Instituto Politécnico Nacional

Centro de Investigación en Computación

VLSI avanzado

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

Profesor:

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Ciudad de México, 21 de junio de 2024

Tabla de contenido

1. Objetivos

- Diseñar un amplificador operacional cascodo de una etapa, realizando el calculo de las corrientes y de las proporciones $\frac{W}{L}$ con el método propuesto por [1]. 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 [1] para diseñar el amplificador simple de una etapa (Ver Figura 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}(sat)
6	$\frac{W_7}{L_7} = \frac{W_8}{L_8} = \frac{2I_1}{K'_7[V_{DD} - ICMR^+ - \lvert V_{T7}\rvert - V_{DS3}(sat) + V_{T1}]^2}$	$ICMR^+ = V_{in}$(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}(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, $R_{out} \approx (r_{ds8} g_{m6} r_{ds6}) \vert\vert (r_{ds2} g_{m4} r_{ds4})$
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}

Figura 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 a$I_{10} = 12.0\mu A$

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.

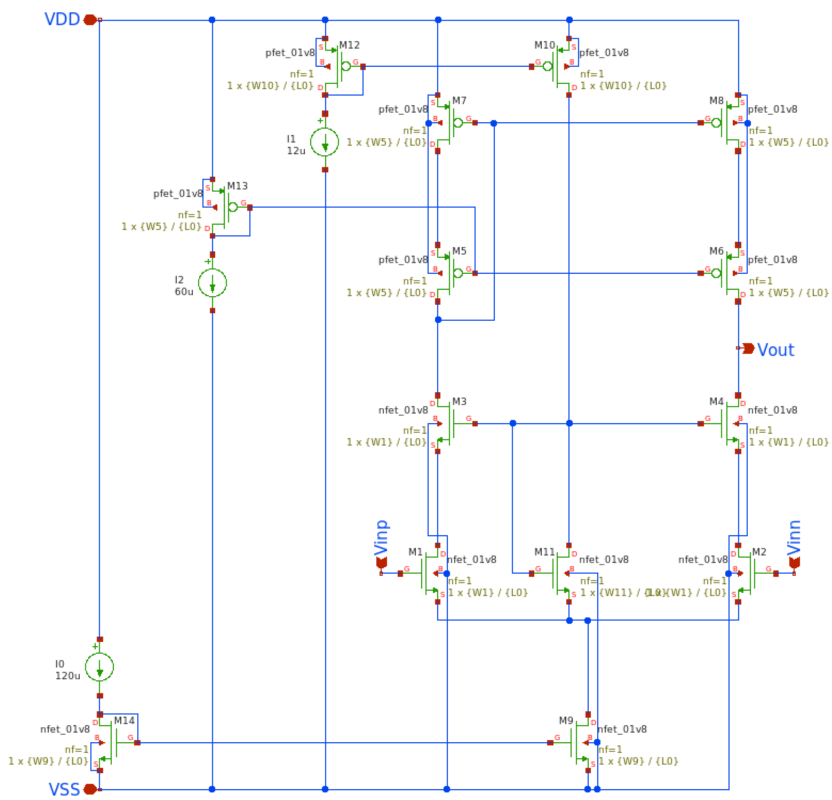

Figura 2: Diagrama esquemático del amplificador operacional cascodo de una etapa.

Resultados obtenidos de la simulación

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

$A_V = 17597.268667$

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

$P_{diss} = 0.2376mW$

$GB = 329.068635KHz$

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

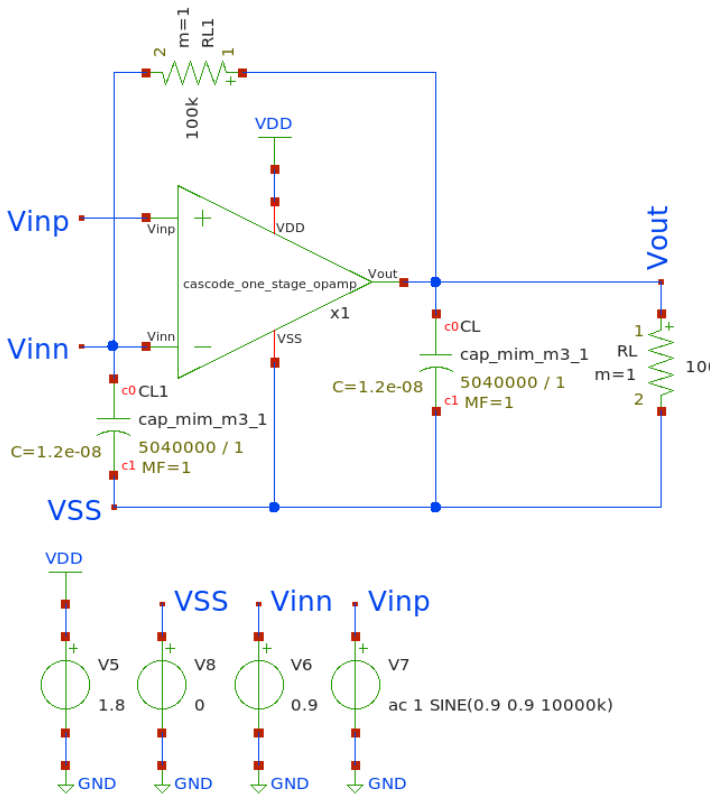

Figura 3: Circuito utilizado para obtener la ganancia del amplificador operacional cascodo de una etapa.

