ECE4902 Lecture 11

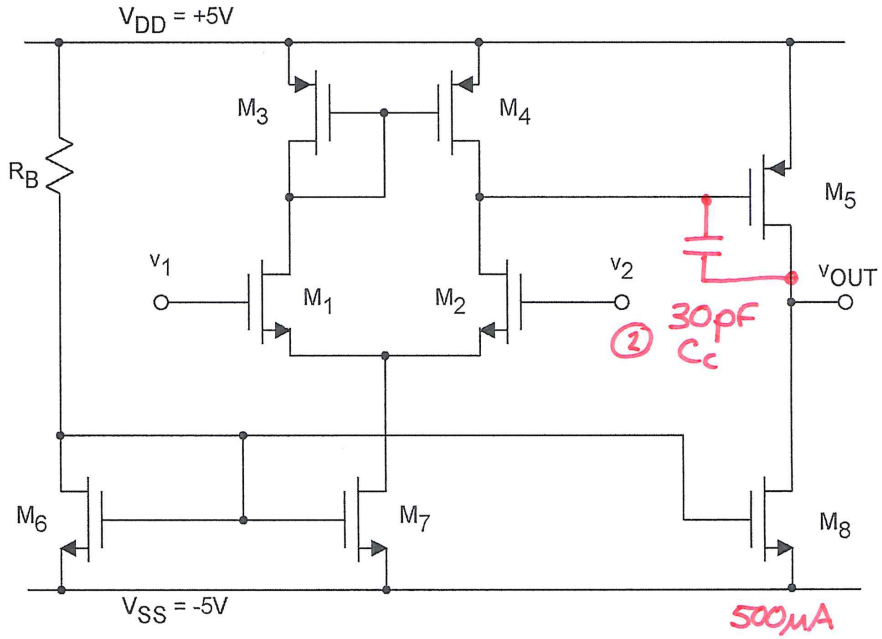
2-Stage Op-Amp
- Finish Design Example
- Simulation results

Improving Performance
- Cascode

Handout:
Design Example

Specifying Op-Amp Design:

MOSFET	DC Bias		Size (1)		Remarks
	ID [µA]	$V_{GS} - V_{TH}$	W [µm]	L [µm]	
M1				10	
M2				10	
M3				10	
M4				10	
M5	500mA	(4) −0.4V	(5) 7200	10	
M6		0.4V		10	
M7		0.4V		10	
M8	(3) 500mA	(4) 0.4V	(5) 2400	10	



Parameter	N-channel	P-channel	Units
V_{TH}	+1.90	-1.60	V
μC_{ox}	2.6E-5	9.1E-6	A/V^2
λ (L=10µm)	0.05	0.028	V^{-1}

① MINIMIZE AREA (CD4007 PARAMETERS) ALL $L = 10\,\mu m$
(COULD CHANGE LATER; HAVE TO START SOMEWHERE!)

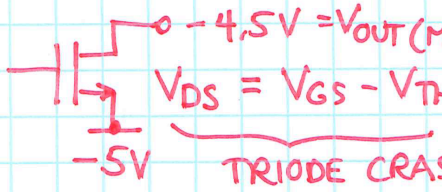
② CHOOSE $C_c = 30\,pF$ [SEE ECE529C; NOISE CONSIDERATIONS]

③ M_8 MUST ALWAYS CONDUCT MAX CURRENT

$450\,mA \Rightarrow 500\,mA = I_{D8}$

④ OUTPUT SWINGS DETERMINED BY TRIODE CRASH

M_8:



