c1}-R_{c2}\right).$$



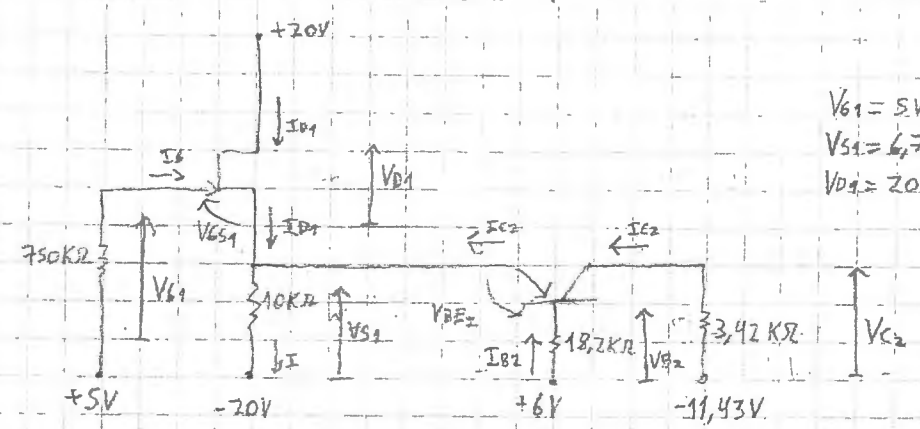


• Con la condición, se asegura de estar en la zona activa

①

25/02/15

1) a)



$V_{G1} = 5V$ $\quad V_{B2} \approx 6V$

$V_{S1} = 6,7V$ $\quad V_{E2} = 6,7V$

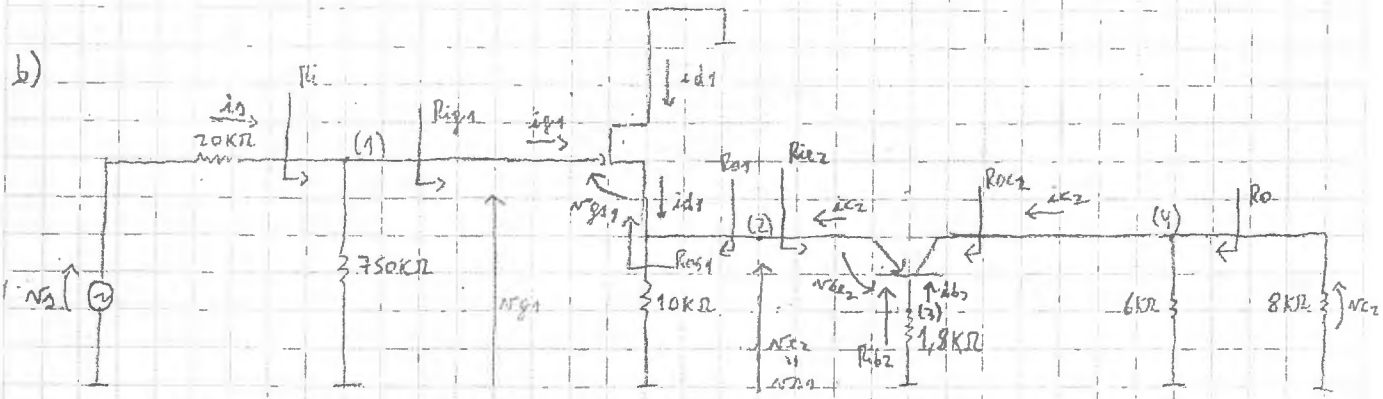
$V_{D1} = 20V$ $\quad V_{C2} = 0,5V$

(1) $6V - (-0,7V) - I \cdot 10K\Omega + 20V = 0 \Rightarrow I = 2,67\ mA$ (se considera I_{B2} despreciable frente a I_{C2})

$\therefore \left.\begin{array}{l} V_{S1} = 6,7V \\ V_{G1} = 5V \end{array}\right\} \Rightarrow V_{GS1} = -1,7V > V_P \checkmark \Rightarrow \left[I_{D1} = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 = 6,16\ mA \right]$

(2) $I = I_{D1} + I_{C2} \Rightarrow \left[\begin{array}{l} I_{C2} = I - I_{D1} = -3,49\ mA \\ I_{B2} = -17,45\ \mu A \end{array}\right\} I_{C2} >> I_{B2} \Rightarrow$ vale lo propuesto

b)



Parámetros de señal: $g_{m1} = \frac{2\sqrt{I_{DSS} \cdot I_{D1Q}}}{V_P} = 2,86\ mA/V$, $r_{gs1} \to \infty$, $r_{ds1} \to \infty$

$g_{m2} = 139,6\ \frac{mA}{V}$, $r_{\pi 2} = 1,43\ K\Omega$, $r_{o2} \to \infty$

Ri)

$R_{ig} = \frac{v_{Rg}}{i_{Rg}} = r_{gs} + \beta_{FET}(10K\Omega // R_{i2}) \to \infty$ $\quad R_i = R_{ig} // 750K\Omega = 750K\Omega$

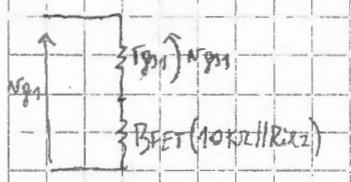
$R_{i2} = r_{\pi 2} + \underbrace{r_x + 1,8K\Omega}_{\beta} = 16,65\Omega$