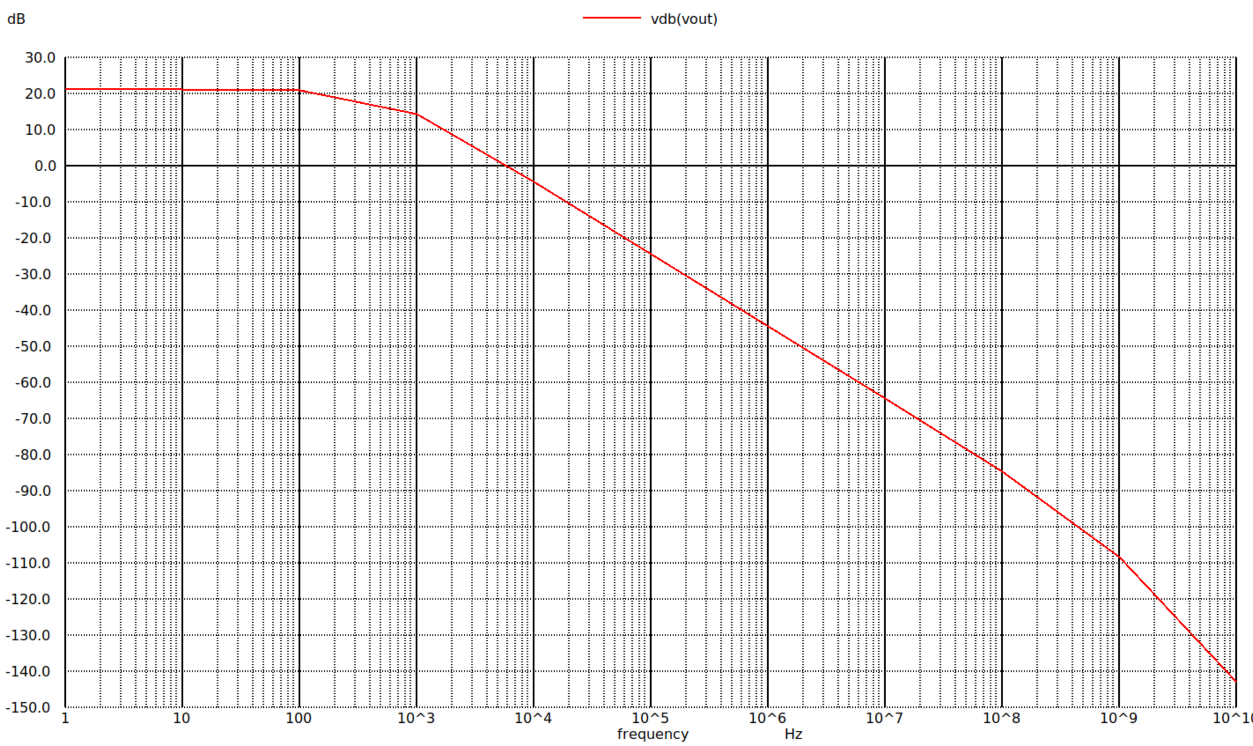

Figura 4: Diagrama de Bode obtenido de la Figura 11.

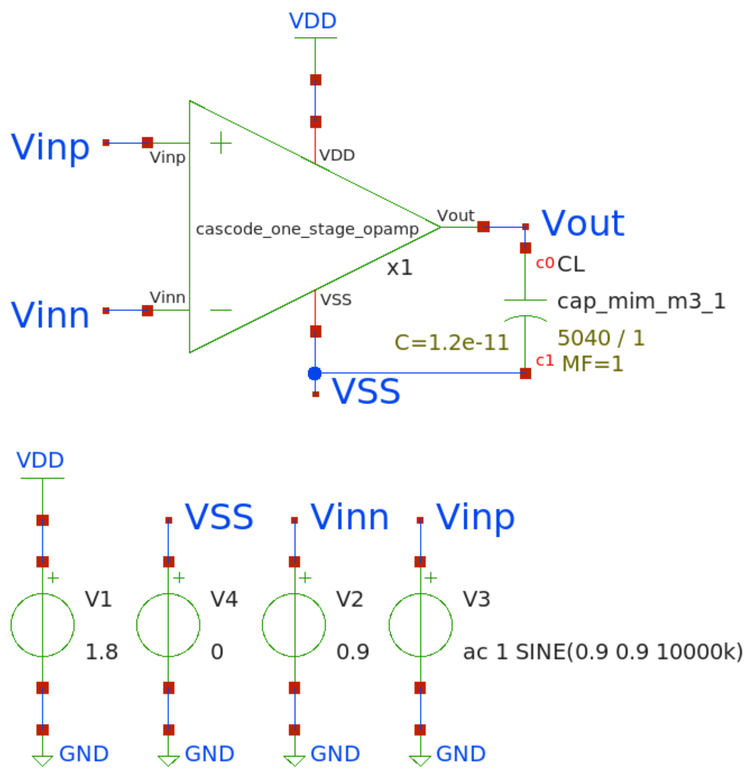

Figura 5: Circuito utilizado para obtener la ganancia en ancho de banda (*Gain Bandwidth*) del amplificador operacional cascodo de una etapa.