SAME FOR M_5

PMOS: $-0.4V$

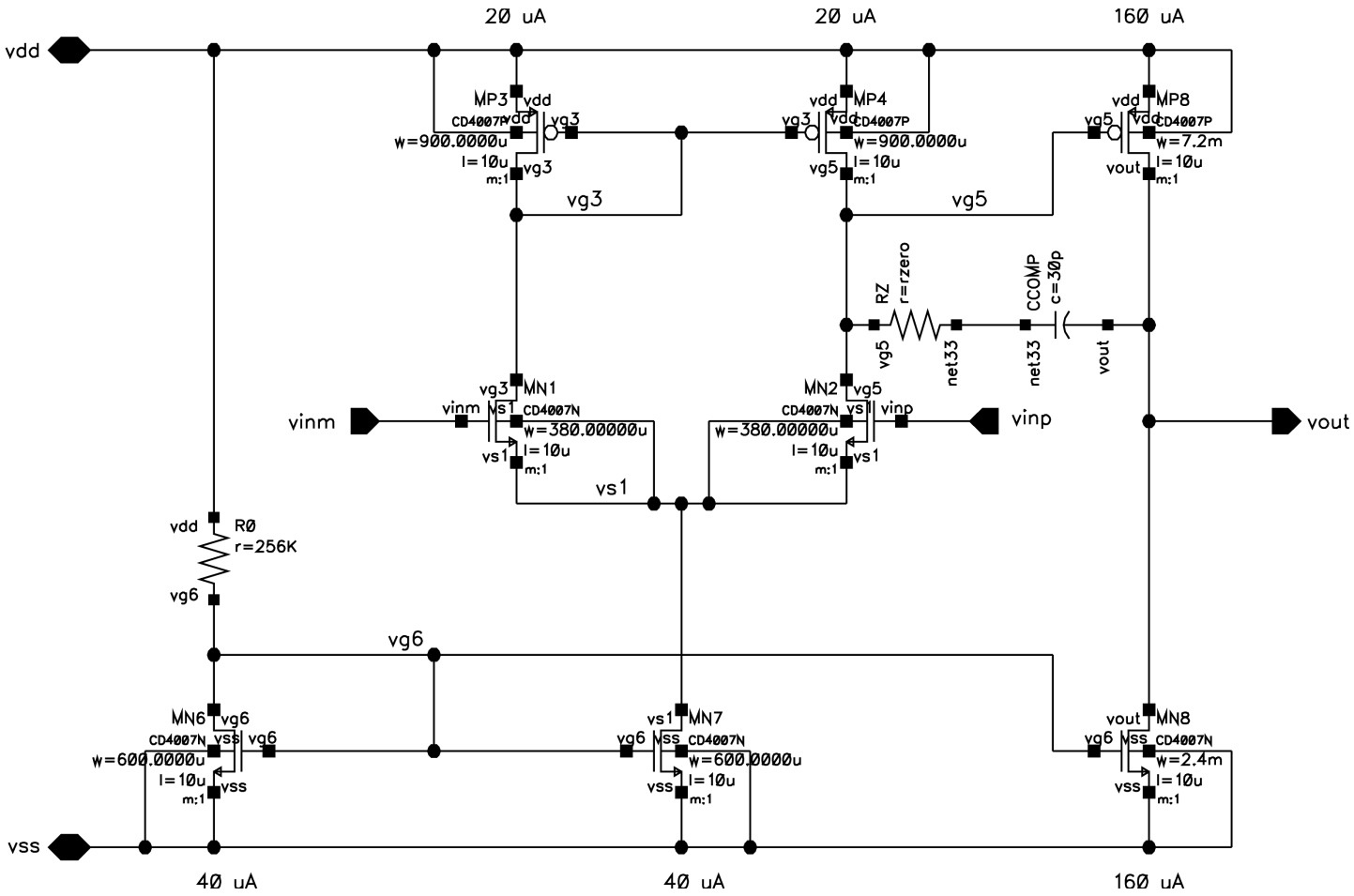
⑤ W_8 FROM SQUARE LAW

$$500\,mA = \frac{2.6E\text{-}5}{2}\,\frac{W}{10}\,(0.4V)^2 \Rightarrow 2400\,\mu m$$

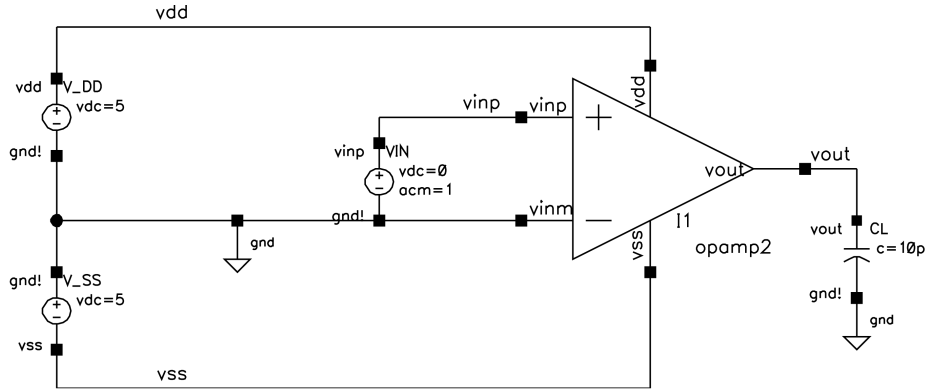
W_5

$$500\,mA = \frac{9.1E\text{-}6}{2}\,\frac{W}{10}\,(-0.4V)^2 \Rightarrow 7200\,\mu m$$