Ro) $R_{os1} = 750K\Omega // 20K\Omega + \underbrace{r_{gs1}}_{\beta_{FET}} = 1/g_{m1} = 350\Omega \Rightarrow R_{o1} = 350\Omega // 10K\Omega = 338\Omega$

$R_{oc2} = \frac{v_{Rc2}}{i_{Rc2}} = r_{o2}\left(1 + \frac{\beta \cdot R_{o1}}{r_x + 1,8K\Omega + R_{o1} + r_{\pi 2}}\right) \to \infty \Rightarrow R_o = R_{oc2} // 6K\Omega = 6K\Omega$

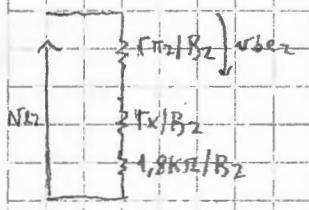
Av) $A_v = \frac{v_{c2}}{v_{g1}} = \frac{v_{c2}}{v_{g1}} \cdot \frac{v_{c2}}{v_{b2}} = A_{v1} \cdot A_{v2} = 8,2$, $A_{vs} = \frac{v_{c2}}{v_s} = A_v \cdot \frac{R_i}{R_i + R_s} = 7,99$

$$A_{v1} = \frac{v_{s1}}{v_{g1}} = \frac{\overbrace{i_{d1}}^{g_{m1}\cdot v_{g1}}\cdot(10K\Omega // R_{iz2})}{v_{g1}} = \frac{\beta_{FET}(10K\Omega // R_{iz2})}{r_{g1}+\beta_{FET}(10K\Omega // R_{iz2})} = \frac{\overbrace{g_{m1}}^{2{,}86\,mS}\,\overbrace{(10K\Omega // R_{iz2})}^{16{,}65\Omega}}{1+g_{m1}(10K\Omega // R_{iz2})} = 0{,}04$$



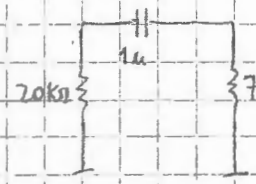
$$A_{v2} = \frac{v_{c2}}{v_{e1}} = \frac{-\overbrace{i_{c2}}^{g_{m2}\cdot v_{be2}}\cdot 3{,}42K\Omega}{v_{e2}} = \frac{g_{m2}\cdot \underbrace{1/g_{m2}}_{r_{\pi2}+r_x+1{,}8K\Omega}\cdot 3{,}42K\Omega}{r_{\pi2}+r_x+1{,}8K\Omega} = \frac{\beta_2\cdot 3{,}42K\Omega}{r_{\pi2}+r_x+1{,}8K\Omega} = 205$$

β_2



C) • Bajas frecuencias:

(A1) R-C equivalente:

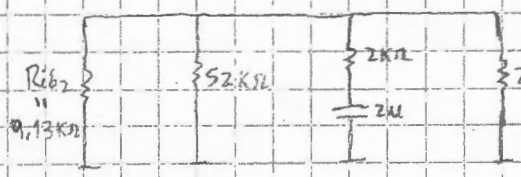


$\tau_{CA1} = 0{,}77\,s$

$f_{CA1} = 0{,}2\,Hz$

(CAB) $R_{ib2} = r_x + r_{\pi2} + \beta_2 \cdot R_{o1} = 9{,}13K\Omega$

R-C equivalente:



$\tau_{CAB} = (\overbrace{6{,}08K\Omega + 7K\Omega}^{R_{ib2}//52K\Omega//28K\Omega})\cdot 2\mu = 1616\,\mu s$

$f_{CAB} = 9{,}84\,Hz$

• f_{CAB} es 10 veces mayor a f_{CA1} => $f_L \approx 9{,}84\,Hz$

• Altas frecuencias: (1) $\tau_1 = (\underbrace{(750K\Omega // 20K\Omega)}_{19K\Omega} // \overbrace{R_{ig}}^{\infty})\,(C_{1gd} + \underbrace{C_{1gs}}_{C_{1gs}\text{ se refleja mas chico}}(\overbrace{1-A_{v1}}^{\text{doble común}}))$

(2) • Se refleja C_{1gs} => $A_{v1} = \frac{v_{g1}}{v_{s1}} = \frac{v_{s1}\cdot(750K\Omega // 20K\Omega)}{v_{s1}(750K\Omega // 20K\Omega + r_{g1})} \to 0$ => se refleja igual

• Se refleja $C_{2\pi}$ => $A_{v3} = \frac{v_b}{v_e} = \frac{1}{v_e}\cdot v_{fe}\cdot\frac{r_x+1{,}8K\Omega}{r_x+1{,}8K\Omega+r_{\pi2}} < 1$ => se refleja mas chico

$\tau_2 = (C_{1gs} + C^*_{\pi2})\cdot(\underbrace{R_{o1} // R_{iz2}}_{16\Omega})$

$C^*_{\pi2} < C_{2\pi}$

(3) • Se refleja $C_{2\pi}$ => A_{v4} de colector común => $C^*_{\pi2}$ se refleja menor a $C_{2\pi}$

• Se refleja C_{2u} => A_{v5} de emisor común realimentado => C_{2u} se refleja mas grande ya que R_{o1}, es decir la resistencia conectada al emisor es chica => Para realimentación => ganancia gm de

g_m

(2)

