University of California
Berkeley

College of Engineering
Department of Electrical Engineering
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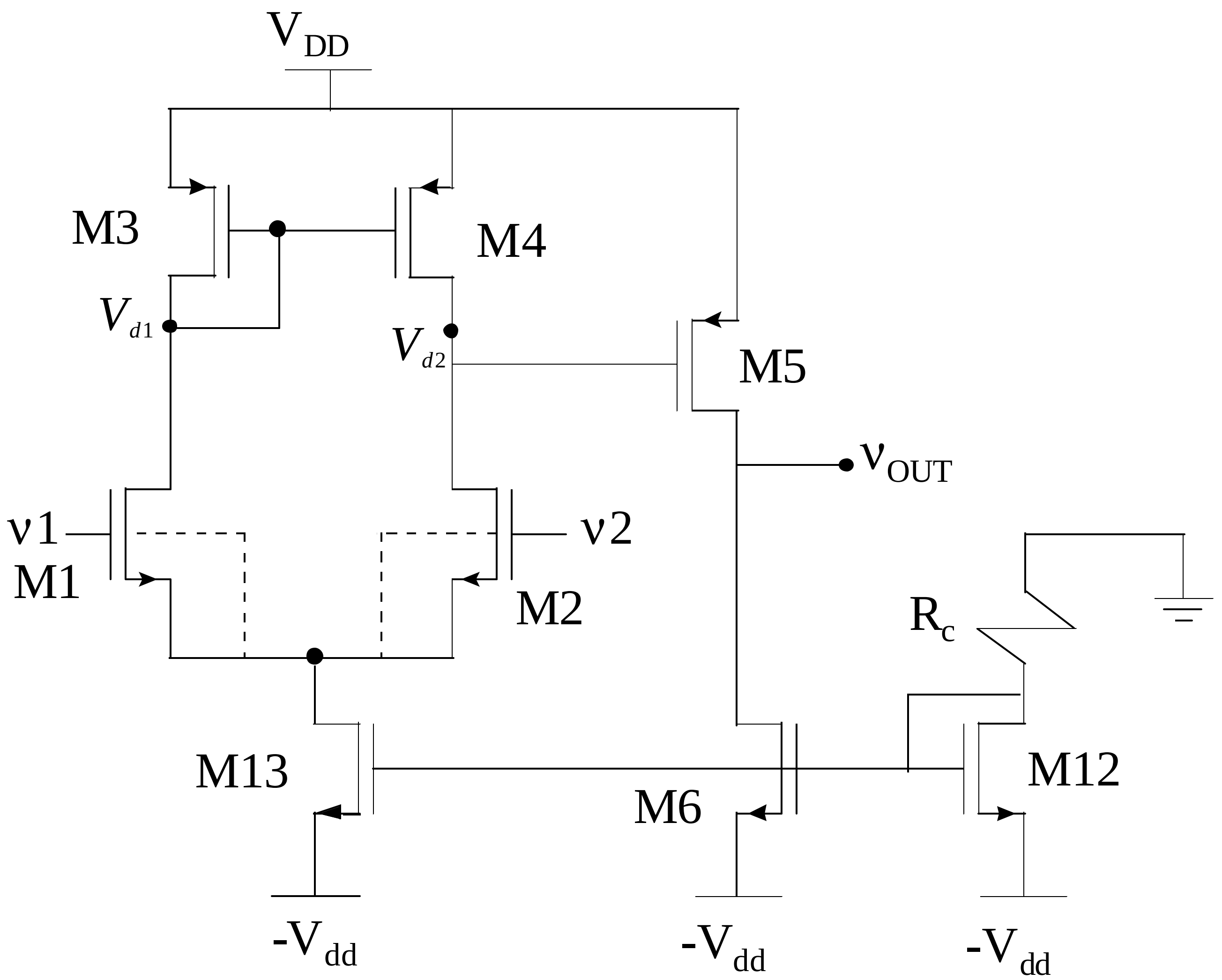
EECS140