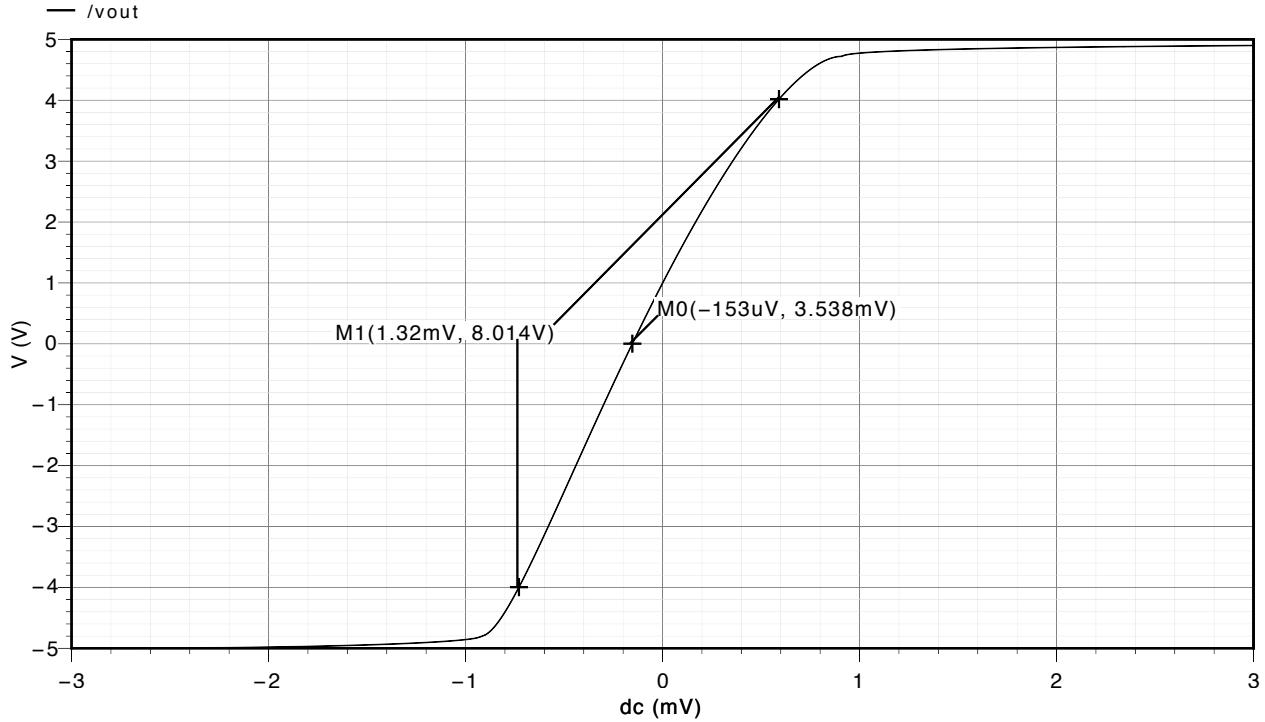
Op-Amp Design



Open Loop Test Simulation



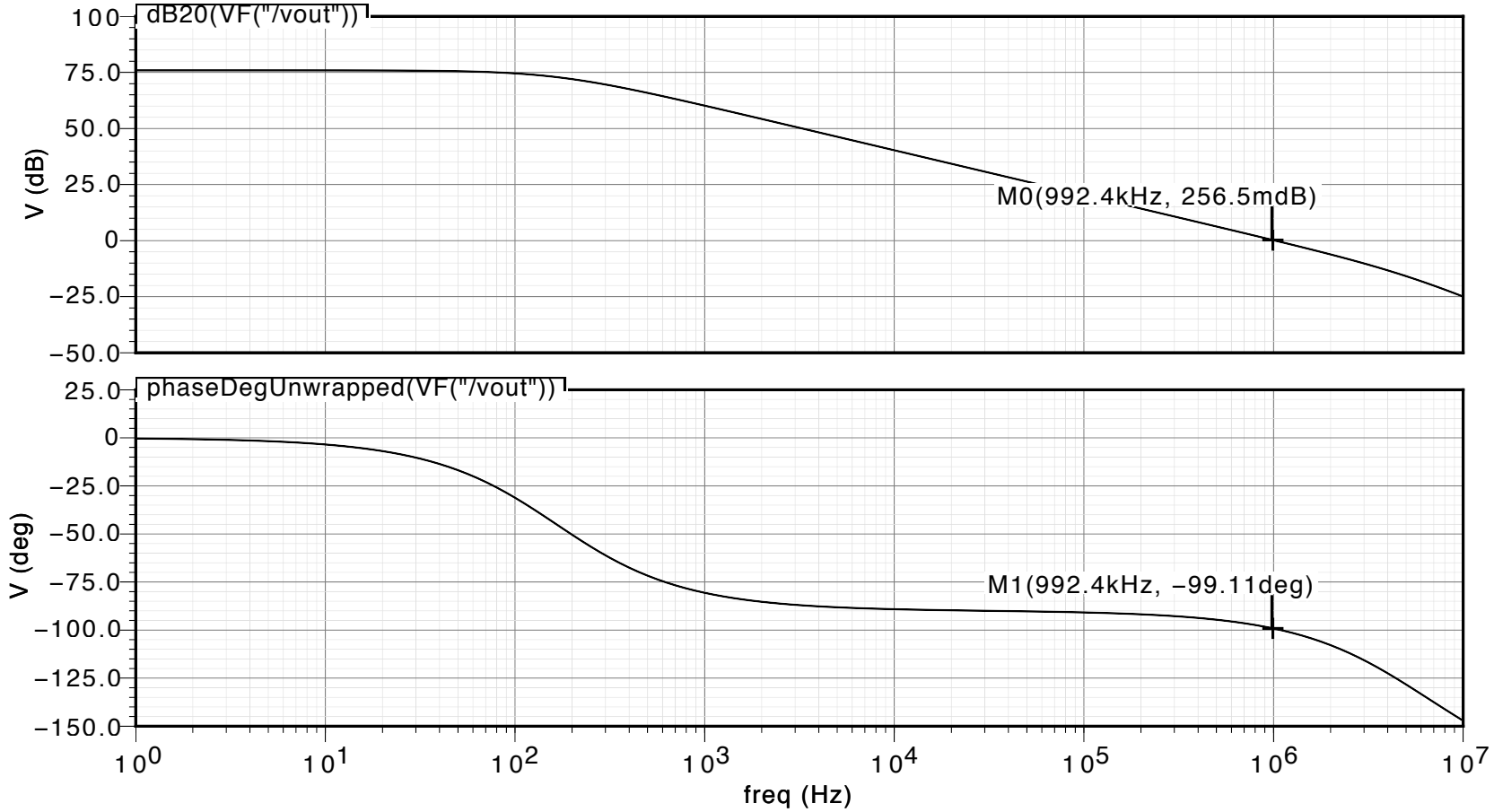
Open Loop DC response



