



Microtecnología y
Sistemas Embebidos

Instituto Politécnico Nacional

Centro de Investigación en Computación

VLSI avanzado

Tarea 2 - Diseño de amplificador
operacional tipo cascode de una etapa

PROFESOR:

DR. HERÓN MOLINA LOZANO

POR:

ING. RICARDO ALDAIR TIRADO TORRES

CIUDAD DE MÉXICO, JUNE 23, 2024

Contents

1	Objetivos	3
2	Cálculo de parámetros $\frac{W}{L}$	4
3	Resultados en Xschem, con los parámetros obtenidos	8
4	Cálculo de parámetros $\frac{W}{L}$	12
5	Resultados en Xschem, con los parámetros obtenidos	16
6	Anexos	20
6.1	Anexo I: Programa utilizado para el cálculo de parámetros del diseño	20

1 Objetivos

- Diseñar un amplificador operacional cascode de una etapa, realizando el calculo de las corrientes y de las proporciones $\frac{W}{L}$ con el método propuesto por [?]. Se deben emplear los transistores CMOS del nodo tecnológico SKY130.
- Simular el circuito con la herramienta de Xschem y NGSPICE para comprobar que el diseño cumple con las especificaciones requeridas.

2 Cálculo de parámetros $\frac{W}{L}$

Actividad 1

Emplear la siguiente metodología, propuesta por [?] para diseñar el amplificador *cascade* de una etapa (Ver Figure 9).

Step	Design Equations	Comments
1	$I_9 = SR \times C_L$	SR and C_L specified
2	$g_m = g_{m1} = g_{m2} = GB \times C_L, \frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{g_m^2}{K'_1 I_5}$	GB is in rads/sec, $M1 = M2$
3	$W_3/L_3 = W_4/L_4 = W_1/L_1 = W_2/L_2$	Simplifies design
4	Use Design Procedure BV1 to design W_{10}/L_{10} and I_{10}	Pick I_{10} considering P_{diss}
5	$W_{11}/L_{11} = (I_{10}/4I_1)(W_1/L_1) = (I_{10}/4I_2)(W_2/L_2)$	$M1$ & $M2$ at $V_{DS}(\text{sat})$
6	$\frac{W_7}{L_7} = \frac{W_8}{L_8} = \frac{2I_1}{K'_7 [V_{DD} - ICMR^+ - V_{T7} - V_{DS3}(\text{sat}) + V_{T1}]^2}$	$ICMR^+ = V_{in}(\text{max})$ specified, $M7 = M8$
7	$W_5/L_5 = W_6/L_6 = W_7/L_7 = W_8/L_8$	Design V_{BP2} to put $M7$ and $M8$ at $V_{DS}(\text{sat})$
Alternatively, one can use the low frequency gain to design W_1/L_1 and W_2/L_2		
2'	$A_o = g_m R_{out} \rightarrow \frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{A_o^2}{2K'_1 I_1 R_{out}^2}$	A_o specified, $M1 = M2$, $R_{out} \approx (r_{ds8} g_{m6} r_{ds6}) (r_{ds2} g_{m4} r_{ds4})$
8	$\frac{W_9}{L_9} = \frac{2I_9}{K'_N (ICMR^- - V_{GS1})^2}, V_{GS1} = \sqrt{i_9 / K'_N (\frac{W_1}{L_1})} + V_{T1}$	Note that $ICMR^-$ must be greater than V_{GS1}

Figure 1: Procedimiento de diseño.

Parametros conocidos

$$V_{DD} = 1.8V$$

$$V_{SS} = 0V$$

$$L_{min} = 150.0nm$$

$$0.8V \leq ICMR \leq 1.8V$$

$$K'_N = 151.37604 \frac{\mu A}{V^2}$$

$$K'_P = 57.013889 \frac{\mu A}{V^2}$$

$$V_{TN} = 0.769432V$$

$$V_{TP} = 0.624345V$$

$$\lambda_N = 0.088964V^{-1}$$

$$\lambda_P = 0.068964V^{-1}$$

$$C_L = 12.0pF$$

Características deseadas

$$A_V = 3000 \frac{V}{V}$$

$$P_{diss} \leq 1.0mW$$

$$GB = 10.0MHz$$

$$SR \geq 10 \frac{V}{\mu s}$$

$$0.3V \leq V_{OUT} \leq 1.5V$$

Paso 1

$$I_9 = SR \times C_L = 10 \times 1.2e - 11$$

$$I_9 = 120.0\mu A$$

Paso 2

$$g_m = g_{m1} = g_{m2} = 2\pi \times GB \times C_L = 2\pi \times 10000000.0 \times 1.2e - 11$$

$$g_m = 753.982237\mu S$$

$$I_5 = \frac{I_9}{2} = \frac{0.00012}{2}$$

$$I_5 = 60.0\mu A$$

$$\frac{W_1}{L_1} = \frac{gm^2}{K'_N \times I_5} = \frac{0.000754^2}{0.000151 \times 6e - 05}$$

$$\frac{W_1}{L_1} = 62.591281$$

$$W_1 = \frac{W_1}{L_1} \times L_{min} = 62.591281 \times 1.5e - 07$$

$$W_1 = W_2 = 9.388692\mu m$$

Paso 3

$$W_4 = W_3 = W_1 = 9.388692\mu m$$

Paso 4

Se escoge $aI_{10} = 12.0\mu A$

Se escoge $a\frac{W_{10}}{L_{10}} = 50$

$$W_{10} = \frac{W_{10}}{L_{10}} \times L_{min} = 50 \times 1.5e - 07$$

$$W_{10} = 7.5\mu m$$

Paso 5

$$I_1 = I_2 = \frac{I_9}{2} = \frac{0.00012}{2}$$

$$I_1 = 60.0\mu A$$

$$\frac{W_{11}}{L_{11}} = \frac{I_{10}}{4 \times I_1} \times \frac{W_1}{L_1} = \frac{1.2e-05}{4 \times 6e-05} \times 62.591281$$

$$\frac{W_{11}}{L_{11}} = 3.129564$$

$$W_{11} = \frac{W_{11}}{L_{11}} \times L_{min} = 3.129564 \times 1.5e - 07$$

$$W_{11} = 0.469435\mu m$$

Paso 6

$$V_{DS3}(sat) = \sqrt{\frac{2 \times I_1}{K'_N \times \frac{W_1}{L_1}}} = \sqrt{\frac{2 \times 6e-05}{0.000151 \times 62.591281}}$$

$$V_{DS3}(sat) = 0.11254V$$

$$\frac{W_7}{L_7} = \frac{2 \times I_1}{K'_P \times (V_{DD} - ICMR^+ - |V_{TP}| - V_{DS3}(sat) + V_{TN})^2} = \frac{2 \times 6e-05}{5.7e-05 \times (1.8 - 1.8 - 0.624345 - 0.11254 + 0.769432)^2}$$

$$\frac{W_7}{L_7} = 64.667113$$

$$W_7 = \frac{W_7}{L_7} \times L_{min} = 64.667113 \times 1.5e - 07$$

$$W_7 = W_8 = 9.700067\mu m$$

Paso 7

$$W_5 = W_6 = W_7 = 9.700067\mu m$$

Paso 8

$$V_{GS1} = \sqrt{\frac{I_9}{K'_N \times \frac{W_1}{L_1}}} + V_{TN} = \sqrt{\frac{0.00012}{0.000151 \times 62.591281}} + 0.769432$$

$$V_{GS1} = 0.881972V$$

$$\frac{W_9}{L_9} = \frac{2 \times I_9}{K'_N \times (ICMR^- - V_{GS1})^2} = \frac{2 \times 0.00012}{0.000151 \times (0.8 - 0.881972)^2}$$