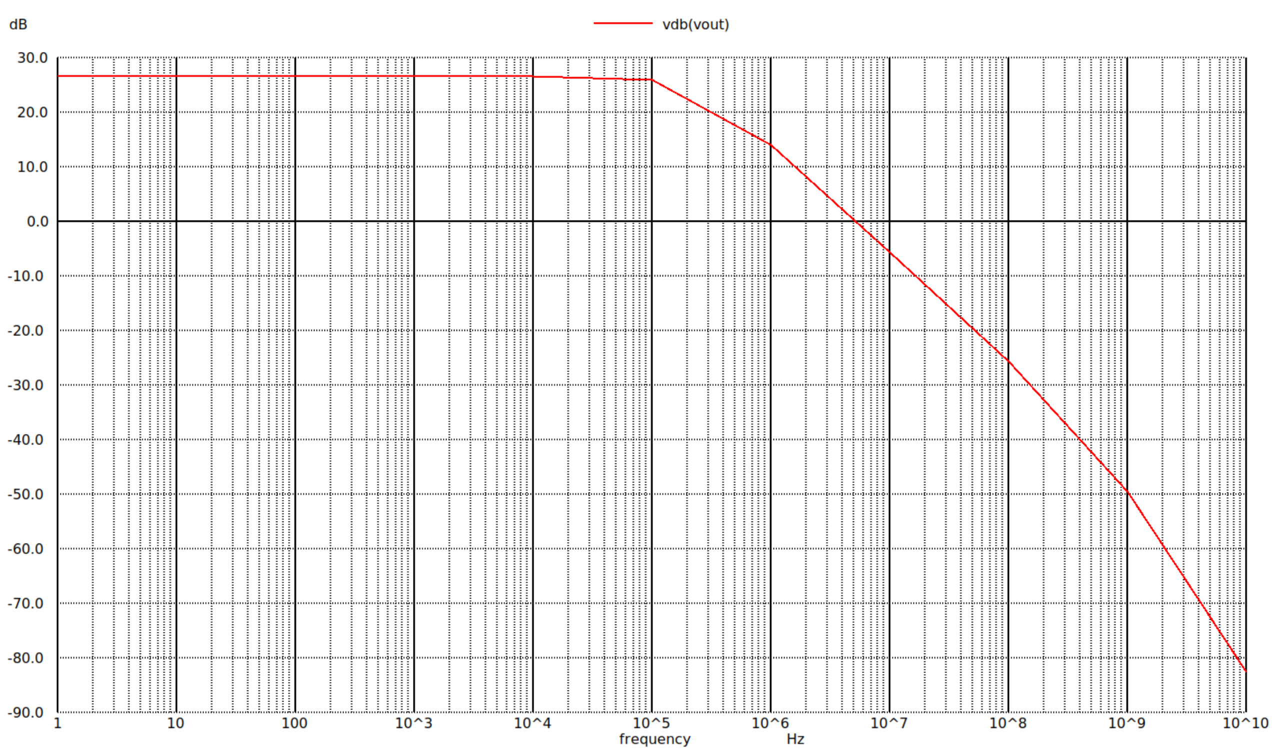

Figura 6: Diagrama de Bode obtenido de la Figura 13.

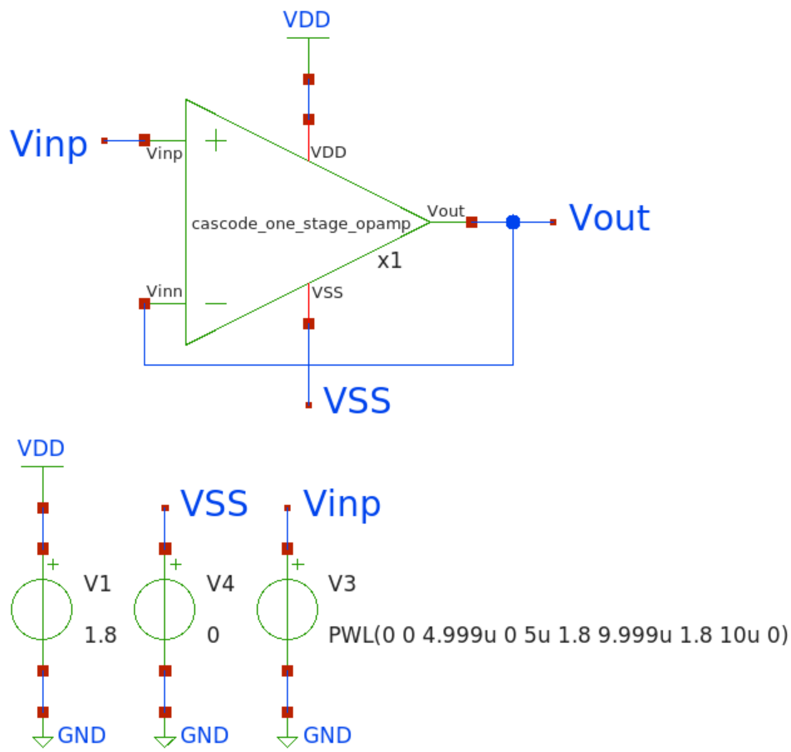

Figura 7: Circuito utilizado para evaluar obtener el *Slew Rate* del amplificador operacional cascodo de una etapa (Seguidor de voltaje).