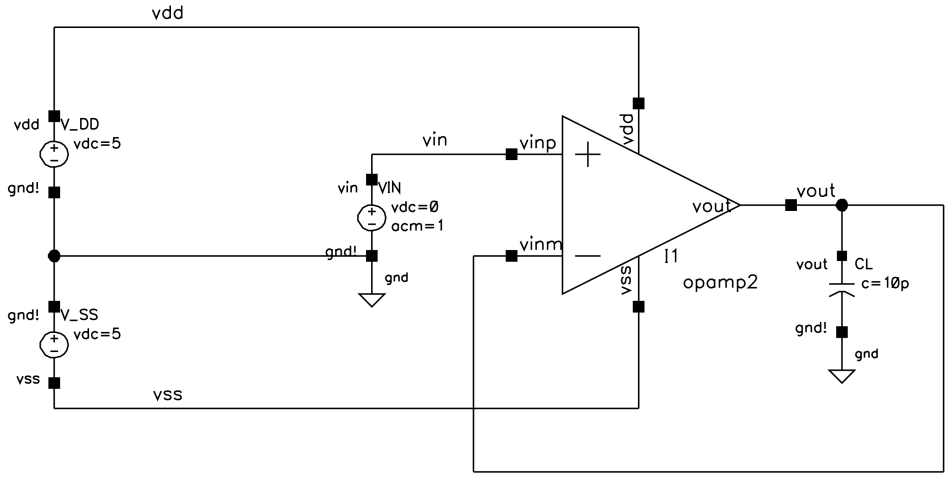
Systematic Offset Voltage -153 µV

Average DC gain = 8.014V / 1.32mV = 6070

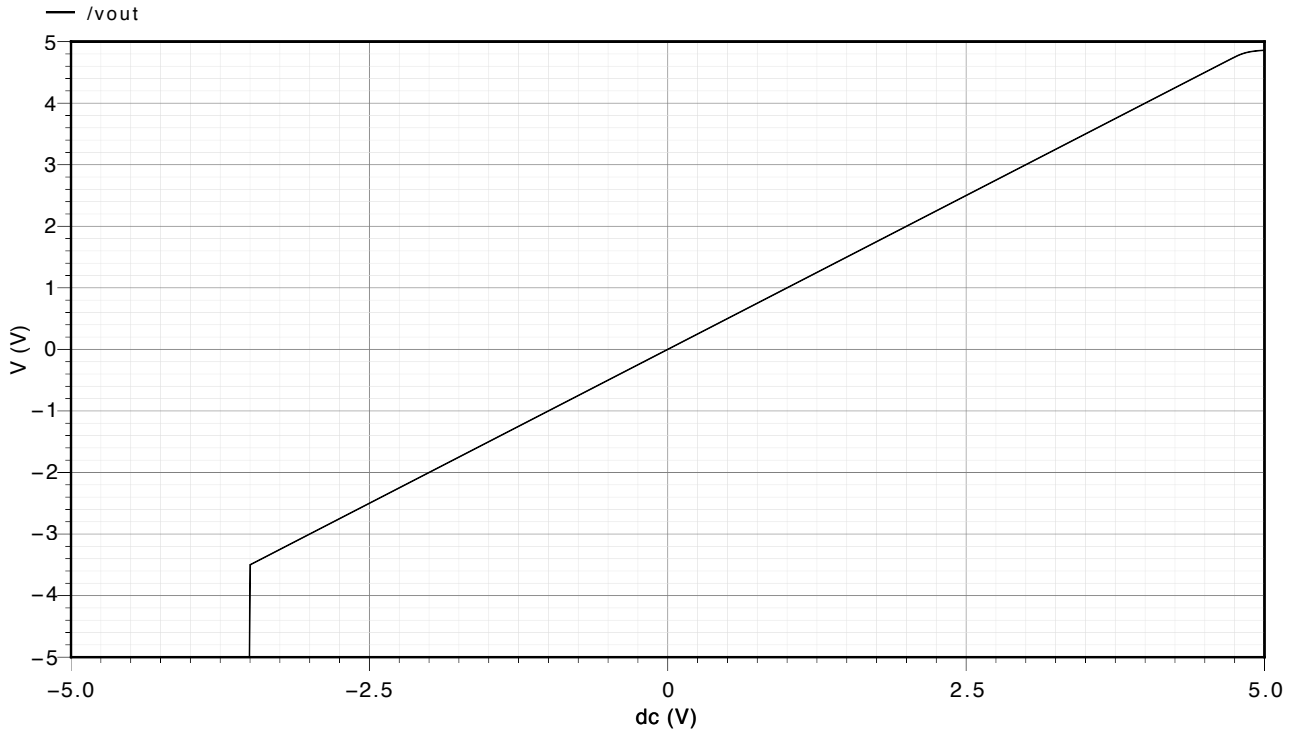