$$\frac{W_9}{L_9} = 235.954312$$

$$W_9 = \frac{W_9}{L_9} \times L_{min} = 235.954312 \times 1.5e - 07$$

$$W_9 = 35.393147\mu m$$

Paso 9

$$r_{ds2} = r_{ds4} = \frac{1}{\lambda_N \times I_2} = \frac{1}{0.088964 \times 6e-05}$$

$$r_{ds2} = 187.342259 K\Omega$$

$$r_{ds6} = r_{ds8} = \frac{1}{\lambda_P \times I_2} = \frac{1}{0.068964 \times 6e-05}$$

$$r_{ds6} = 241.67292 K\Omega$$

$$g_{m4} = \sqrt{2 \times K'_N \times \frac{W_4}{L_4} \times I_2} = \sqrt{2 \times 0.000151 \times 62.591281 \times 6e-05}$$

$$g_{m4} = 1066.291905 \mu S$$

$$g_{m6} = \sqrt{2 \times K'_P \times \frac{W_6}{L_6} \times I_2} = \sqrt{2 \times 5.7e-05 \times 64.667113 \times 6e-05}$$

$$g_{m6} = 665.154742 \mu S$$

$$R_{OUT} \approx (r_{ds2} \times g_{m4} \times r_{ds4}) || (r_{ds6} \times g_{m6} \times r_{ds8})$$

$$R_{OUT} \approx (187342.258928 \times 0.001066 \times 187342.258928) || (241672.919784 \times 0.000665 \times 241672.919784)$$

$$R_{OUT} \approx 19.061511 M\Omega$$

$$A_0 = g_m \times R_{OUT} = 0.000754 \times 19061511.096319$$

$$A_0 = 14372.040774 = 83.150369 db$$

Paso 10

$$V_{DS8}(sat) = \sqrt{\frac{2 \times I_2}{K'_N \times \frac{W_8}{L_8}}} = \sqrt{\frac{2 \times 6e-05}{0.000151 \times 64.667113}}$$

$$V_{DS8}(sat) = 0.110719 V$$

$$V_{DS9}(sat) = \sqrt{\frac{2 \times I_9}{K'_N \times \frac{W_9}{L_9}}} = \sqrt{\frac{2 \times 0.00012}{0.000151 \times 235.954312}}$$

$$V_{DS9}(sat) = 0.081972 V$$

$$V_{OUT}(max) = V_{DD} - 2 \times V_{DS8}(sat) = 1.8 - 2 \times 0.110719$$

$$V_{OUT}(max) = 1.578563 V$$

$$V_{OUT}(min) = 2 \times V_{DS3}(sat) + V_{DS9}(sat) = 2 \times 0.11254 + 0.081972$$

$$V_{OUT}(min) = 0.307051 V$$

Parámetros calculados

$$W_1 = W_2 = W_3 = W_4 = 9.388692 \mu m$$

$$W_5 = W_6 = W_7 = W_8 = 9.700067 \mu m$$

$$W_9 = 35.393147 \mu m$$

$$W_{10} = 7.5 \mu m$$

$$W_{11} = 0.469435 \mu m$$

$$L_1 - L_{11} = 0.15 \mu m$$

3 Resultados en Xschem, con los parámetros obtenidos

Actividad 2

Utilizando el simulador NGSPICE en la herramienta de Xschem, simular el amplificador operacional con las razones $\frac{W}{L}$ calculadas previamente.

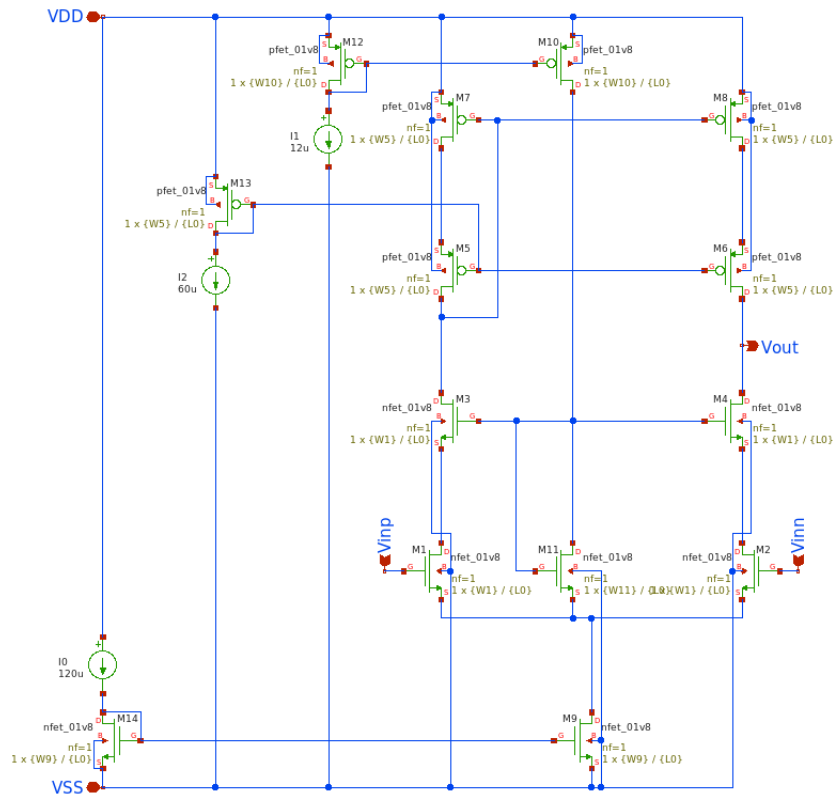


Figure 2: Diagrama esquemático del amplificador operacional cascode de una etapa.

Resultados obtenidos de la simulación

$$A_V = \frac{A_V(0)}{R \times C} = \frac{21.116722}{100000.0 \times 1.2e-08}$$

$$A_V = 17597.268667$$

$$P_{diss} = V_{DD} \times (I_9 + I_{10}) = 1.8 \times (0.00012 + 1.2e-05)$$

$$P_{diss} = 0.2376mW$$

$$GB = 329.068635KHz$$

$$SlewRate = 18.923227 \frac{V}{\mu s}$$

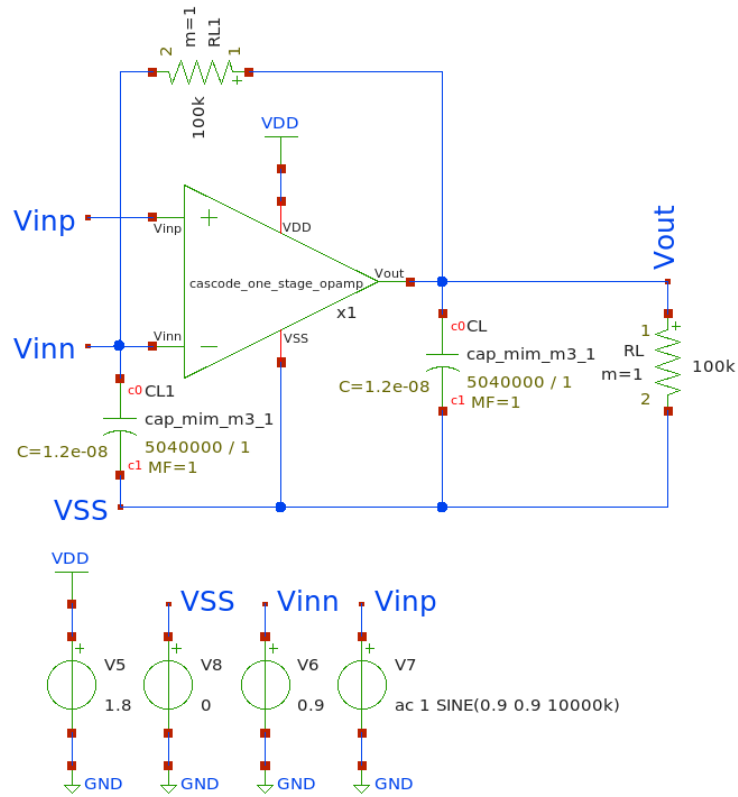


Figure 3: Circuito utilizado para obtener la ganancia del amplificador operacional cascode de una etapa.