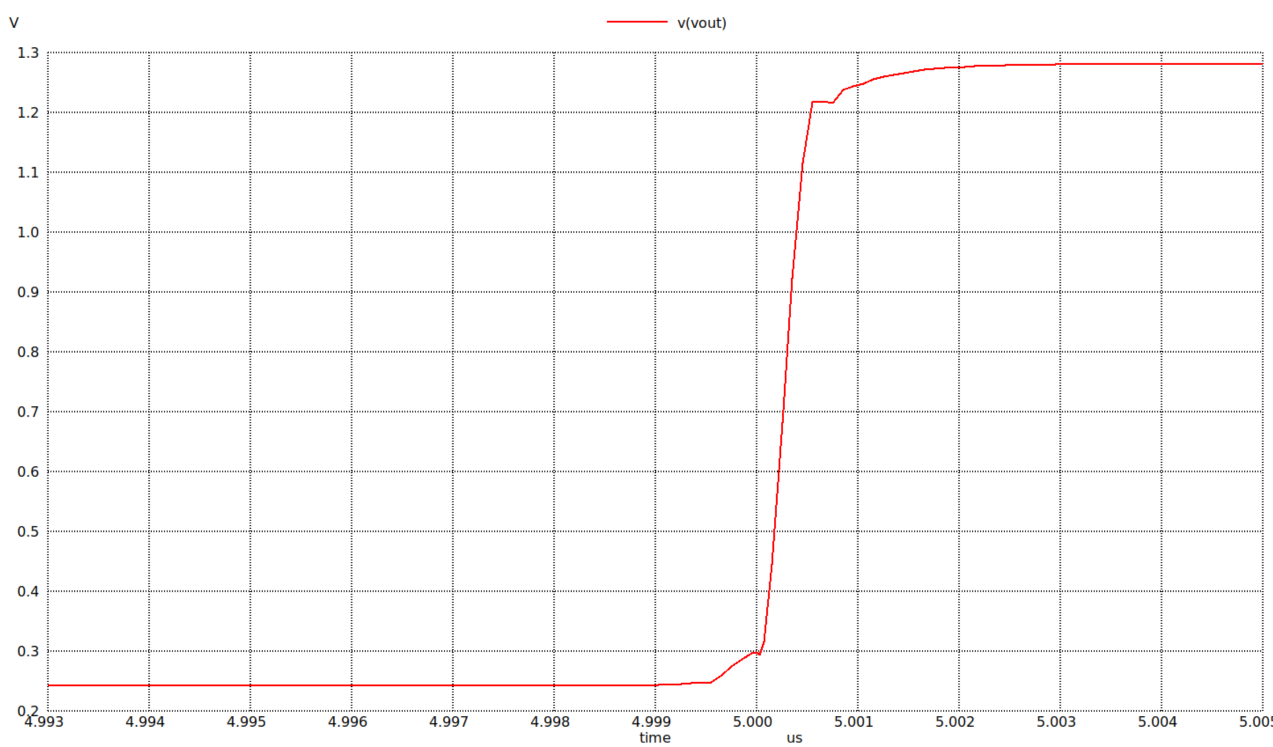

Figura 8: Grafica del voltaje de salida obtenido de la Figura 15.

4. Cálculo de parámetros $\frac{W}{L}$

Actividad 1

Emplear la siguiente metodología, propuesta por [1] para diseñar el amplificador simple de una etapa (Ver Figura 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}(sat)
6	$\frac{W_7}{L_7} = \frac{W_8}{L_8} = \frac{2I_1}{K'_7[V_{DD} - ICMR^+ - \lvert V_{T7}\rvert - V_{DS3}(sat) + V_{T1}]^2}$	$ICMR^+ = V_{in}$(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}(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, $R_{out} \approx (r_{ds8} g_{m6} r_{ds6}) \vert\vert (r_{ds2} g_{m4} r_{ds4})$
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}

Figura 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 a$I_{10} = 12.0\mu A$

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

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

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

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

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

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

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

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

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

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.