Open Loop AC response



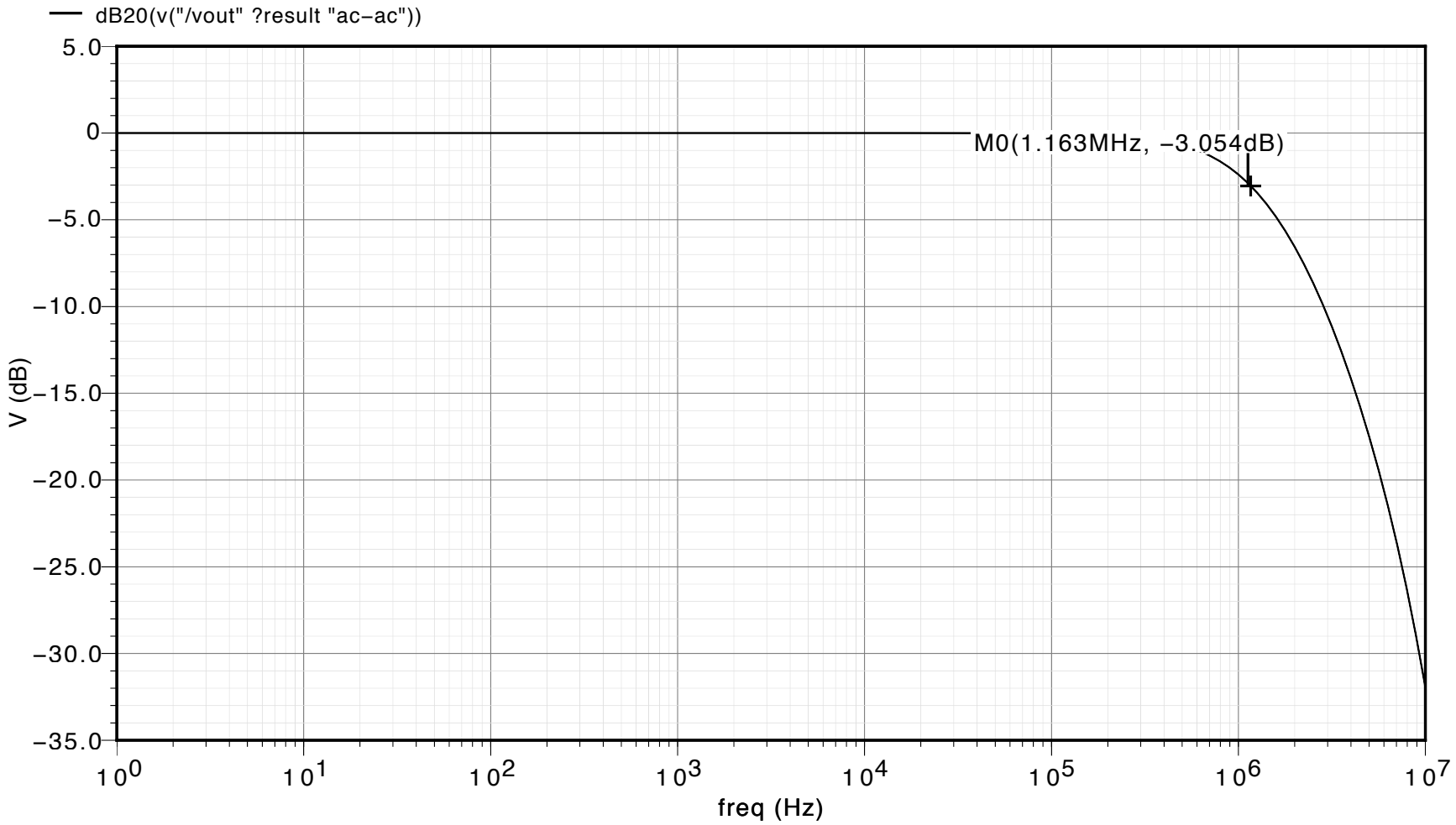
Closed Loop Simulations



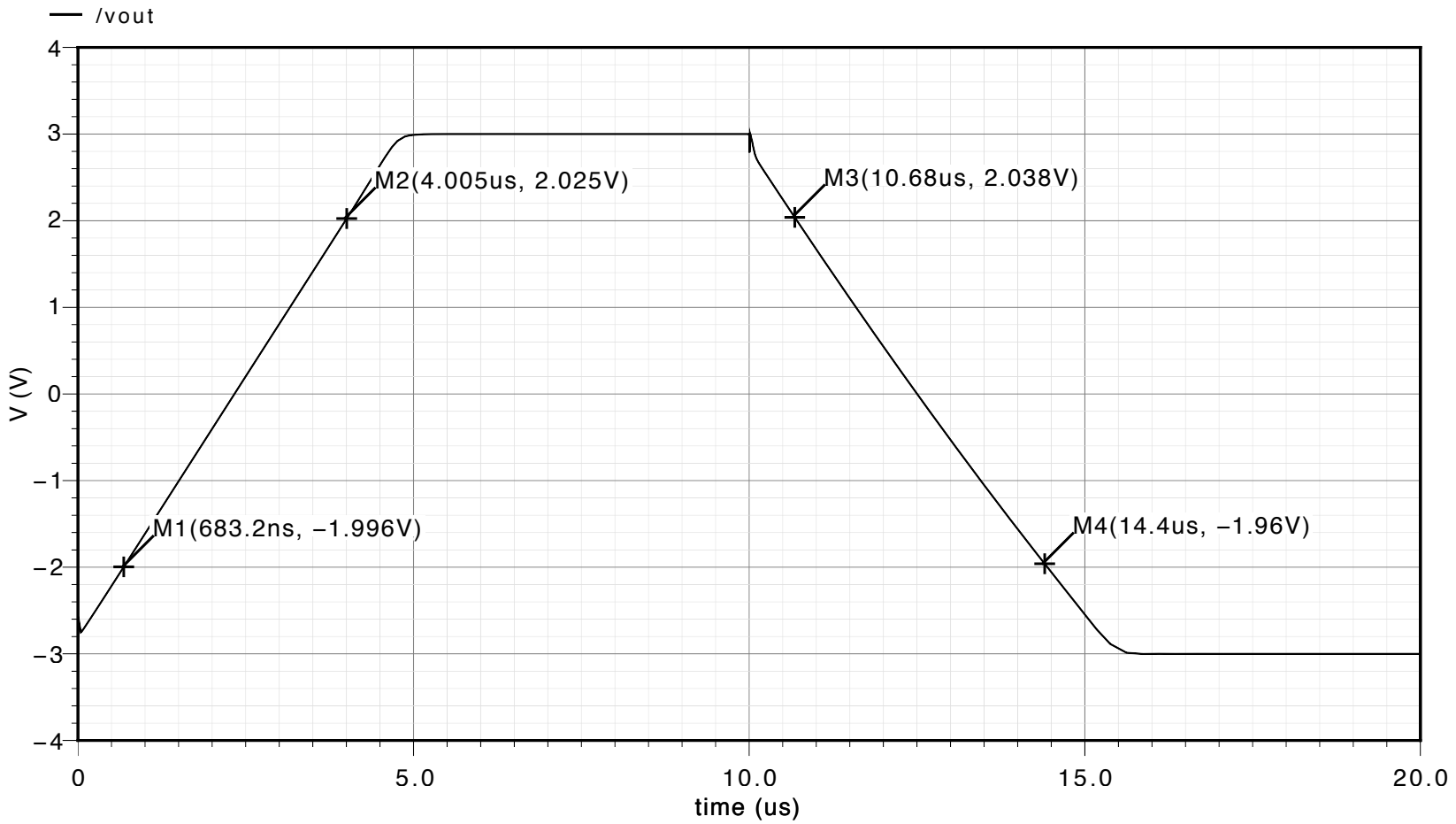