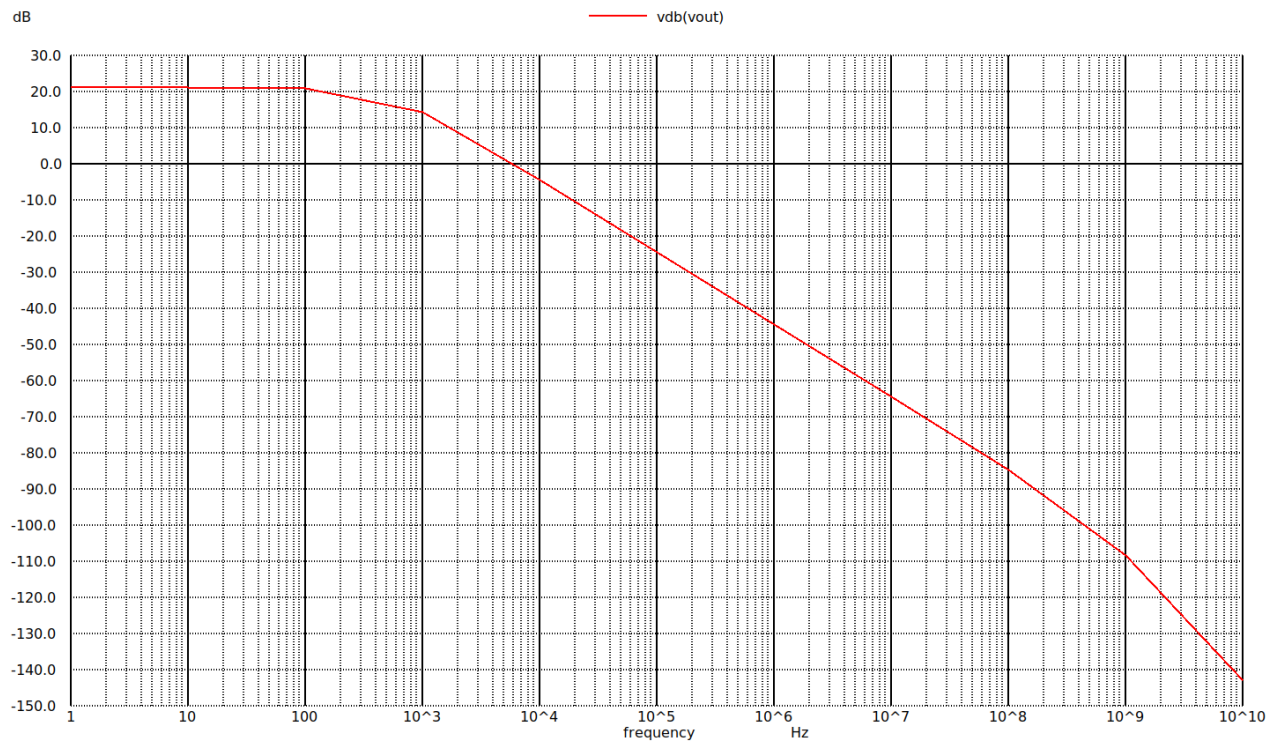


Figure 4: Diagrama de Bode obtenido de la Figure 11.

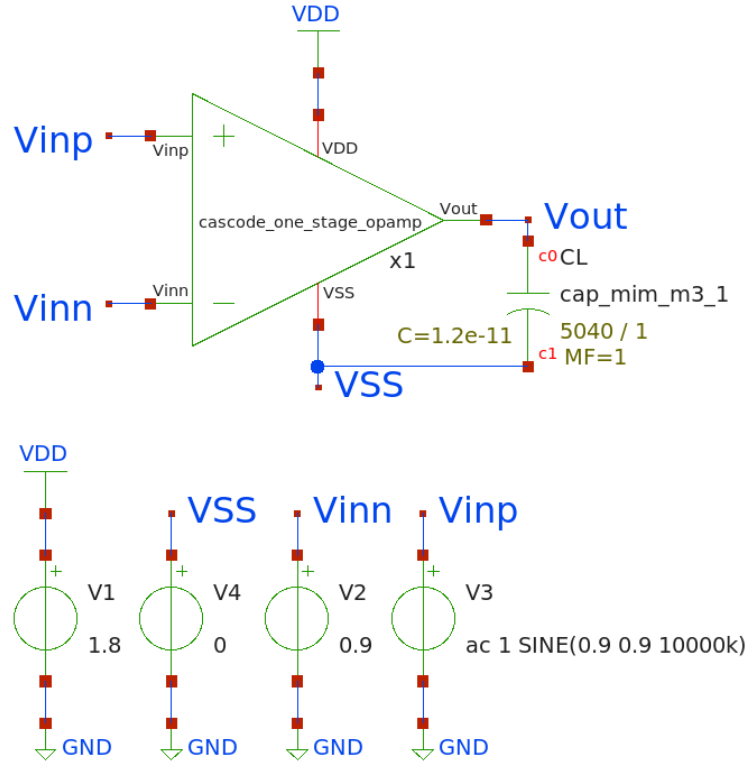


Figure 5: Circuito utilizado para obtener la ganancia en ancho de banda (*Gain Bandwidth*) del amplificador operacional cascode de una etapa.

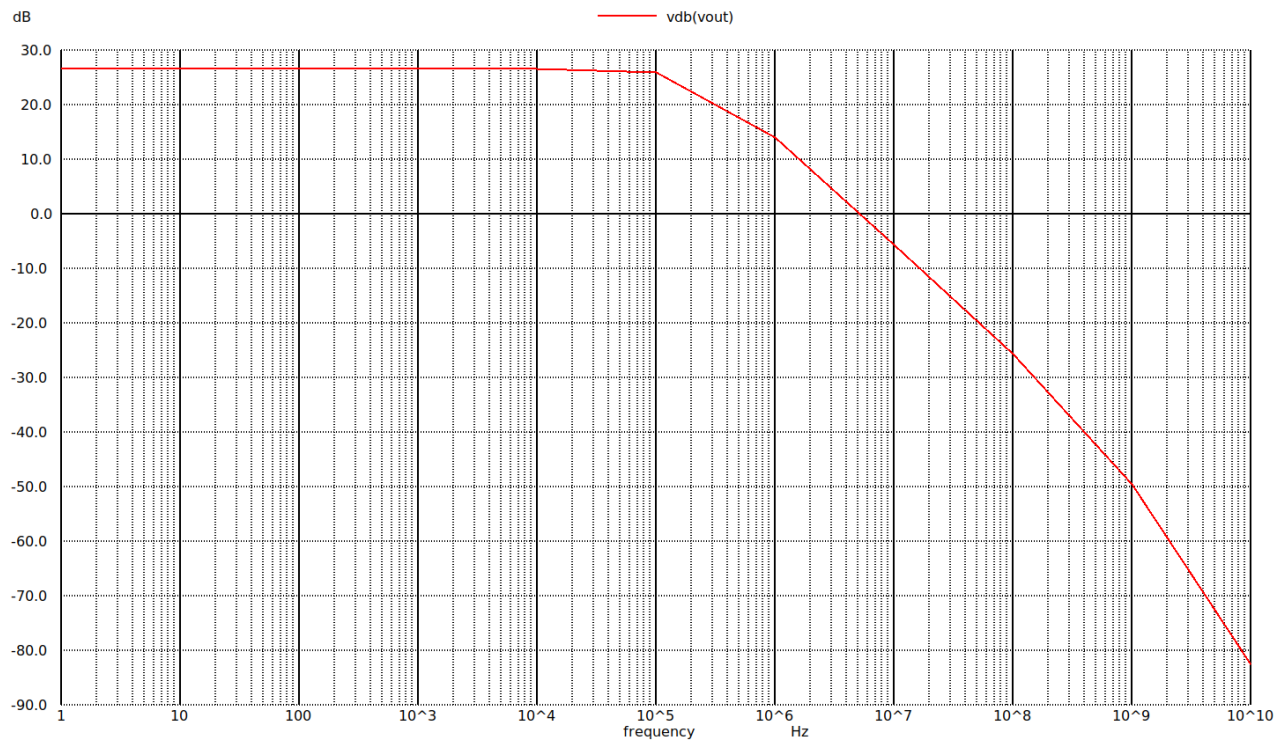


Figure 6: Diagrama de Bode obtenido de la Figure 13.