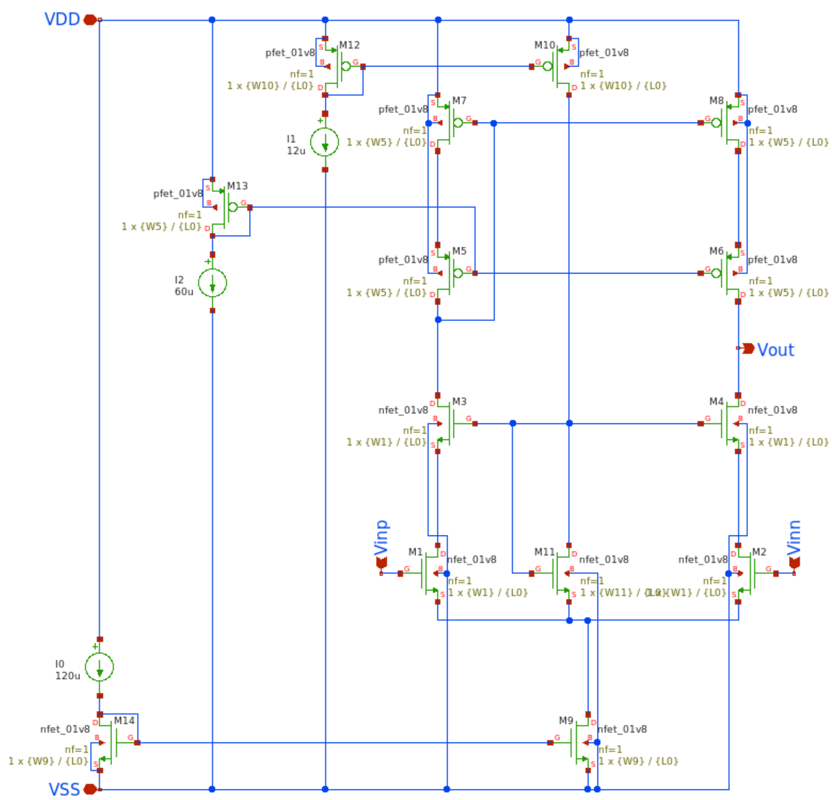

Figura 10: Diagrama esquemático del amplificador operacional cascodo de una etapa.

Resultados obtenidos de la simulación

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

$A_V = 17597.268667$

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

$P_{diss} = 0.2376mW$

$GB = 329.068635KHz$

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

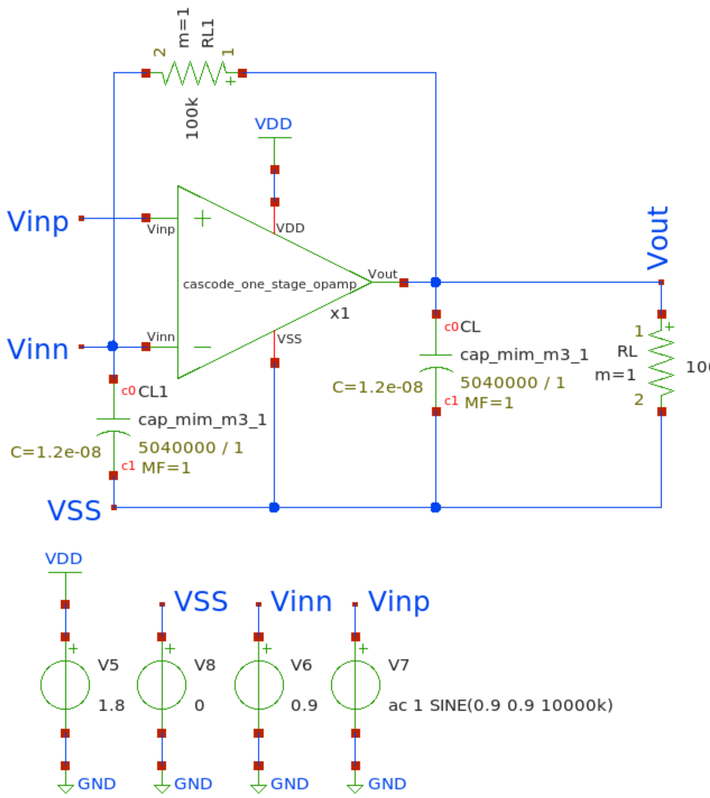

Figura 11: Circuito utilizado para obtener la ganancia del amplificador operacional cascodo de una etapa.