25/02/15

$$Z_3 = (\underbrace{C^*_{2\pi 3}}_{<C_{2\pi}} + \underbrace{C^*_{2\mu 3}}_{>C_{2\mu}}) \cdot (\underbrace{R_{ib2} // 1{,}8K\Omega}_{1{,}5K\Omega})$$

(4) Se refleja $C_{2\mu} \Rightarrow A_{v4} = \frac{v_{b2}}{v_{e2}} \to 0 \Rightarrow$ se refleja idéntico

$Z_4 = C_{2\mu} \cdot 3{,}47K\Omega$

∴ El modo (4) presenta una resistencia mucho mayor que los otros modos

- La capacidad de (3) es mayor a la de (4), $C_{2\mu}$ se refleja mas grande, y además se le suma $C^*_{2\pi 3}$. Esto le "gana" a la R mayor de 4 $\Rightarrow Z_3 > Z_4$ ($R_4 \approx 2R_3$)
- La R de (3) es mucho mayor a la de (2). En ambos $C_{2\pi}$ se refleja menor, pero en (3) $C^*_{2\mu 3} > C_{2\mu}$ es mayor a $C_{1gs} \Rightarrow Z_3 > Z_2$
- Considerando $C_{gs} = 5PF$ y $C_\mu = C_{gd} \approx 1PF$
  $C_{2\pi} >> C_{gs}$
  $C_{2\pi} >> C_{gd} = C_\mu$
  } La R de (1) pesa mas que la mayor capacidad de (3)
- El modo dominante puede ser el (1) o el (3). Se descarta el (2) por el valor chico de impedancia R_{ie2} que afecta el polo y se descarta el (4) ya que si bien R es grande su C será chica.

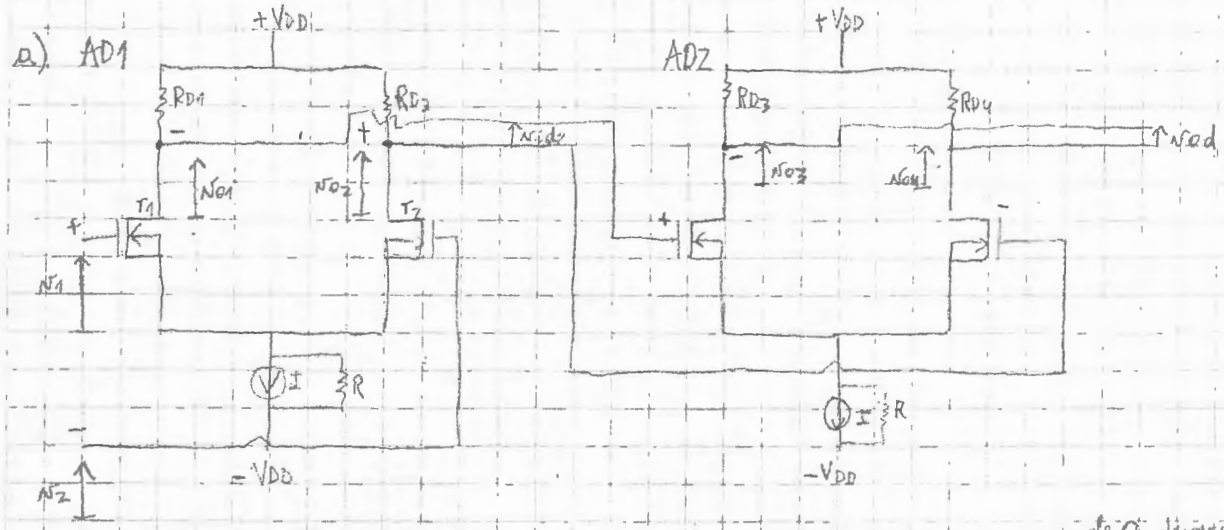
28,5ms

60ms

③ 25/03/15

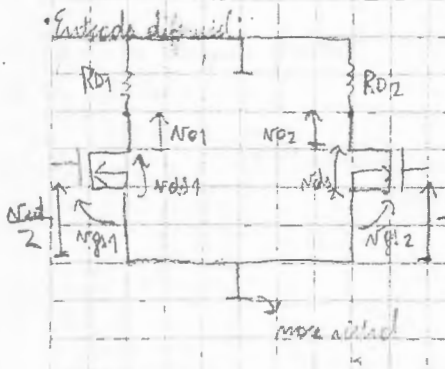
2)

a) AD1



$V_{od} = A_{vdd(2)} \cdot V_{id2} + \underbrace{A_{vdc(2)} \cdot V_{ic2}}_{\text{vale 0, RD3, RD4 y T3, T4 apagados}}$ y $V_{id2} = V_{od1} = A_{vdd(1)} \cdot V_{id1} + \overbrace{A_{vdc(1)} \cdot V_{ic1}}^{\text{no vale 0, dependiendo RD1 y RD2}}$

• Entrada diferencial:



$V_{o1} = -g_{m1} \cdot V_{gs1} \cdot R_{D1} = +g_{m1} \cdot \frac{V_{id}}{2} \cdot R_{D1}$

$V_{o2} = -g_{m2} \cdot V_{gs2} \cdot R_{D2} = g_{m2} \cdot \frac{V_{id}}{2} \cdot R_{D2}$

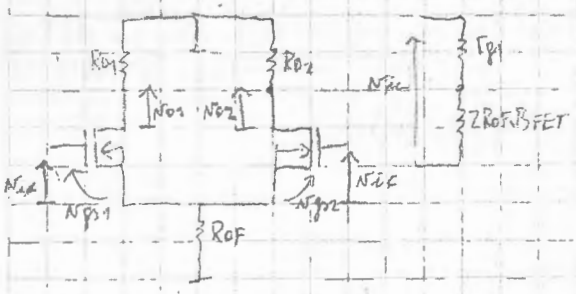
$V_{od1} = V_{id2} = -\frac{V_{id}}{2}(g_{m1} \cdot R_{D1} + g_{m2} \cdot R_{D2})$

• Considero ajustados las tensiones de offset => anulo corrientes, de las somas de los dos pares, son iguales.