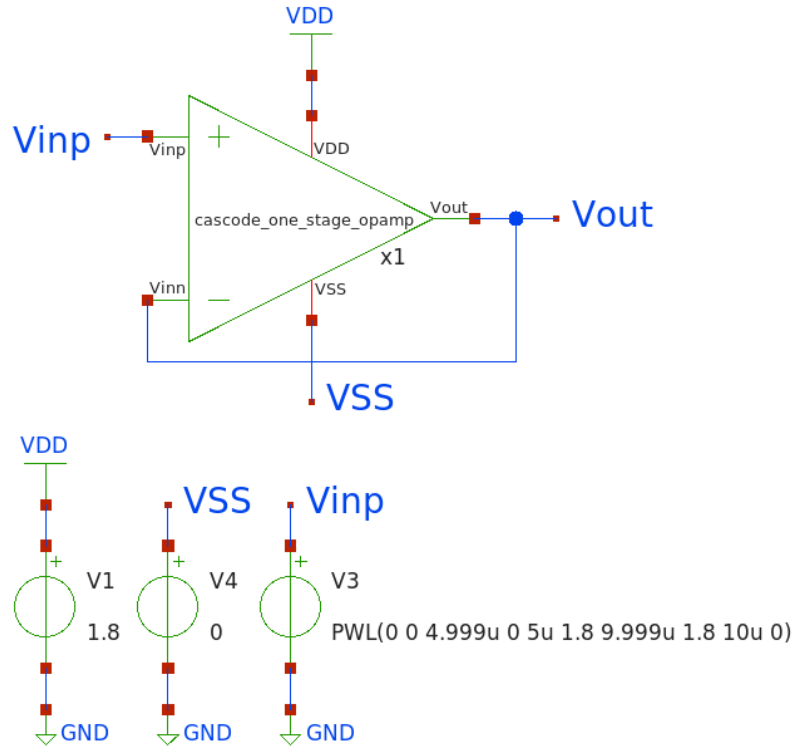


Figure 7: Circuito utilizado para evaluar obtener el *Slew Rate* del amplificador operacional cascode de una etapa (Seguidor de voltaje).

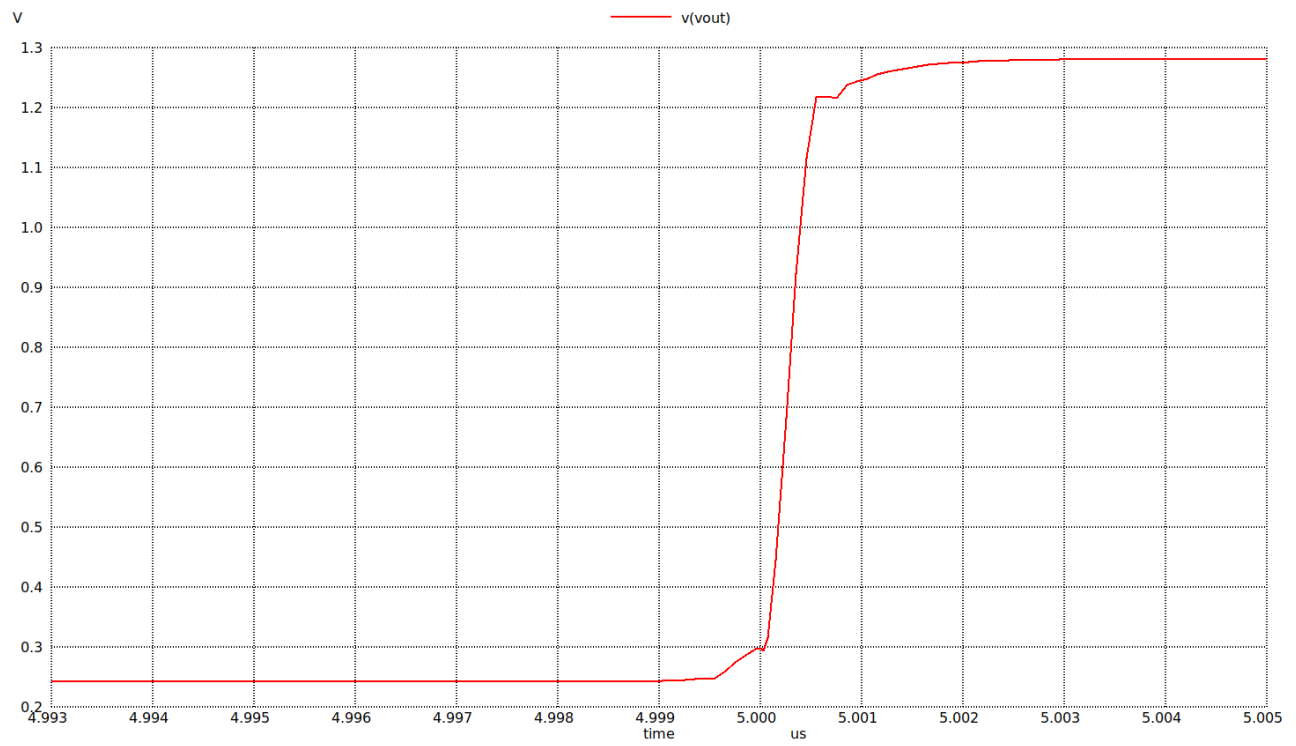


Figure 8: Grafica del voltaje de salida obtenido de la Figure 15.

4 Cálculo de parámetros $\frac{W}{L}$

Actividad 2

Emplear la siguiente metodología, propuesta por [?] para diseñar el amplificador *folded cascode* de una etapa (Ver Figure 9).

Step	Design Equations	Comments
1	$I_9 = SR \times C_L$	SR and C_L specified
2	$g_m = g_{m1} = g_{m2} = GB \times C_L, \frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{g_m^2}{K'_1 I_5}$	GB is in rads/sec, $M1 = M2$
3	$W_3/L_3 = W_4/L_4 = W_1/L_1 = W_2/L_2$	Simplifies design
4	Use Design Procedure BV1 to design W_{10}/L_{10} and I_{10}	Pick I_{10} considering P_{diss}
5	$W_{11}/L_{11} = (I_{10}/4I_1)(W_1/L_1) = (I_{10}/4I_2)(W_2/L_2)$	$M1$ & $M2$ at $V_{DS}(\text{sat})$
6	$\frac{W_7}{L_7} = \frac{W_8}{L_8} = \frac{2I_1}{K'_7[V_{DD} - ICMR^+ - V_{T7} - V_{DS3}(\text{sat}) + V_{T1}]^2}$	$ICMR^+ = V_{in}(\text{max})$ specified, $M7 = M8$
7	$W_5/L_5 = W_6/L_6 = W_7/L_7 = W_8/L_8$	Design V_{BP2} to put $M7$ and $M8$ at $V_{DS}(\text{sat})$
Alternatively, one can use the low frequency gain to design W_1/L_1 and W_2/L_2		
2'	$A_o = g_m R_{out} \rightarrow \frac{W_1}{L_1} = \frac{W_2}{L_2} = \frac{A_o^2}{2K'_1 I_1 R_{out}^2}$	A_o specified, $M1 = M2$, $R_{out} \approx (r_{ds8} g_{m6} r_{ds6}) (r_{ds2} g_{m4} r_{ds4})$
8	$\frac{W_9}{L_9} = \frac{2I_9}{K'_N(ICMR^- - V_{GS1})^2}, V_{GS1} = \sqrt{i_9/K'_N(\frac{W_1}{L_1})} + V_{T1}$	Note that $ICMR^-$ must be greater than V_{GS1}

Figure 9: Procedimiento de diseño.