Closed Loop DC Sweep



Closed Loop Transfer Function (Unity Gain)



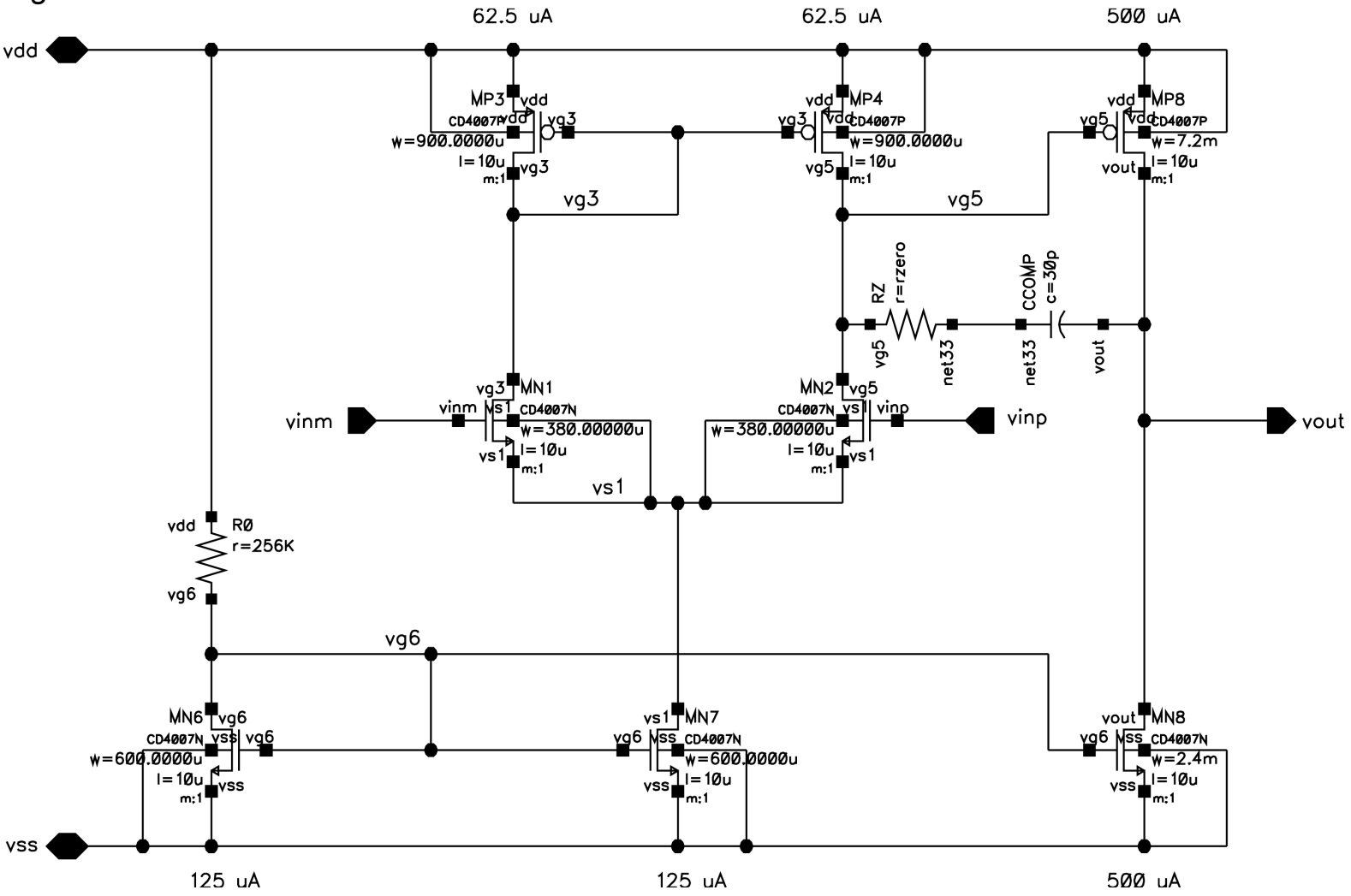
Closed Loop Step Response (Large Signal)