$A_{vdd2} = \left.\frac{V_{od2}}{V_{id2}}\right|_{V_{ic2}=0} = -\frac{V_{id2}(g_{m3} \cdot R_{D3} + g_{m4} \cdot R_{D4})}{V_{id2}} = -\frac{1}{2}(g_{m3} \cdot R_{D3} + g_{m4} \cdot R_{D4}) = -g_{m2} \cdot R_{D2}$

$A_{vdd} = \left.\frac{V_{od1}}{V_{id1}}\right|_{V_{ic1}=0} = -\frac{1}{2}(g_{m1} R_{D1} + g_{m2} \cdot R_{D2}) = -\frac{1}{2}(g_{m1} \cdot (R_{D1} + R_{D2})$

• Entrada común:



$V_{o1} = -g_{m1} \cdot V_{gs1} \cdot R_{D1} = -g_{m1} \cdot R_{D1} \cdot \frac{r_{d1} V_{ic}}{r_{d1} + 2R_{OF}} = -\frac{R_{D1} \cdot V_{ic}}{r_{d1} + 2R_{OF}}$

$V_{o2} = -g_{m2} \cdot V_{gs2} \cdot R_{D2} = -g_{m2} \cdot R_{D2} \cdot \frac{r_{d2} V_{ic}}{r_{d2} + 2R_{OF}} = -\frac{R_{D2} \cdot V_{ic}}{r_{d2} + 2R_{OF}}$

$V_{od1} = \frac{V_{ic}}{r_{d1} + 2R_{OF}}(R_{D2} - R_{D1})$.

$V_{oc1} = -\frac{V_{ic} \cdot 2 \cdot R_{D1}}{r_{d1} + 2R_{OF}}$ → punto b)

$A_{vdc(1)} = \left.\frac{V_{od1}}{V_{ic1}}\right|_{V_{id1}=0} = \frac{1}{r_{d1} + 2R_{OF}} \cdot (R_{D2} - R_{D1})$

$A_{vdc(2)} = \left.\frac{V_{od2}}{V_{ic2}}\right|_{V_{id2}=0} = 0$

$$N_{od} = A_{rdd(2)} \cdot N_{id2} = A_{rdd(2)} \left(A_{rdd(1)} \cdot \overbrace{N_{id1}}^{N_{id}} + A_{rdc(1)} \cdot \overbrace{N_{ic1}}^{N_{ic}} \right)$$

$$\left[A_{rd} = \frac{N_{od}}{N_{id}} \Big|_{N_{ic}=0} = A_{rdd(2)} \cdot A_{rdd(1)} = +\frac{1}{2} g_{mA1} \cdot g_{mA2} \cdot R_{A2} \left(R_{D1} + R_{D2} \right) \right.$$

$$A_{rd} = +\frac{1}{2} \cdot g_{mA1} g_{mA2} \cdot R_{A2} \cdot \frac{R_{D1}}{100} \left(\frac{2R_{D1} \cdot 100}{R_{D1}} + \underbrace{100 \cdot \frac{R_{D2} - R_{D1}}{R_{D1}}}_{\alpha} \right) = +\frac{1}{2} \cdot g_{mA1} \cdot g_{mA2} \cdot R_{A2} \cdot \frac{R_{D1}}{100} \left(200 + \alpha \right) \Bigg]$$

$$\left[A_{rc} = \frac{N_{od}}{N_{ic}} \Big|_{N_{id}=0} = A_{rdd(2)} \cdot A_{rdc(1)} = -\frac{g_{mA2} \cdot R_{A2}}{r_{dA1} + 2R_{oF}} \left(R_{D2} - R_{D1} \right) = -\frac{g_{mA2} \cdot R_{A2}}{r_{dA1} + 2R_{oF}} \cdot \frac{R_{D1}}{100} \underbrace{\left(100 \cdot \frac{R_{D2} - R_{D1}}{R_{D1}} \right)}_{\alpha} \right.$$

$$\left. = -\frac{g_{mA2} \cdot R_{A2}}{r_{dA1} + 2R_{oF}} \cdot \frac{R_{D1}}{100} \cdot \alpha \right]$$

$$\left| \frac{A_{rd}}{A_{rc}} \right| = \frac{1}{2} g_{mA2} \cdot g_{mA1} \cdot R_{A2} \frac{R_{D1}}{100} \left(200 + \alpha \right) \cdot \frac{r_{dA1} + 2R_{oF}}{g_{mA2} \cdot R_{A2}} \cdot \frac{100}{R_{D1}} \cdot \frac{1}{\alpha} = \frac{1}{2} g_{mA1} \frac{\left(200 + \alpha \right)}{\alpha} \left(r_{dA1} + 2R_{oF} \right)$$

$$\rightarrow \left| \frac{A_{rdd(1)}}{A_{rdc(1)}} \right|$$

b) $A_{rdd(1)} = \frac{N_{od1}}{N_{id1}} \Big|_{N_{ic1}=0} = -g_{mA1} \cdot R_{A1}$ $\quad A_{rdc(1)} = 0$ $\quad A_{rcc(1)} = \frac{N_{oc1}}{N_{ic1}} \Big|_{N_{id1}=0} = -\frac{2R_{A1}}{r_{dA1} + 2R_{oF}}$