Parametros conocidos

$$V_{DD} = 1.8V$$

$$V_{SS} = 0V$$

$$L_{min} = 150.0nm$$

$$0.8V \leq ICMR \leq 1.8V$$

$$K'_N = 151.37604 \frac{\mu A}{V^2}$$

$$K'_P = 57.013889 \frac{\mu A}{V^2}$$

$$V_{TN} = 0.769432V$$

$$V_{TP} = 0.624345V$$

$$\lambda_N = 0.088964V^{-1}$$

$$\lambda_P = 0.068964V^{-1}$$

$$C_L = 12.0pF$$

Características deseadas

$$A_V = 3000 \frac{V}{V}$$

$$P_{diss} \leq 1.0mW$$

$$GB = 10.0MHz$$

$$SR \geq 10 \frac{V}{\mu s}$$

$$0.3V \leq V_{OUT} \leq 1.5V$$

Paso 1

$$I_9 = SR \times C_L = 10 \times 1.2e - 11$$

$$I_9 = 120.0\mu A$$

Paso 2

$$g_m = g_{m1} = g_{m2} = 2\pi \times GB \times C_L = 2\pi \times 10000000.0 \times 1.2e - 11$$

$$g_m = 753.982237\mu S$$

$$I_5 = \frac{I_9}{2} = \frac{0.00012}{2}$$

$$I_5 = 60.0\mu A$$

$$\frac{W_1}{L_1} = \frac{gm^2}{K'_N \times I_5} = \frac{0.000754^2}{0.000151 \times 6e - 05}$$

$$\frac{W_1}{L_1} = 62.591281$$

$$W_1 = \frac{W_1}{L_1} \times L_{min} = 62.591281 \times 1.5e - 07$$

$$W_1 = W_2 = 9.388692\mu m$$

Paso 3

$$W_4 = W_3 = W_1 = 9.388692\mu m$$

Paso 4

Se escoge $aI_{10} = 12.0\mu A$

Se escoge $a\frac{W_{10}}{L_{10}} = 50$

$$W_{10} = \frac{W_{10}}{L_{10}} \times L_{min} = 50 \times 1.5e - 07$$

$$W_{10} = 7.5\mu m$$

Paso 5

$$I_1 = I_2 = \frac{I_9}{2} = \frac{0.00012}{2}$$

$$I_1 = 60.0\mu A$$

$$\frac{W_{11}}{L_{11}} = \frac{I_{10}}{4 \times I_1} \times \frac{W_1}{L_1} = \frac{1.2e-05}{4 \times 6e-05} \times 62.591281$$

$$\frac{W_{11}}{L_{11}} = 3.129564$$

$$W_{11} = \frac{W_{11}}{L_{11}} \times L_{min} = 3.129564 \times 1.5e - 07$$

$$W_{11} = 0.469435\mu m$$

Paso 6

$$V_{DS3}(sat) = \sqrt{\frac{2 \times I_1}{K'_N \times \frac{W_1}{L_1}}} = \sqrt{\frac{2 \times 6e-05}{0.000151 \times 62.591281}}$$

$$V_{DS3}(sat) = 0.11254V$$

$$\frac{W_7}{L_7} = \frac{2 \times I_1}{K'_P \times (V_{DD} - I_{CMR}^+ - |V_{TP}| - V_{DS3}(sat) + V_{TN})^2} = \frac{2 \times 6e-05}{5.7e-05 \times (1.8 - 1.8 - 0.624345 - 0.11254 + 0.769432)^2}$$

$$\frac{W_7}{L_7} = 64.667113$$

$$W_7 = \frac{W_7}{L_7} \times L_{min} = 64.667113 \times 1.5e - 07$$

$$W_7 = W_8 = 9.700067\mu m$$

Paso 7

$$W_5 = W_6 = W_7 = 9.700067\mu m$$

Paso 8

$$V_{GS1} = \sqrt{\frac{I_9}{K'_N \times \frac{W_1}{L_1}}} + V_{TN} = \sqrt{\frac{0.00012}{0.000151 \times 62.591281}} + 0.769432$$

$$V_{GS1} = 0.881972V$$

$$\frac{W_9}{L_9} = \frac{2 \times I_9}{K'_N \times (I_{CMR}^- - V_{GS1})^2} = \frac{2 \times 0.00012}{0.000151 \times (0.8 - 0.881972)^2}$$

$$\frac{W_9}{L_9} = 235.954312$$

$$W_9 = \frac{W_9}{L_9} \times L_{min} = 235.954312 \times 1.5e - 07$$

$$W_9 = 35.393147\mu m$$

Paso 9

$$r_{ds2} = r_{ds4} = \frac{1}{\lambda_N \times I_2} = \frac{1}{0.088964 \times 6e-05}$$

$$r_{ds2} = 187.342259 K\Omega$$

$$r_{ds6} = r_{ds8} = \frac{1}{\lambda_P \times I_2} = \frac{1}{0.068964 \times 6e-05}$$

$$r_{ds6} = 241.67292 K\Omega$$

$$g_{m4} = \sqrt{2 \times K'_N \times \frac{W_4}{L_4} \times I_2} = \sqrt{2 \times 0.000151 \times 62.591281 \times 6e-05}$$

$$g_{m4} = 1066.291905 \mu S$$

$$g_{m6} = \sqrt{2 \times K'_P \times \frac{W_6}{L_6} \times I_2} = \sqrt{2 \times 5.7e-05 \times 64.667113 \times 6e-05}$$

$$g_{m6} = 665.154742 \mu S$$

$$R_{OUT} \approx (r_{ds2} \times g_{m4} \times r_{ds4}) || (r_{ds6} \times g_{m6} \times r_{ds8})$$

$$R_{OUT} \approx (187342.258928 \times 0.001066 \times 187342.258928) || (241672.919784 \times 0.000665 \times 241672.919784)$$

$$R_{OUT} \approx 19.061511 M\Omega$$

$$A_0 = g_m \times R_{OUT} = 0.000754 \times 19061511.096319$$

$$A_0 = 14372.040774 = 83.150369 db$$

Paso 10

$$V_{DS8}(sat) = \sqrt{\frac{2 \times I_2}{K'_N \times \frac{W_8}{L_8}}} = \sqrt{\frac{2 \times 6e-05}{0.000151 \times 64.667113}}$$

$$V_{DS8}(sat) = 0.110719 V$$

$$V_{DS9}(sat) = \sqrt{\frac{2 \times I_9}{K'_N \times \frac{W_9}{L_9}}} = \sqrt{\frac{2 \times 0.00012}{0.000151 \times 235.954312}}$$

$$V_{DS9}(sat) = 0.081972 V$$

$$V_{OUT}(max) = V_{DD} - 2 \times V_{DS8}(sat) = 1.8 - 2 \times 0.110719$$

$$V_{OUT}(max) = 1.578563 V$$

$$V_{OUT}(min) = 2 \times V_{DS3}(sat) + V_{DS9}(sat) = 2 \times 0.11254 + 0.081972$$

$$V_{OUT}(min) = 0.307051 V$$

Parámetros calculados

$$W_1 = W_2 = W_3 = W_4 = 9.388692 \mu m$$

$$W_5 = W_6 = W_7 = W_8 = 9.700067 \mu m$$

$$W_9 = 35.393147 \mu m$$

$$W_{10} = 7.5 \mu m$$

$$W_{11} = 0.469435 \mu m$$

$$L_1 - L_{11} = 0.15 \mu m$$

5 Resultados en Xschem, con los parámetros obtenidos

Actividad 2

Utilizando el simulador NGSPICE en la herramienta de Xschem, simular el amplificador operacional con las razones $\frac{W}{L}$ calculadas previamente.