Rising slew rate 4V / 3.31μs = 1.21 V / μs

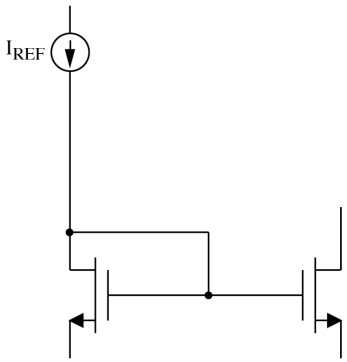
Falling slew rate 4V / 3.72μs = 1.08 V / μs

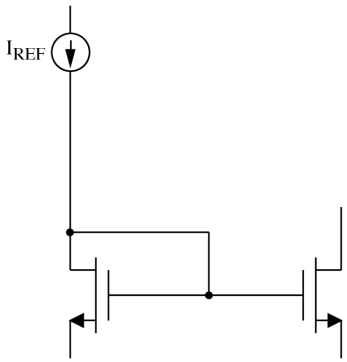
Op-Amp Design

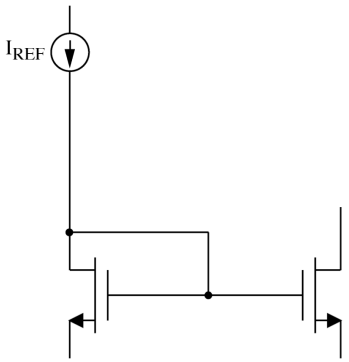


How to Increase Open Loop Gain?