$A_{rdd(2)} = \frac{N_{od2}}{N_{id2}} \Big|_{N_{ic2}=0} = -\frac{1}{2} g_{mA2} \left(R_{D3} + R_{D4} \right)$ $\quad A_{rdc(2)} = \frac{1}{r_{dA2} + 2R_{oF}} \left(R_{D4} - R_{D3} \right)$

$\neq 0$ ahora R_{D3} y R_{D4} no apareado

- $N_{od} = A_{rdd(2)} \cdot N_{id2} + A_{rdc(2)} \cdot N_{ic2}$

$$N_{od} = A_{rdd(2)} \cdot \left(A_{rdd(1)} \cdot N_{id} + \underbrace{A_{rdc(1)}}_{0} \cdot N_{ic} \right) + A_{rdc(2)} \left(A_{rcc(1)} \cdot N_{ic} + \underbrace{A_{rcd(1)}}_{0} \cdot N_{id} \right)$$

$$\left[N_{od} = A_{rdd(2)} \cdot A_{rdd(1)} \cdot N_{id} + A_{rdc(2)} \cdot A_{rcc(1)} \cdot N_{ic} \right]$$

- $\left[A_{rd} = \frac{N_{od}}{N_{id}} \Big|_{N_{ic}=0} = A_{rdd(2)} \cdot A_{rdd(1)} = -\frac{1}{2} g_{mA2} \left(R_{D3} + R_{D4} \right) \cdot g_{mA1} \cdot R_{A1} = \frac{1}{2} g_{mA1} \cdot g_{mA2} \cdot R_{A1} \cdot \frac{R_{D3}}{100} \left(200 + \alpha \right) \right]$

- $\left[A_{rc} = \frac{N_{od}}{N_{ic}} \Big|_{N_{id}=0} = A_{rdc(2)} \cdot A_{rcc(1)} = \frac{-1}{r_{dA2} + 2R_{oF}} \left(R_{D4} - R_{D3} \right) \cdot \frac{2R_{A1}}{r_{dA1} + 2R_{oF}} = -\frac{R_{D3} \cdot \alpha}{100 \left(r_{dA2} + 2R_{oF} \right)} \cdot \frac{2R_{A1}}{r_{dA1} + 2R_{oF}} \right]$

- $\left| \frac{A_{rd}}{A_{rc}} \right| = \frac{1}{2} \cdot g_{mA1} \cdot g_{mA2} \cdot R_{A1} \cdot \frac{R_{D3}}{100} \left(200 + \alpha \right) \cdot \frac{100 \left(r_{dA2} + 2R_{oF} \right)}{R_{D3} \cdot \alpha} \cdot \frac{\left(r_{dA1} + 2R_{oF} \right)}{2R_{A1}}$

$$\rightarrow \left| \frac{A_{rdd(2)} \cdot A_{rdd(1)}}{A_{rdc(2)} \cdot A_{rcc(1)}} \right|$$

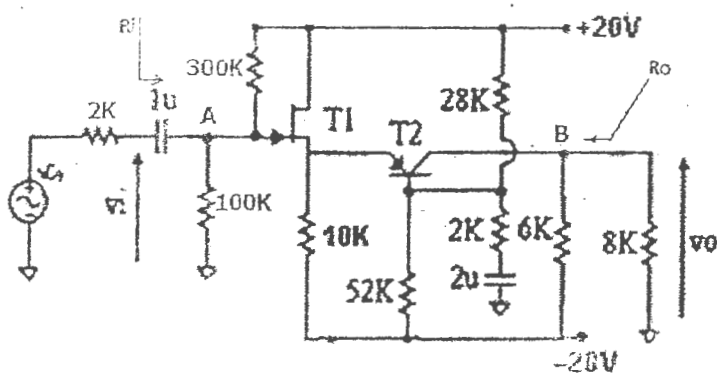
- Si existiera ambos desapareamientos al juego 1 se acercará más en valor a la RRMC, ya que el amplificador que limita el rad. es de modo común es el primero, dado que el segundo amplificará la señal de modo diferencial que le entregue el primero. $RRMC = \left| \frac{A_{rdd(1)}}{A_{rdc(1)}} \right|$ → sale de ganancia N_{od} conjunta y note que A_{rcc}, A_{rdc} ↓

P/ Fotocopiar ✓

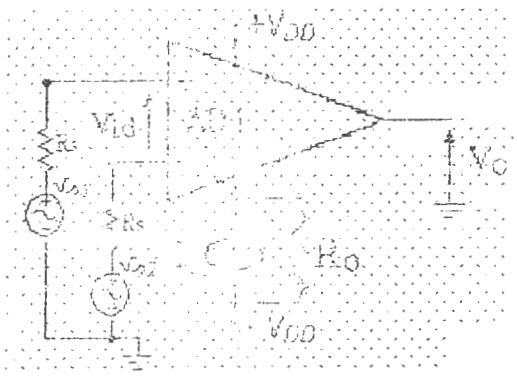
66.06 - 86.03 Evaluación integradora 1/2016- cuarta fecha - 27/07/16

APELLIDO	NOMBRE	PADRON	TURNO		N° de hojas	Corrección	
			T	N			

1.- $\beta = 200$; $V_A \to \infty$; $r_x = 100\Omega$; $I_{DSS} = 12mA$; $V_P = -6V$; $\lambda = 0$; $f_T = 200MHz$; $C_\mu = 1pF$; $C_{gs} = 5pF$; $C_{gd} = 1pF$



Analizar *cualitativamente* cuál podría considerarse el nodo dominante que determine el valor de f_h. Obtener f_h.