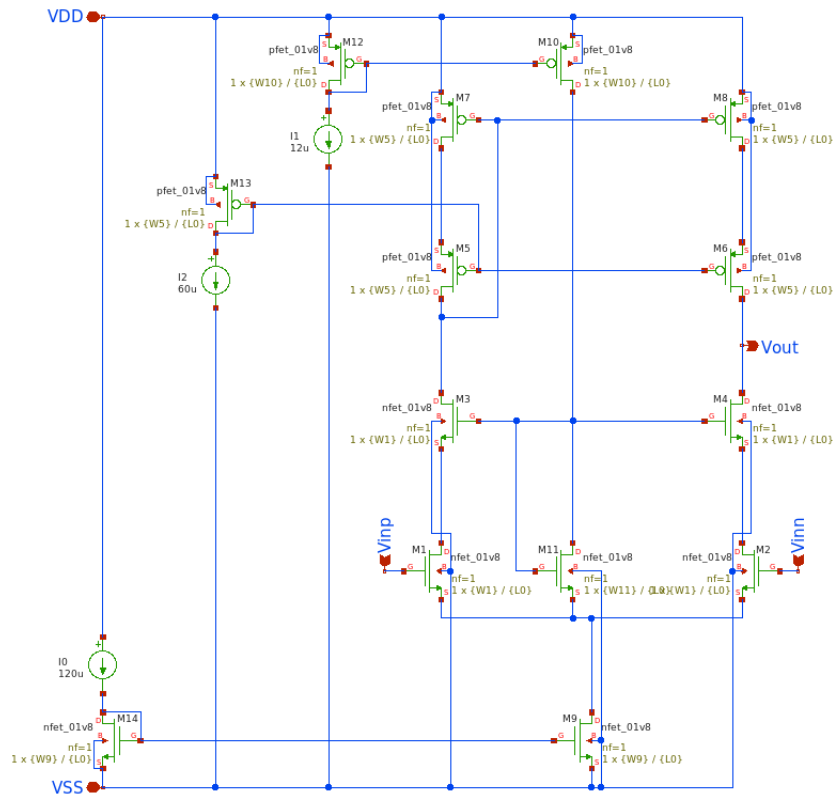


Figure 10: Diagrama esquemático del amplificador operacional cascode de una etapa.

Resultados obtenidos de la simulación

$$A_V = \frac{A_V(0)}{R \times C} = \frac{21.116722}{100000.0 \times 1.2e-08}$$

$$A_V = 17597.268667$$

$$P_{diss} = V_{DD} \times (I_9 + I_{10}) = 1.8 \times (0.00012 + 1.2e-05)$$

$$P_{diss} = 0.2376mW$$

$$GB = 329.068635KHz$$

$$SlewRate = 18.923227 \frac{V}{\mu s}$$

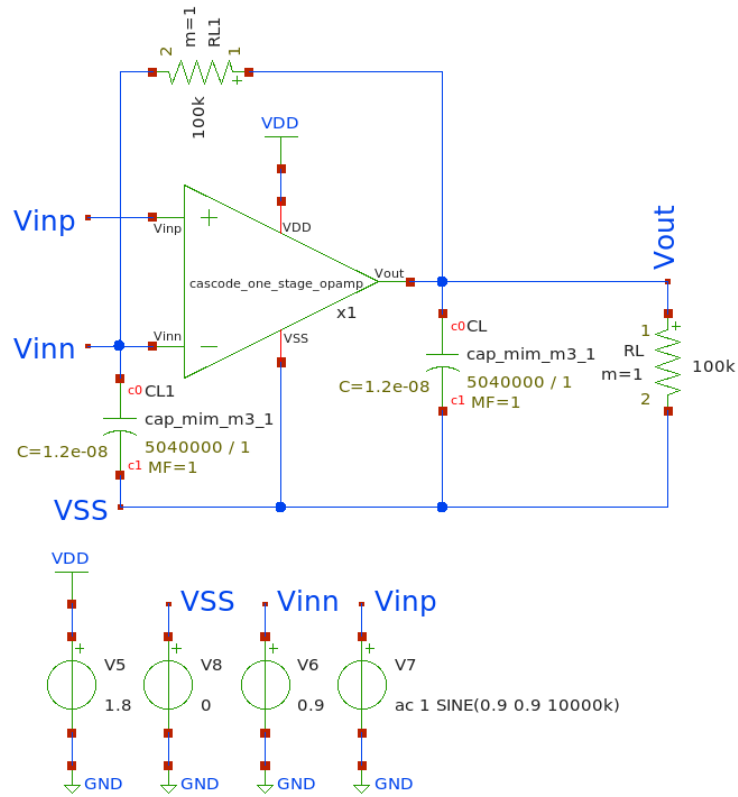


Figure 11: Circuito utilizado para obtener la ganancia del amplificador operacional cascode de una etapa.

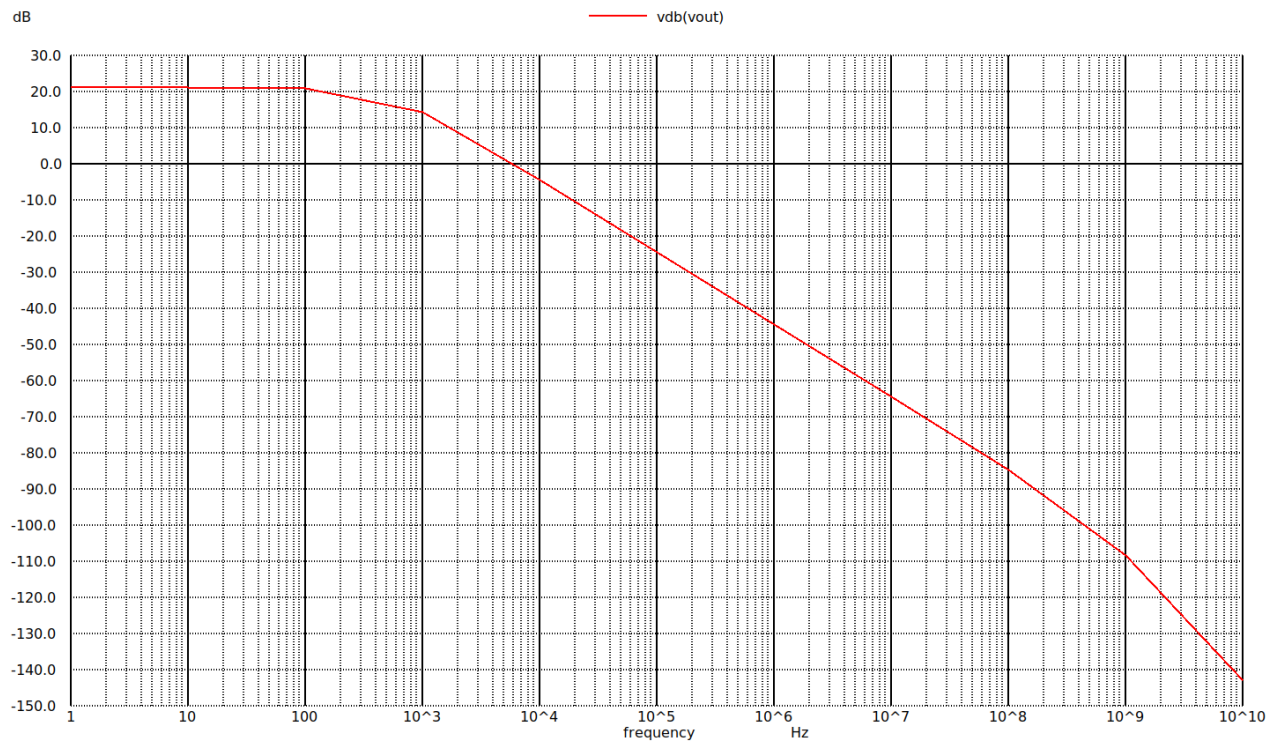


Figure 12: Diagrama de Bode obtenido de la Figure 11.