Analog Circuit Design

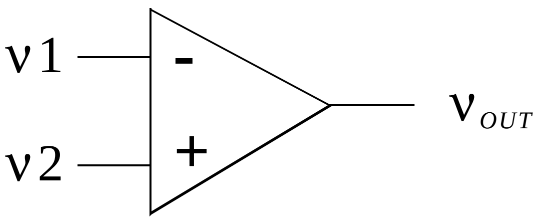
Lectures
on
OP AMPS

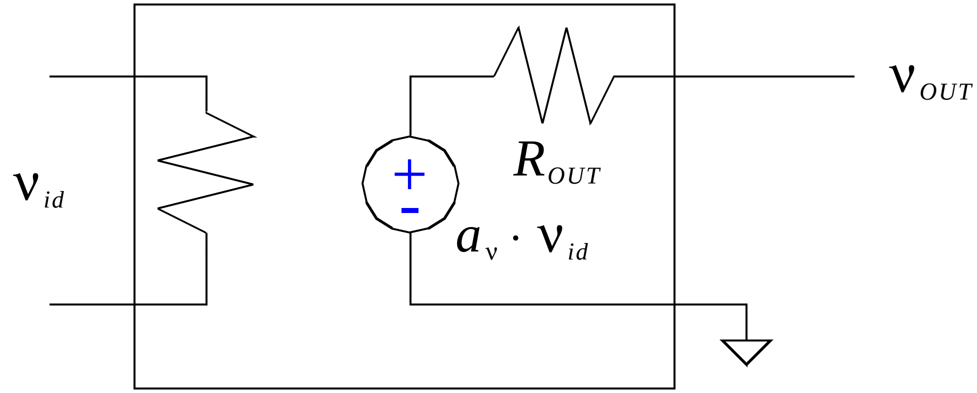
Miller Op Amp



Miller Op Amp (Cont.)

OP-2





$$R_{id} = \infty$$

$$R_{OUT} = r_{o5} \parallel r_{o6}$$

$$\frac{v_{d2}}{v_{id}} \cdot \frac{v_{OUT}}{v_{d2}} = \frac{v_{OUT}}{v_{id}}$$

$g_{m2} \cdot (r_{o2} \parallel r_{o4})$

$g_{m5} \cdot R_{OUT}$

Miller Op Amp (Cont.)

What is the DC voltage at V_{d2}?

$$I_{DS1} = I_{DS2} = I_{DS3} = I_{DS4}$$

$$I_{DS3} = \frac{k'}{2} \cdot \frac{W}{L} \cdot (V_{SG3} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD3})$$

$$I_{DS4} = \frac{k'}{2} \cdot \frac{W}{L} \cdot (V_{SG4} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD4})$$

$$I_{DS3} = I_{DS4}$$

$$(V_{SG3} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD3}) = (V_{SG4} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD4})$$

$$V_{SG3} = V_{SG4}$$

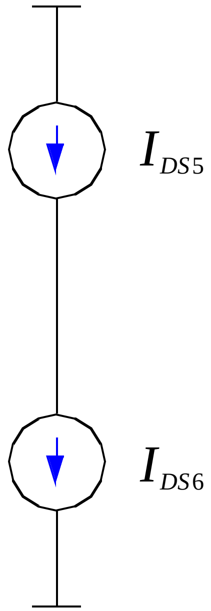
$$\cancel{(V_{SG3} - |V_T|)^2} \cdot (1 + \lambda \cdot V_{SD3}) = \cancel{(V_{SG3} - |V_T|)^2} \cdot (1 + \lambda \cdot V_{SD4})$$

$$V_{SD3} = V_{SD4} = V_{SG3} = V_T + V_{DSAT3}$$

$$V_{D1} = V_{DD} - V_{SG3} = V_{DD} - V_T - V_{DSAT3} = V_{D2}$$

Miller Op Amp (Cont.)