2.- AD1 es un par acoplado por source de NMOSFETs de canal inducido (T_1 - T_2), con una fuente espejo PMOSFET como carga (T_3 - T_4).
Se admiten transistores con características nominalmente similares ($T_1 = T_2$ y $T_3 = T_4$). *Definir y hallar la expresión* de la tensión de offset, V_{off}, para los siguientes casos:

a) $|V_{T2} - V_{T1}| / V_{T1} = \delta$, donde $\delta << 1$.

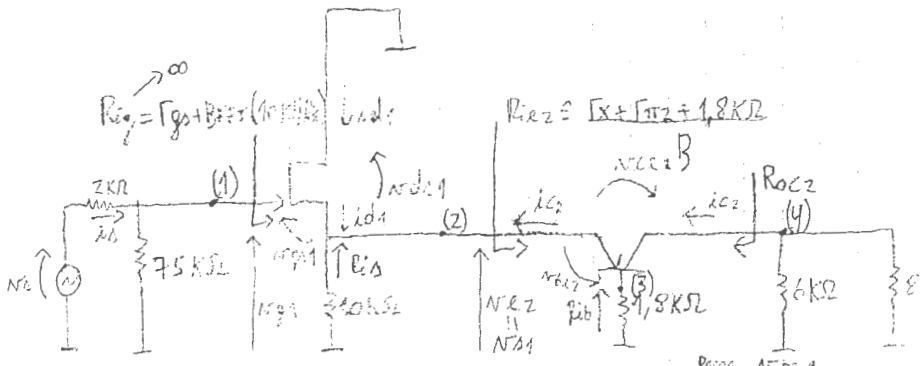
b) $|W_2 - W_1| / W_1 = \delta$, donde $\delta << 1$.

(1)

27/7/16

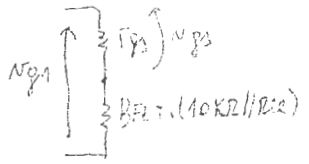
1) FRECUENCIAS DE CORTE: En alta, capacitores internos

$\beta = 200$, $V_A \to \infty$
$r_x = 100\Omega$, $I_{DSS} = 12\,mA$
$V_P = -6V$, $\lambda = 0$
$f_T = 200\,MHz$
$C_{\mu} = 1pF$, $C_{gs} = 5pF$, $C_{gd} = 1pF$



$6K\Omega // 8K\Omega = 3,42K\Omega$

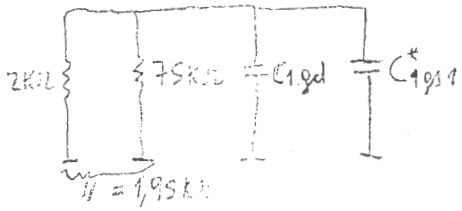
(1) Se refleja C_{1gs} a la entrada $\Rightarrow A_{v1} = \frac{v_{s1}}{v_{gs1}} = \frac{\overbrace{i_{d1}}^{g_{m1} \cdot v_{gs1}}(10K\Omega // R_{ie})}{v_{gs1}} = \frac{g_{m1} r_{gs}(10K\Omega // R_{ie})}{r_{gs} + g_{m1} r_{gs}(10K\Omega // R_{ie})}$



$A_{v1} = \frac{g_{m1}(10K\Omega // R_{ie})}{1 + g_{m1}(10K\Omega // R_{ie})} < 1 \to$ es un seguidor

$C^*_{1gs1} = C_{1gs}(1 - A_{v1}) \to$ se refleja mas chico

$\therefore$ La red equivalente de RC varía:



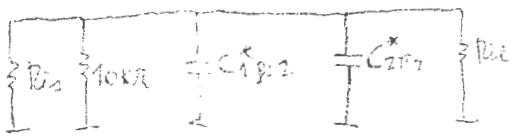
$\tau_1 = 1,95K\Omega\,(C_{1gd} + \underbrace{C^*_{1gs1}}_{< C_{1gs}})$

(2) $R_{is} = \underbrace{r_x + 1,95K\Omega}_{R_{EQ1}} \times \frac{1}{g_{m1}}$, $R_{ie} = \frac{r_x + r_{\pi 2} + 1,8K\Omega}{\beta}$

- Refleja $C_{1gs} \Rightarrow A_{v2} = \frac{v_{gs1}}{v_{s1}} \approx 0 \Rightarrow C^*_{1gs2} = C_{1gs}(1 - A_{v2}) = C_{1gs}$