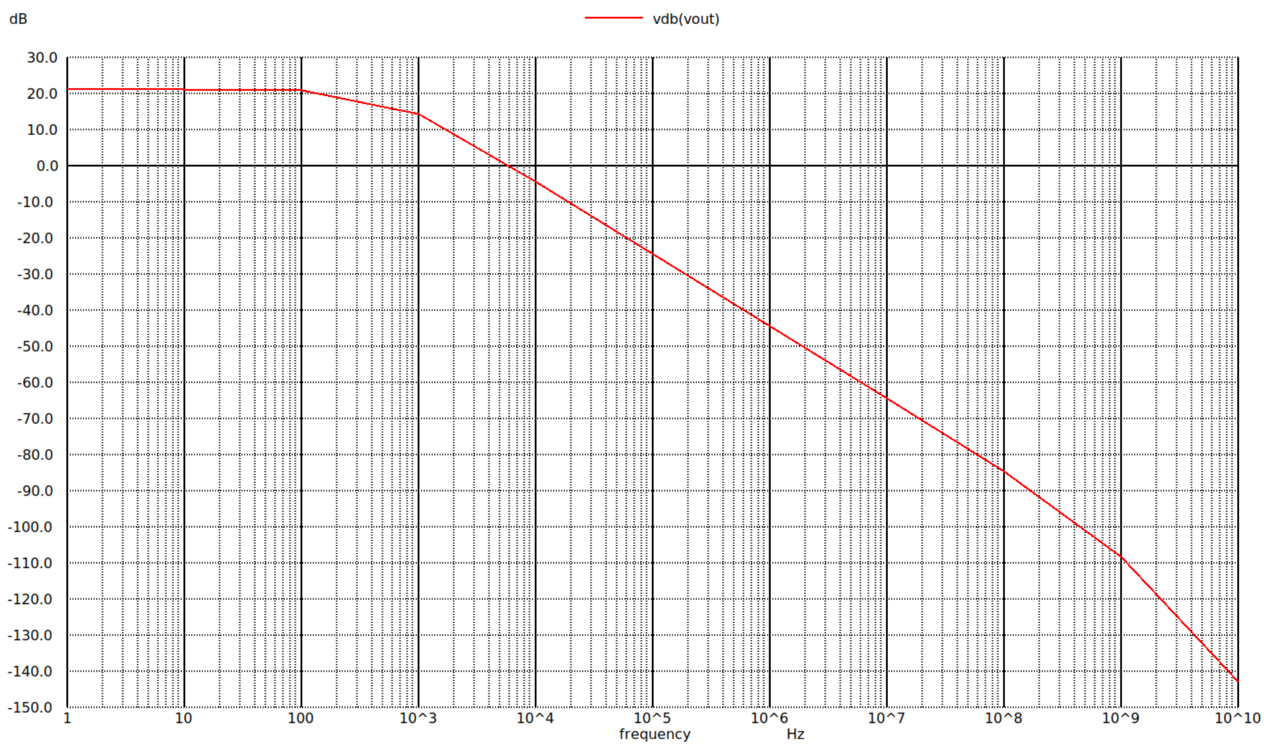

Figura 12: Diagrama de Bode obtenido de la Figura 11.

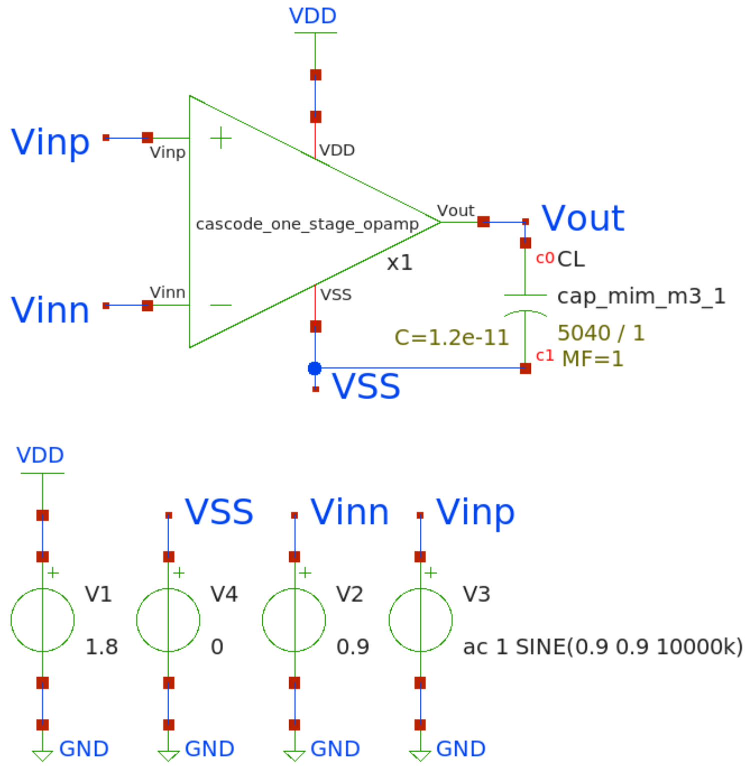

Figura 13: Circuito utilizado para obtener la ganancia en ancho de banda (*Gain Bandwidth*) del amplificador operacional cascodo de una etapa.