To set offset at output or 2nd stage M5, M6 to near zero, set $I_{DS5} = I_{DS6}$



$$I_{SD5} = \frac{k'}{2} \cdot \left(\frac{W}{L}\right)_5 \cdot (V_{SG5} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD5})$$

$$I_{SD6} = \frac{k'}{2} \cdot \left(\frac{W}{L}\right)_6 \cdot (V_{GS6} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{DS6})$$

Since $V_{SD4} = V_{SG3} = V_{SG5}$

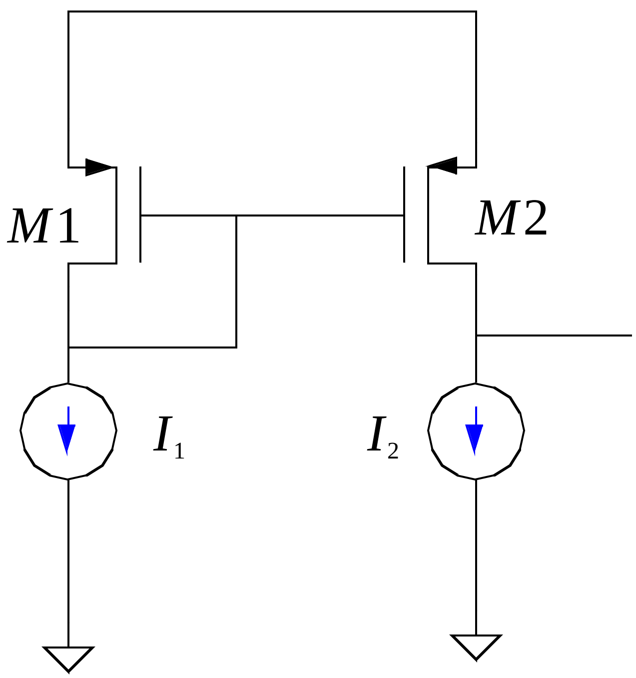
$$I_{SD5} = I_{DS3} \qquad \text{if} \quad \left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_3$$

$$I_{SD6} = \frac{1}{2} \cdot I_{SD13} \qquad \text{if} \quad \left(\frac{W}{L}\right)_{13} = 2 \cdot \left(\frac{W}{L}\right)_6$$

then $I_{DS6} = I_{DS5}$ or,

$$\frac{I_{DS5}}{I_{DS3}} = \frac{\left(\frac{W}{L}\right)_5}{\left(\frac{W}{L}\right)_3} = \frac{\left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_{13} / 2} = \frac{2 \cdot \left(\frac{W}{L}\right)_6}{\left(\frac{W}{L}\right)_{13}}$$

Miller Op Amp (Cont.)



What happens if $I_1 = \alpha \cdot I_2$

$$\frac{k'}{2} \cdot \left(\frac{W}{L}\right)_1 \cdot (V_{SG1} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD1})$$

$$= \alpha \cdot \frac{k'}{2} \cdot \left(\frac{W}{L}\right)_2 \cdot (V_{SG2} - |V_T|)^2 \cdot (1 + \lambda \cdot V_{SD'2})$$

$$1 + \lambda \cdot V_{SD1} = \alpha \cdot (1 + \lambda \cdot V_{SD2})$$

$$V_{SD2} = \frac{\frac{1}{\lambda} + V_{SD1}}{\alpha} - \frac{1}{\lambda}$$

$$\alpha = 1 \qquad V_{SD2} = V_{SD1}$$

$$\alpha = \frac{1}{2} \qquad V_{SD2} = \frac{100 + V_{SD1}}{1/2} - 100$$

$$\lambda = 0.01 \qquad = 100 + 2 \cdot V_{SD1}$$ Big Offset

Miller Op Amp (Cont.)