- Refleja $C_{c\mu} \Rightarrow A_{v3} = \frac{v_{c2}}{v_{be2}} = \frac{v_{c2}}{v_{s1}} \cdot \frac{1,8K\Omega + r_x}{1,8K\Omega + r_x + r_{\pi 2}} \to$ valor $< 1 \Rightarrow C^*_{c\mu 2} = C_{c\mu}(1 - A_{v3})$
$\to$ se refleja mas chico

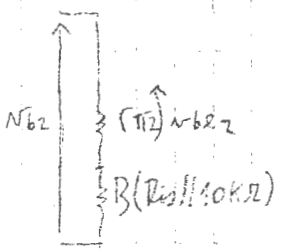
$\therefore$ La red equivalente de RC:



$\tau_2 = \underbrace{(R_{is} // 10K\Omega // R_{ie})}_{\text{menor a R de (1)}}(C_{1gs} - \underbrace{C^*_{c\mu 2}}_{< C_{c\mu}})$

(3) Reflejo $C_{2\pi} \Rightarrow A_{v4} = \frac{v_{ce2}}{v_{b2}} = \frac{g_{m4} \cdot v_{be2} \cdot (R_{is} // 10k\Omega)}{v_{b2}} = \frac{\beta \cdot (R_{is} // 10k\Omega)}{r_{\pi 2} + \beta (R_{is} // 10k\Omega)} \leq 1$

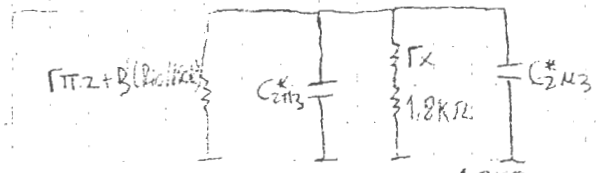
$\therefore C^*_{2\pi 3} = C_{2\pi}(1 - A_{v4}) \Rightarrow$ se refleja mas chico



Reflejo $C_{2\mu} \Rightarrow A_{v5} = \frac{v_{c2}}{v_{b2}} = -\frac{g_{m2} \cdot v_{be2} \cdot 3{,}47k\Omega}{v_{b2}} = \frac{-\beta \cdot 3{,}47k\Omega}{r_{\pi 2} + \beta (R_{is} // 10k\Omega)}$

$\therefore C^*_{2\mu 3} = C_{2\mu}(1 - A_v) \Rightarrow$ se refleja mas grande (muy grande)

$\therefore$ La red equivalente RC sería:

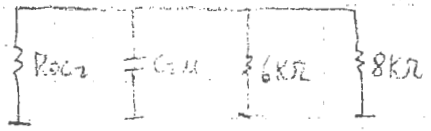


$$Z_3 = \underbrace{\left[(r_{\pi 2} \quad \beta(R_{is} // 10k\Omega)) // \overbrace{(r_x + 1{,}8k\Omega)}^{1{,}9k\Omega} \right]}_{\text{Menor que R de (1) (// = menor a 1,9k}\Omega)} \cdot (\underbrace{C^*_{2\pi 3}}_{< C_{2\pi}} + \underbrace{C^*_{2\mu 3}}_{>> C_{2\mu}})$$

(4) $R_{OC2} = r_{o2}\left(1 + \frac{\beta(R_{is} // 10k\Omega)}{r_{\pi 2} + r_x + (R_{is} // 10k\Omega) + 1{,}8k\Omega}\right) \xrightarrow{V_A \to \infty \Rightarrow r_{o2} \to \infty} \infty$

Reflejo $C_{2\mu} \Rightarrow A_{v6} = \frac{v_b}{v_c} = 0 \Rightarrow C^*_{2\mu 4} = C_{2\mu}(1 - A_{v6}) = C_{2\mu}$

$\therefore$ La red equivalente RC sería:



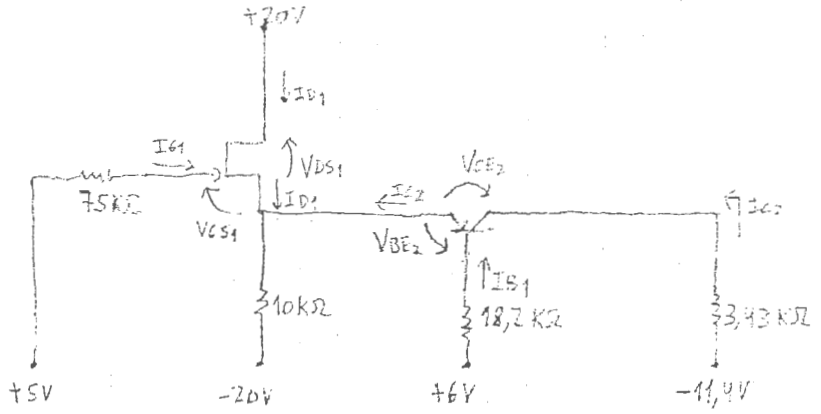
$Z_4 = \underbrace{3{,}43k\Omega}_{> \text{ a todas las R}} \cdot C_{2\mu} = 3{,}42\,ms$

$C_1 > C_4$ (pese con A_{v4} cerca de 1)

- El Z_1 sería menor al Z_4, sin embargo $C_{2\mu}$ se refleja muy grande al modo (3) y R de (3) será cercana a la de (1) $\Rightarrow Z_3 > Z_1$, mientras que R de 2 es muy chica (por las R reflejadas desde $\Delta 1$ y b_2) $\Rightarrow$ El modo dominante será el (3).