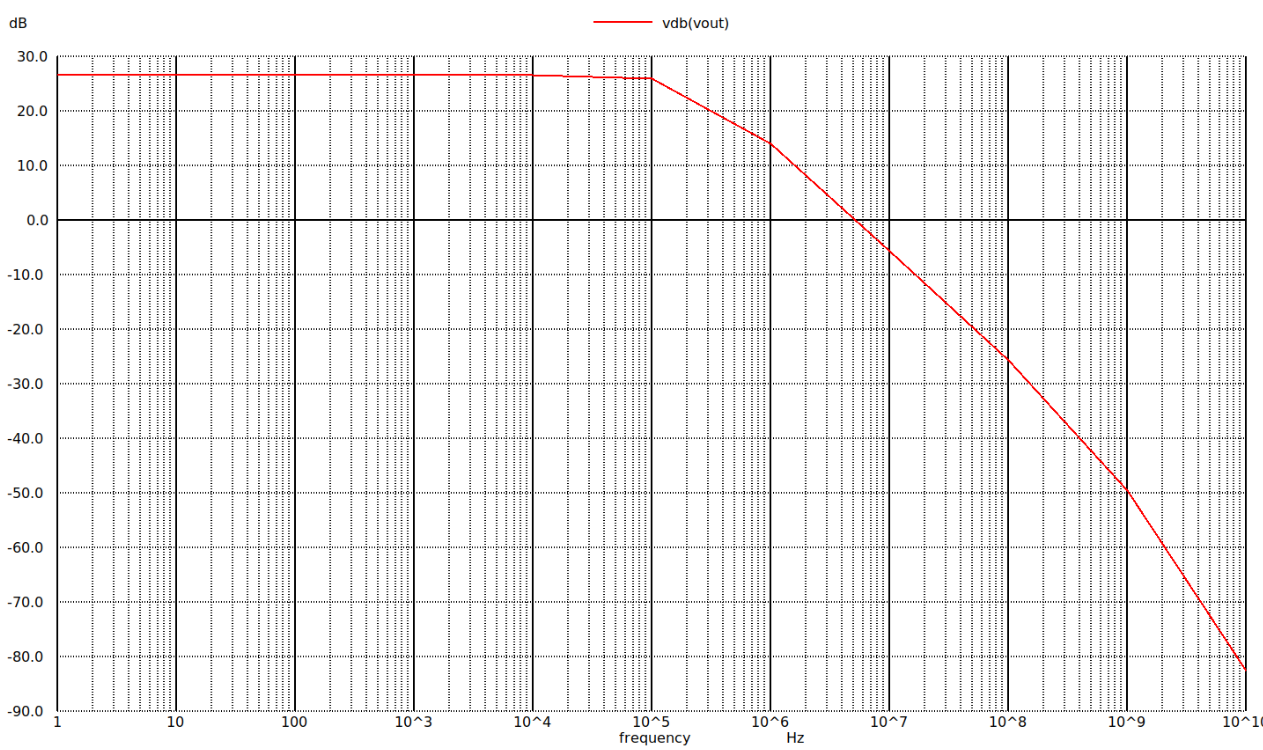

Figura 14: Diagrama de Bode obtenido de la Figura 13.

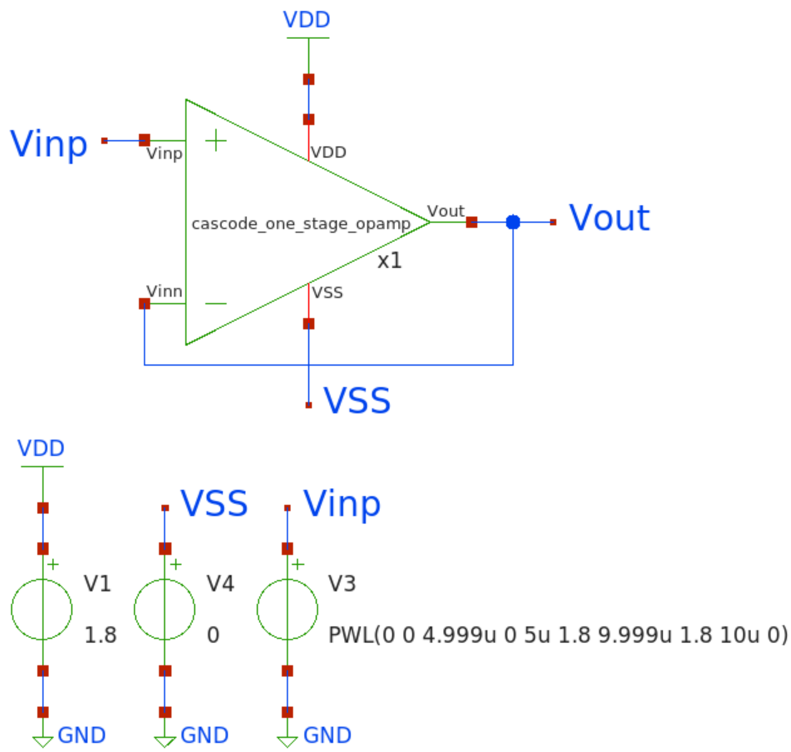

Figura 15: Circuito utilizado para evaluar obtener el *Slew Rate* del amplificador operacional cascodo de una etapa (Seguidor de voltaje).