Gain :

First Stage

$$\frac{v_{ds}}{v_{id}} = -g_{m1} \cdot (r_{o4} \| r_{o2})$$

Second Stage

$$\frac{v_{OUT}}{v_{d2}} = -g_{m5} \cdot (r_{o6} \| r_{o5})$$

Overall

$$A_v = g_{m1} \cdot g_{m5} \cdot (r_{o4} \| r_{o2}) \cdot (r_{o5} \| r_{o6})$$

Miller Op Amp (Cont.)

$$A_v = \frac{2 \cdot I_{DS1}}{V_{DSAT1}} \cdot \left(\frac{2 \cdot I_{DS5}}{V_{DSAT5}}\right) \cdot \frac{1}{(\lambda_n + \lambda_p) \cdot I_{DS1}} \cdot \frac{1}{(\lambda_n + \lambda_p) \cdot I_{DS5}}$$

$$= \frac{4}{(V_{DSAT1}) \cdot (V_{DSAT5}) \cdot (\lambda_n + \lambda_p)^2}$$

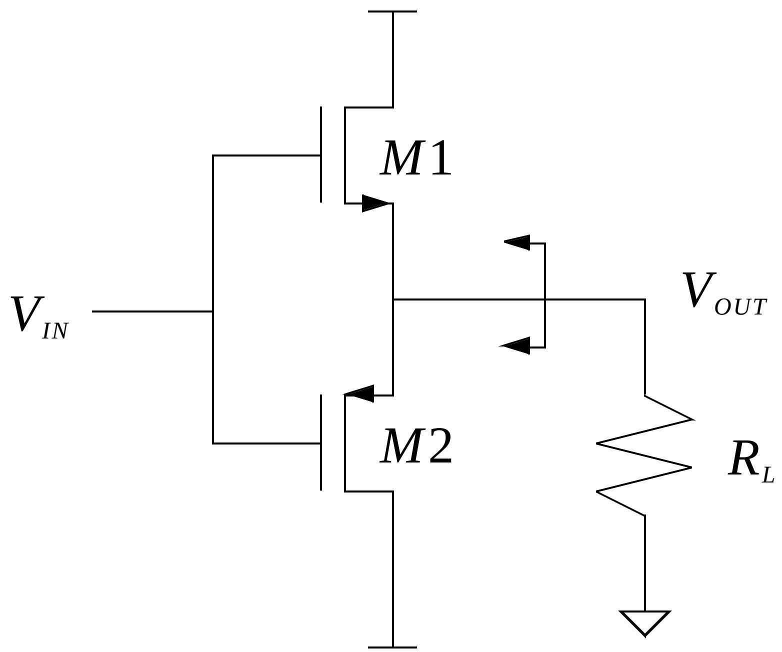
$$A_v = \frac{4}{\left(\frac{2 \cdot I_{SD1}}{k'_n \cdot (W/L)_1}\right)^{\frac{1}{2}} \cdot \left(\frac{2 \cdot I_{DS5}}{k'_P \cdot (W/L)_5}\right)^{\frac{1}{2}} \cdot (\lambda_n + \lambda_p)^2}$$

$$= \frac{2 \cdot (k'_n \cdot k'_P)^{\frac{1}{2}} \cdot \left(\frac{W}{L}\right)_1^{\frac{1}{2}} \cdot \left(\frac{W}{L}\right)_5^{\frac{1}{2}}}{(\lambda_n + \lambda_p)^2 \cdot (I_{SD1} \cdot I_{DS5})^{\frac{1}{2}}}$$

Miller Op Amp (Cont.)

$$R_{OUT} = r_{o5} \parallel r_{o6} = \frac{1}{(\lambda_p + \lambda_n) \cdot I_{DS5}}$$

Add output stage if this is too high.



What is the output resistance of this ?

Miller Op Amp (Cont.)

You need to choose an operating point since the R_{out} is very non-linear.

$$R_{OUT} = \left.\frac{1}{g_{m1}}\right|_{V_{IN} > V_{Tn}}$$

$$= \left.\frac{1}{g_{m2}}\right|_{V_{IN} < -|V_{Tp}|}$$

$$g_m = \left(2 \cdot \frac{W}{L} \cdot k' \cdot I_{DS}\right)^{\frac{1}{2}} = \left(2 \cdot \frac{W}{L} \cdot k' \cdot I_{OUT}\right)^{\frac{1}{2}}$$