(2) 23/7/16

POLARIZACIÓN



(1) $5V - V_{GS1} - (I_{D1} + I_{C2}) \cdot 10k\Omega + 20V = 0$

(2) $5V - V_{BE1} - (-0,7V) + \frac{I_{C1}}{200} \cdot 18,2k\Omega - 6V = 0$

(3) $I_{D1} = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

De (2) $I_{C2} \cdot 91\Omega = V_{GS1} + 0,3V$

$I_{C2} = \frac{V_{GS1}}{91\Omega} + \frac{0,3V}{91\Omega}$ → en (1) $5V - V_{GS1} - I_{D1} \cdot 10k\Omega - \overbrace{\frac{V_{GS1}}{91\Omega} \cdot 10k\Omega}^{\sim 110 \cdot V_{GS1}} + \frac{0,3V}{91\Omega} \cdot 10k\Omega = 0$

$58V - I_{D1} \cdot 10k\Omega - V_{GS1} \cdot 110 = 0$

$V_{GS1} = \frac{58V}{110} - I_{D1} \cdot \frac{10k\Omega}{110}$ → en (3)

$I_{D1} = 12mA\left(1 - \frac{(58V/110 - I_{D1}\, 10k/110)}{-6V}\right)^2$

$I_{D1} = 12mA\left(\overbrace{1 + 0,0879}^{1,0879} - 15,15 \cdot I_{D1}\right)^2$

$0 = 14,20m - 1,395 \cdot I_{D1} + 2,72V \cdot I_{D1}^2$ → [$I_{D1} = 10mA$ → $V_{GS1} = -0,38V > V_P$ ✗] / $I_{D1} = 0,5A$

$I_{D1} = 10mA \Rightarrow g_{m1} = \frac{2\sqrt{I_{DSS} \cdot I_{D1}}}{V_P} = 3,65 \frac{mA}{V}$, $r_{g1} \to \infty$, $r_{d1} \to \infty$

$I_{C2} = -0,88mA \Rightarrow g_{m2} = 35,2 \frac{mA}{V}$

$r_{\pi 2} = 5,7k\Omega$, $r_{o2} \to \infty$

} Parámetros de señal

$f_T = \frac{1}{2\pi \tau_{\pi}}$

∴ (1) $R_{i2} = 35\Omega$ $C^*_{1gs1} = 4,4pF \Rightarrow Z_1 = 10,5m\Omega$

$A_{v1} = 0,12$

(2) $R_{i2} = 38\Omega$ $C^*_{1gs2} = 21pF \Rightarrow Z_2 = 16\Omega \cdot 26pF = 416pF$

$R_{i3} = 28\Omega$

$C_{2\pi} = 28pF$

$A_{v3} = 0,25$

b) $A_{v4} = \frac{200.28\Omega}{100\Omega + 5{,}7k\Omega + 200.28\Omega} = 0{,}49 \Rightarrow C^*_{2\pi 3} = 14{,}28pF$

$A_{v5} = \frac{-200.3{,}92k\Omega}{100\Omega + 5{,}7k\Omega + 200.28\Omega} = -60 \Rightarrow C^*_{2\mu 3} = 61pF$

$\left[\tau_3 = (11{,}3k\Omega \,//\, 1{,}9k\Omega) . 75{,}28pF = 122\,ns \right]$

③ 23/3/16

2) $I_D = K' \frac{W}{L} (V_{GS} - V_{TH})^2$

$\sqrt{\frac{I_D \cdot L}{W K'}} + V_{TH} = V_{GS}$

debe igualar I_D en ambas ⇒ debe compensar el desparejamiento de los pares T1 y T2 ⇒ $V_{id(OFF)}$

a) $V_{OFF} = V_{GS1} - V_{GS2} = \sqrt{\frac{I_D \cdot L}{W_1 K'}} + V_{TH1} - \sqrt{\frac{I_D \cdot L}{W_2 K'}} - V_{TH2} = V_{TH1} - V_{TH2} = V_{TH1} \left(\frac{V_{TH1} - V_{TH2}}{V_{TH1}} \right) =$

$V_{OFF} = \pm V_{TH1} \cdot \delta$ → La variación es aleatoria

b) $V_{OFF} = V_{GS1} - V_{GS2} = \sqrt{\frac{I_D \cdot L}{W_1 \cdot K'}} + V_{TH} - \sqrt{\frac{I_D \cdot L}{W_2 \cdot K'}} - V_{TH} = \sqrt{\frac{I_D \cdot L}{K'}} \left(\frac{1}{\sqrt{W_1}} - \frac{1}{\sqrt{W_2}} \right) = \sqrt{\frac{I_D \cdot L}{K'}} \left(\frac{1}{\sqrt{W_2}} \left(\sqrt{\frac{W_2}{W_1}} - 1 \right) \right)$

$= \sqrt{\frac{I_D \cdot L}{K' \cdot W_2}} \left(\sqrt{\underbrace{\frac{W_2 - W_1}{W_1} + 1}_{\substack{\text{desarr.} \\ \alpha \frac{\alpha}{2} + 1}}} - 1 \right) = \sqrt{\frac{I_D \cdot L}{K' \cdot W_2}} \left(\frac{1}{2} \alpha + 1 - 1 \right) = \sqrt{\frac{I_D \cdot L}{K' \cdot W_2}} \cdot \frac{1}{2} \cdot \alpha$

∴