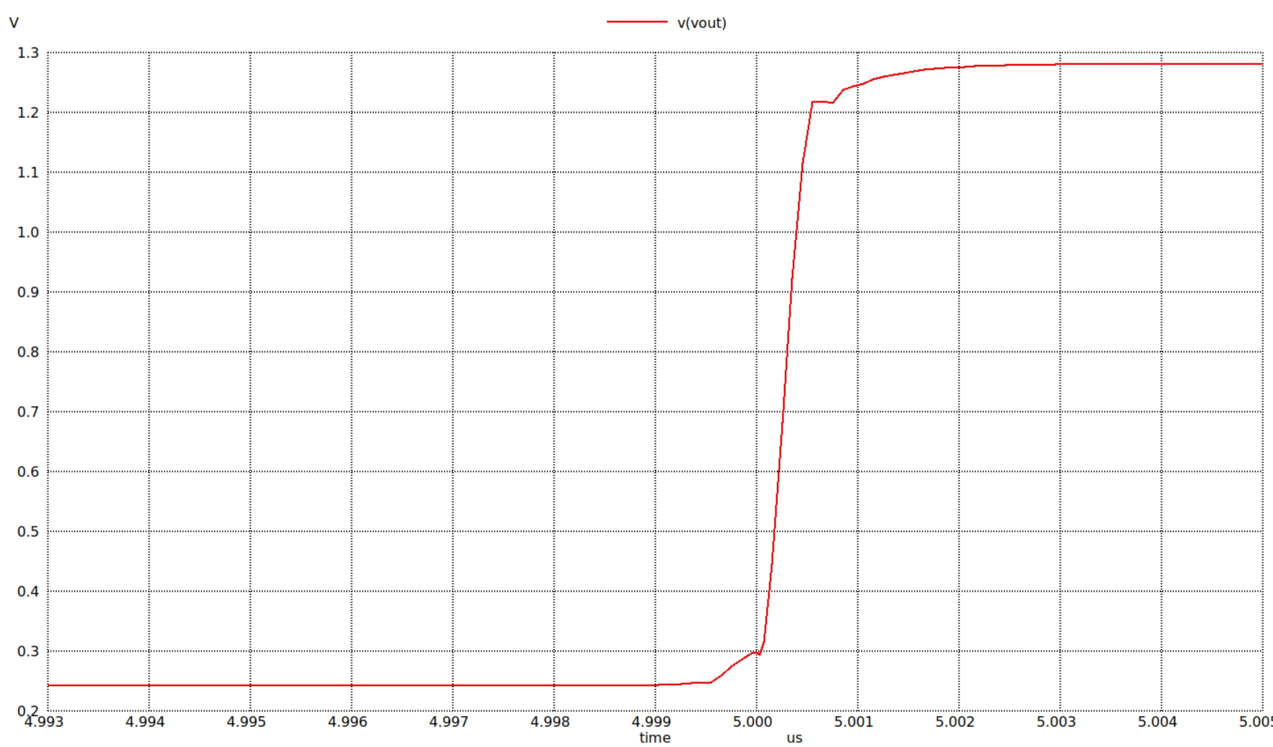

Figura 16: Grafica del voltaje de salida obtenido de la Figura 15.

Referencias

[1] P. E. Allen and D. R. Holberg, *CMOS Analog Circuit Design.* Oxford University Press, Incorporated, 2012.

6. Anexos

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

```
from math import sqrt
from math import pi
from math import log10
import math
import numpy as np

# Datos propuestos:
AV = 3000
VDD = 1.8
VSS = 0
GB = 10e6
SR = 10
Vout_max = 1.5      #Vout(max)
Vout_min = 0.3      #Vout(min)
ICMR_max = 1.8      #Vin(max)
ICMR_min = 0.8      #Vin(min)
Pd = 1e-3

# Parametros
L0 = 0.15e-6
Cl = 12e-12
#   Transistor canal N
Vthn = 0.769432
Kn = 0.00015137603990044484
Lambda_n = 0.08896373280684104
#   Transistor canal P
Vthp = 0.624345
Kp = 0.000057013889055450486
Lambda_p = 0.06896373280684104

# Paso 1
I9=SR*Cl/(1e-6)

# Paso 2
gm=2*pi*GB*Cl
I5=0.5*I9
W1_L1=(gm**2)/(Kn*I5)
W1=W1_L1*L0
```

```
W2=W1

# Paso 3
W3=W1
W4=W1

# Paso 4
I10=12e-6         # I9/10
W10_L10=50
W10=W10_L10*L0

# Paso 5
I1=0.5*I9
I2=I1
W11_L11=(I10/(4*I1))*W1_L1
W11=W11_L11*L0

# Paso 6
Vds3_sat=sqrt((2*I1)/(Kn*W1_L1))
W7_L7=(2*I1)/(Kp*(VDD-ICMR_max-Vthp-Vds3_sat+Vthn))
W7=W7_L7*L0
W8=W7

# Paso 7
W5=W7
W6=W7

# Paso 8
Vgs1=sqrt(I9/(Kn*W1_L1))+Vthn
W9_L9=(2*I9)/(Kn*(ICMR_min-Vgs1)**2)
W9=W9_L9*L0

# Paso 9
rds2=1/(Lambda_n*I2)
rds6=1/(Lambda_p*I2)
gm4=sqrt(2*Kn*W1_L1*I2)
gm6=sqrt(2*Kp*W7_L7*I2)
Rout=1/((1/(rds2*gm4*rds2))+(1/(rds6*gm6*rds6)))
A0=gm*Rout
A0_db=20*log10(A0)

# Paso 10
Vds8_sat=sqrt((2*I2)/(Kn*W7_L7))
Vds9_sat=sqrt((2*I9)/(Kn*W9_L9))
V0_max=VDD-(2*Vds8_sat)
```

```python
VO_min=(2*Vds3_sat)+Vds9_sat

# Calculo de Av
Datos_Av = np.loadtxt('/home/ricardo/RATT_repos/Proyectos_xschem/simulations/cascode_one_stage_opamp_av.ssv')
Y_Av = Datos_Av[0:1, 1]
Av_final = Y_Av[0]/(100e3*1.2e-8)

# Calculo de GB
Datos_GB = np.loadtxt('/home/ricardo/RATT_repos/Proyectos_xschem/simulations/cascode_one_stage_opamp_gb.ssv')
X_GB = Datos_GB[5:7, 0]
Y_GB = Datos_GB[5:7, 1]
m_GB = (Y_GB[1]-Y_GB[0])/(X_GB[1]-X_GB[0])
b_GB = Y_GB[1]-(m_GB*X_GB[1])
GB_final = (Y_GB[0]-3-b_GB)/m_GB

# Calculo de Pdiss
Pdiss=VDD*(I9+I10)

# Calculo de SR
Datos_SR = np.loadtxt('/home/ricardo/RATT_repos/Proyectos_xschem/simulations/cascode_one_stage_opamp_sr.ssv')
X = Datos_SR[50010:50018, 0]
Y = Datos_SR[50010:50018, 1]
x_bias1 = np.c_[np.ones(X.shape[0]), X]
# Calculo de la pendiente para el SR -> theta = (X^T * X)^-1 * X^T * y
theta = np.linalg.inv(x_bias1.T @ x_bias1) @ x_bias1.T @ Y
```

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