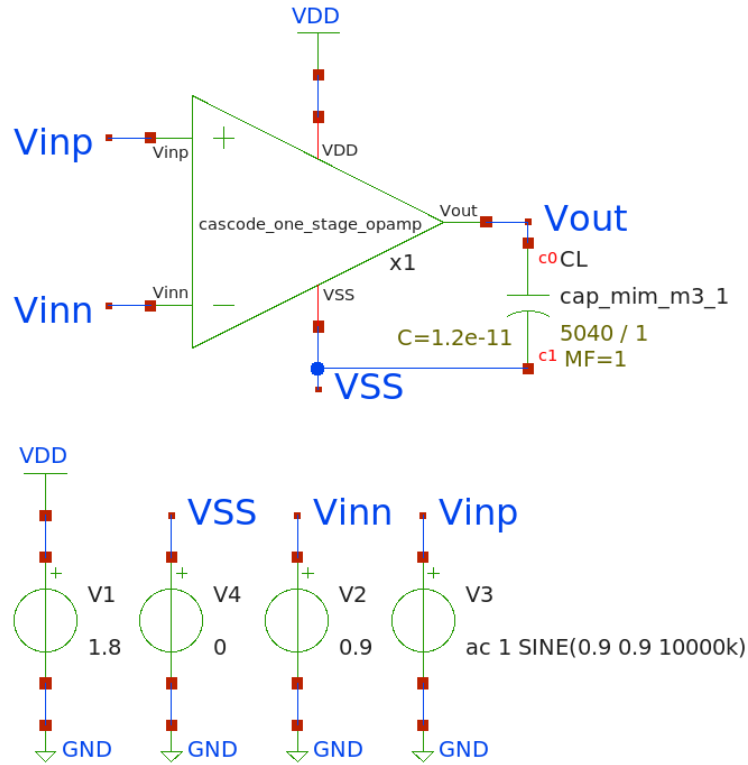


Figure 13: Circuito utilizado para obtener la ganancia en ancho de banda (*Gain Bandwidth*) del amplificador operacional cascode de una etapa.

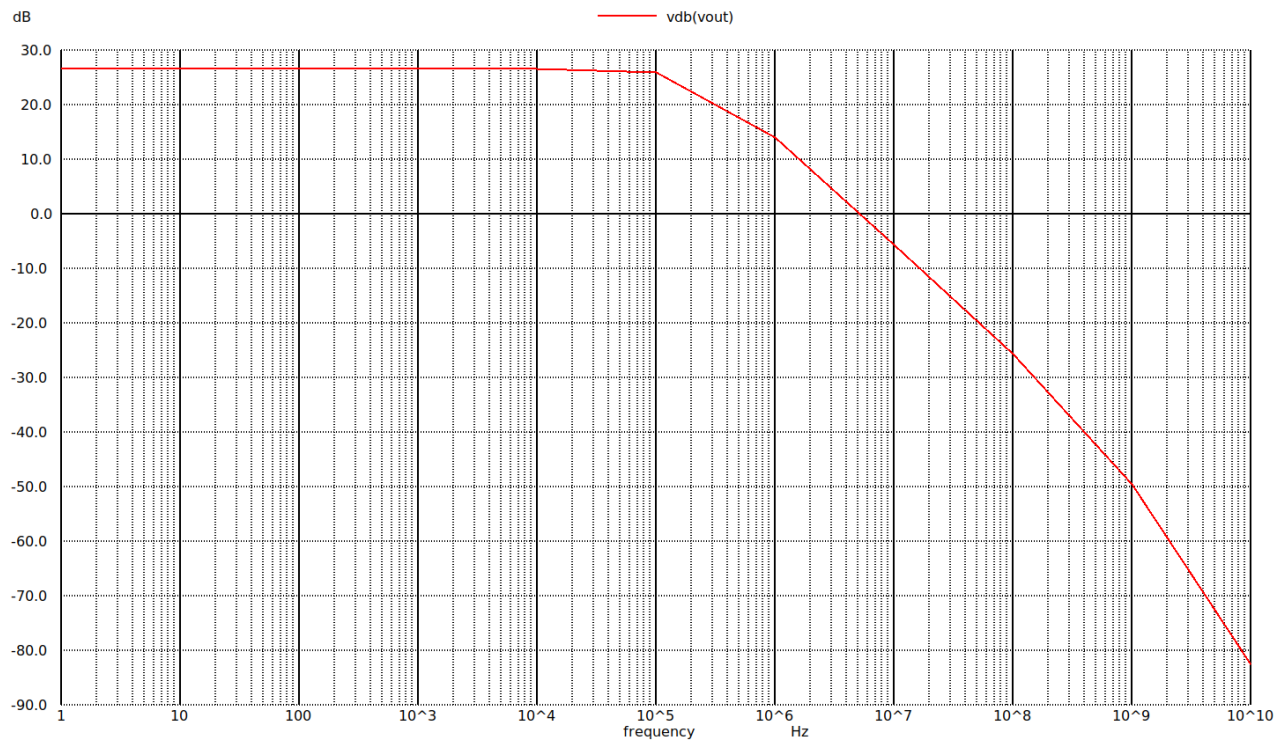


Figure 14: Diagrama de Bode obtenido de la Figure 13.

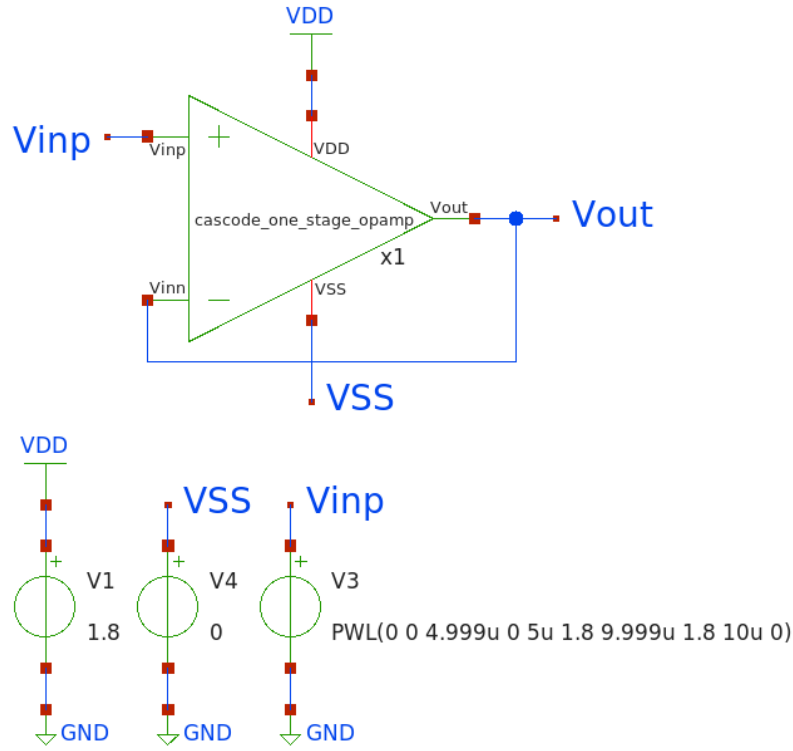


Figure 15: Circuito utilizado para evaluar obtener el *Slew Rate* del amplificador operacional cascode de una etapa (Seguidor de voltaje).