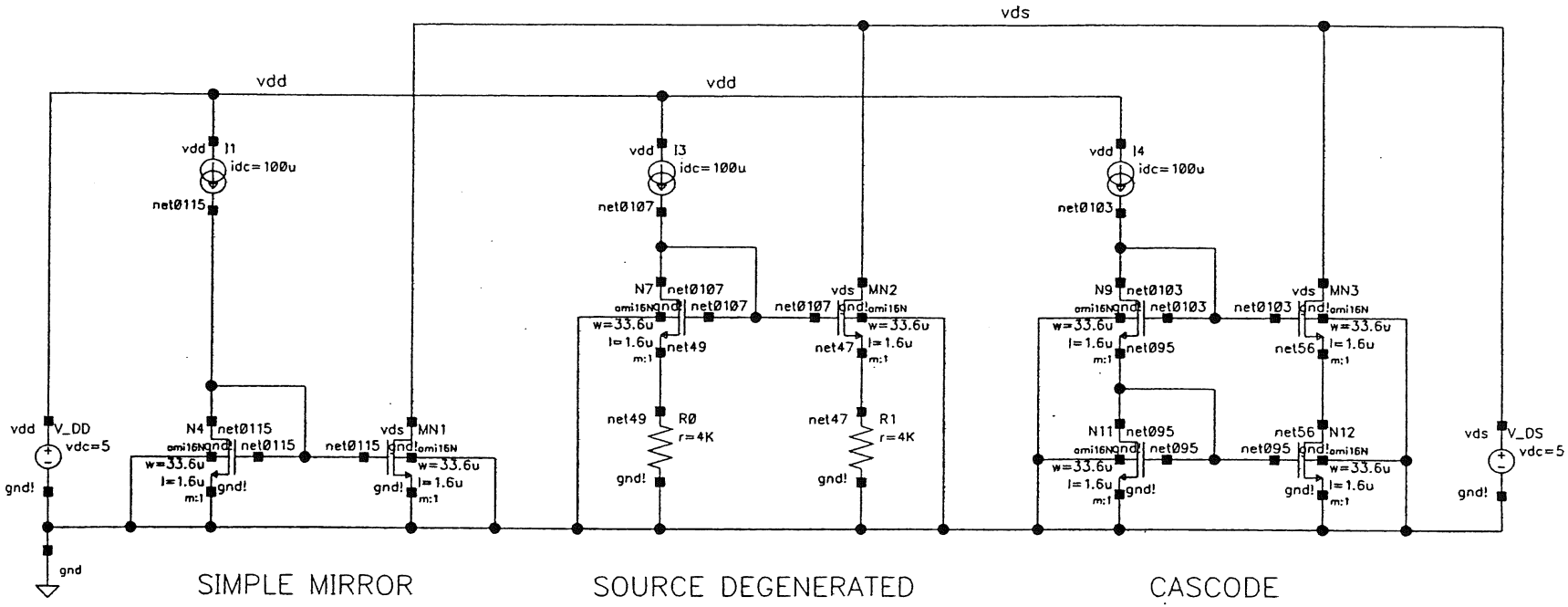
Cascode Current Source Development

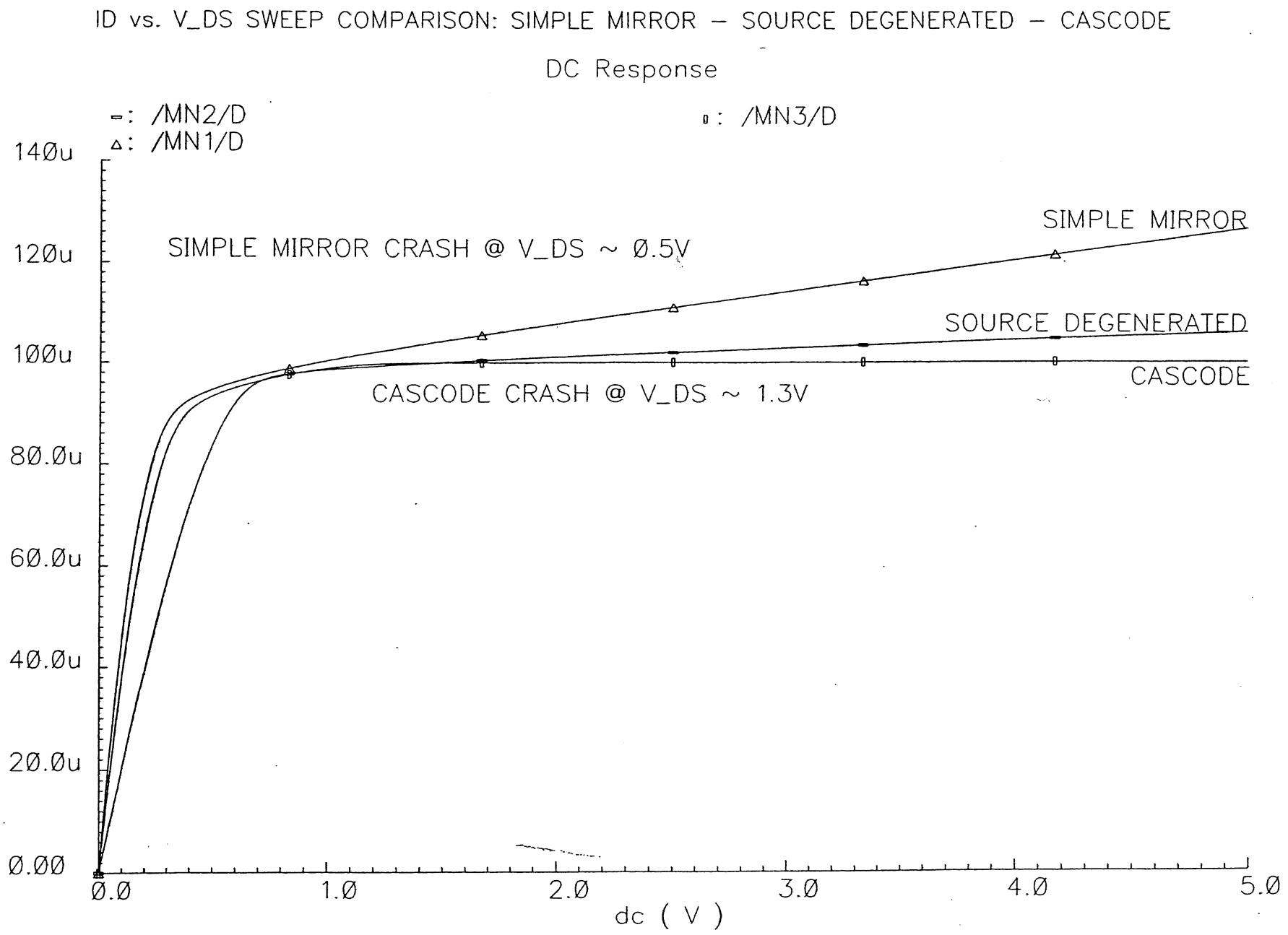






Current source comparison: Simulation




ID vs. V_DS SWEEP COMPARISON: SIMPLE MIRROR – SOURCE DEGENERATED – CASCODE
DC Response
▫: /MN2/D
▵: /MN1/D
▯: /MN3/D
140u
120u
100u
80.0u
60.0u
40.0u
20.0u
0.00
SIMPLE MIRROR
SIMPLE MIRROR CRASH @ V_DS ~ 0.5V
SOURCE DEGENERATED
CASCODE
CASCODE CRASH @ V_DS ~ 1.3V
0.0
1.0
2.0
3.0
4.0
5.0
dc (V)