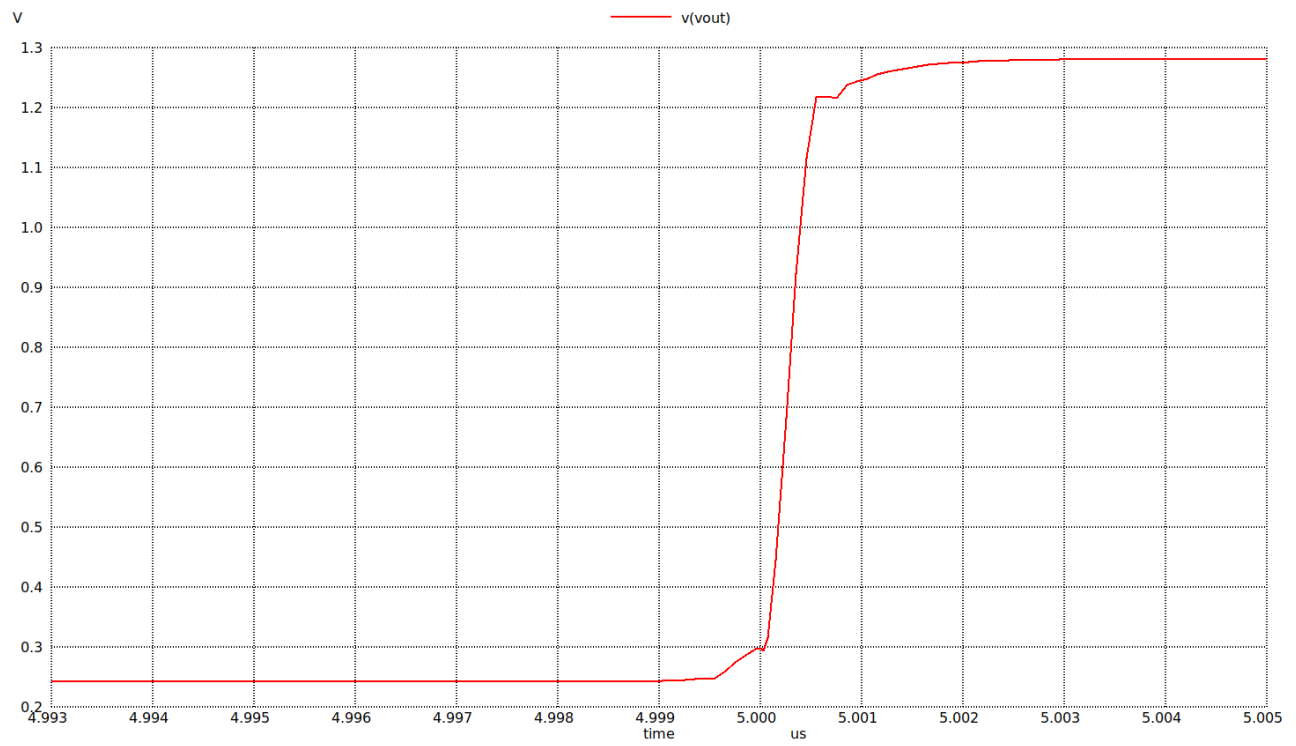


Figure 16: Grafica del voltaje de salida obtenido de la Figure 15.

6 Anexos

6.1 Anexo I: Programa utilizado para el cálculo de parámetros del diseño

```
1 from math import sqrt
2 from math import pi
3 from math import log10
4 import math
5 import numpy as np
6
7 # Datos propuestos:
8 AV = 3000
9 VDD = 1.8
10 VSS = 0
11 GB = 10e6
12 SR = 10
13 Vout_max = 1.5      #Vout(max)
14 Vout_min = 0.3      #Vout(min)
15 ICMR_max = 1.8      #Vin(max)
16 ICMR_min = 0.8      #Vin(min)
17 Pd = 1e-3
18
19 # Parametros
20 LO = 0.15e-6
21 Cl = 12e-12
22 # Transistor canal N
23 Vthn = 0.769432
24 Kn = 0.00015137603990044484
25 Lambda_n = 0.08896373280684104
26 # Transistor canal P
27 Vthp = 0.624345
28 Kp = 0.000057013889055450486
29 Lambda_p = 0.06896373280684104
30
31 # Paso 1
32 I9=SR*Cl/(1e-6)
33
34 # Paso 2
35 gm=2*pi*GB*Cl
36 I5=0.5*I9
37 W1_L1=(gm**2)/(Kn*I5)
38 W1=W1_L1*LO
```

```

39 W2=W1
40
41 # Paso 3
42 W3=W1
43 W4=W1
44
45 # Paso 4
46 I10=12e-6          # I9/10
47 W10_L10=50
48 W10=W10_L10*L0
49
50 # Paso 5
51 I1=0.5*I9
52 I2=I1
53 W11_L11=(I10/(4*I1))*W1_L1
54 W11=W11_L11*L0
55
56 # Paso 6
57 Vds3_sat=sqrt((2*I1)/(Kn*W1_L1))
58 W7_L7=(2*I1)/(Kp*(VDD-ICMR_max-Vthp-Vds3_sat+Vthn))
59 W7=W7_L7*L0
60 W8=W7
61
62 # Paso 7
63 W5=W7
64 W6=W7
65
66 # Paso 8
67 Vgs1=sqrt(I9/(Kn*W1_L1))+Vthn
68 W9_L9=(2*I9)/(Kn*(ICMR_min-Vgs1)**2)
69 W9=W9_L9*L0
70
71 # Paso 9
72 rds2=1/(Lambda_n*I2)
73 rds6=1/(Lambda_p*I2)
74 gm4=sqrt(2*Kn*W1_L1*I2)
75 gm6=sqrt(2*Kp*W7_L7*I2)
76 Rout=1/((1/(rds2*gm4*rds2))+(1/(rds6*gm6*rds6)))
77 A0=gm*Rout
78 A0_db=20*log10(A0)
79
80 # Paso 10
81 Vds8_sat=sqrt((2*I2)/(Kn*W7_L7))
82 Vds9_sat=sqrt((2*I9)/(Kn*W9_L9))
83 V0_max=VDD-(2*Vds8_sat)

```

```

84 V0_min=(2*Vds3_sat)+Vds9_sat
85
86 # Calculo de Av
87 Datos_Av = np.loadtxt('/home/ricardo/RATT_repos/Proyectos_xschem/
      simulations/cascode_one_stage_opamp_av.ssv')
88 Y_Av = Datos_Av[0:1, 1]
89 Av_final = Y_Av[0]/(100e3*1.2e-8)
90
91 # Calculo de GB
92 Datos_GB = np.loadtxt('/home/ricardo/RATT_repos/Proyectos_xschem/
      simulations/cascode_one_stage_opamp_gb.ssv')
93 X_GB = Datos_GB[5:7, 0]
94 Y_GB = Datos_GB[5:7, 1]
95 m_GB = (Y_GB[1]-Y_GB[0])/(X_GB[1]-X_GB[0])
96 b_GB = Y_GB[1]-(m_GB*X_GB[1])
97 GB_final = (Y_GB[0]-3-b_GB)/m_GB
98
99 # Calculo de Pdis
100 Pdis=VDD*(I9+I10)
101
102 # Calculo de SR
103 Datos_SR = np.loadtxt('/home/ricardo/RATT_repos/Proyectos_xschem/
      simulations/cascode_one_stage_opamp_sr.ssv')
104 X = Datos_SR[50010:50018, 0]
105 Y = Datos_SR[50010:50018, 1]
106 x_bias1 = np.c_[np.ones(X.shape[0]), X]
107 # Calculo de la pendiente para el SR -> theta = (X^T * X)^-1 * X^T * y
108 theta = np.linalg.inv(x_bias1.T @ x_bias1) @ x_bias1.T @ Y

```

Listing 1: Programa utilizado para el cálculo de parámetros del diseño.