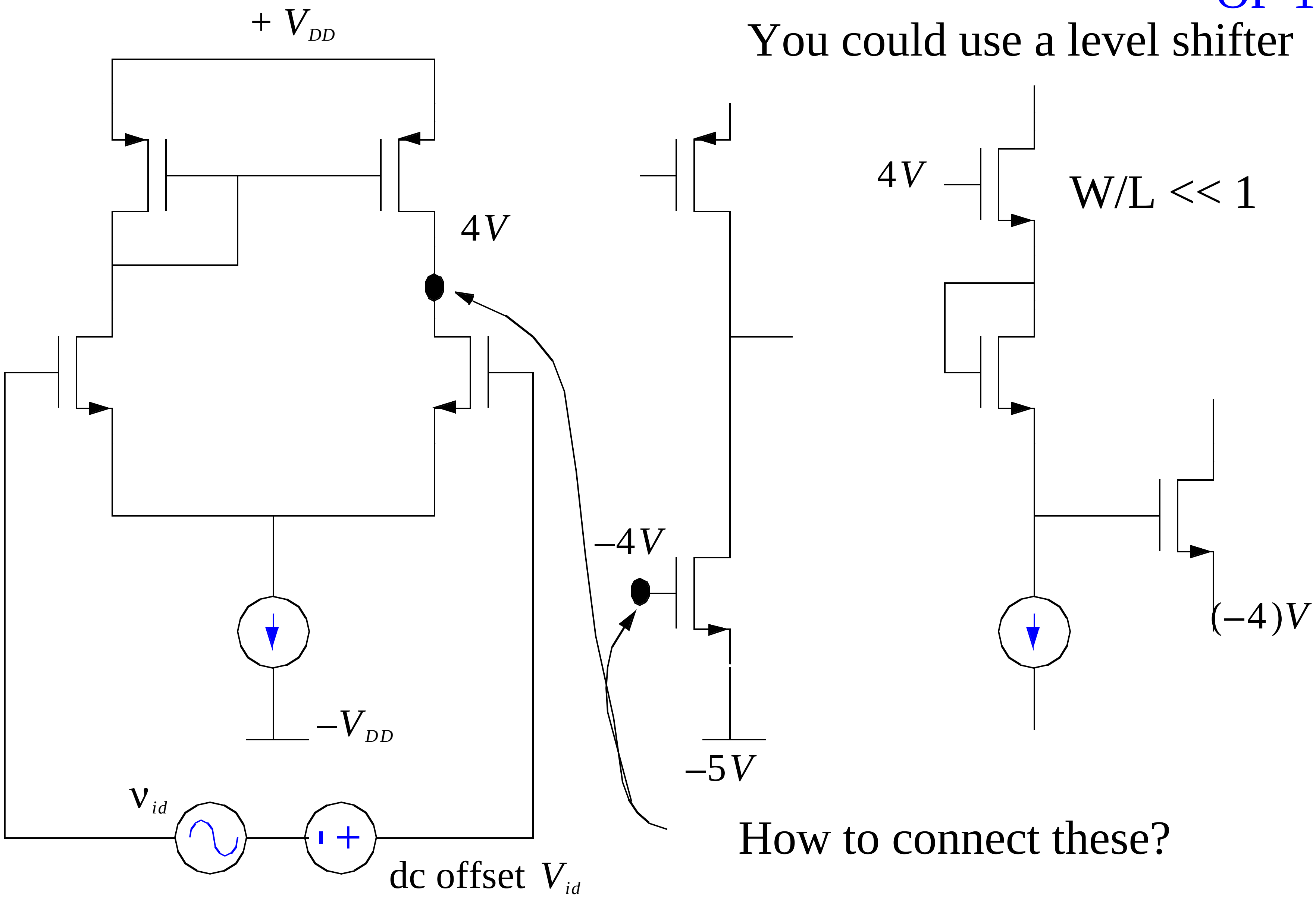
$$= \left(2 \cdot \frac{W}{L} \cdot k' \cdot \frac{V_{OUT}}{R_L}\right)^{\frac{1}{2}}$$

h

OP-10

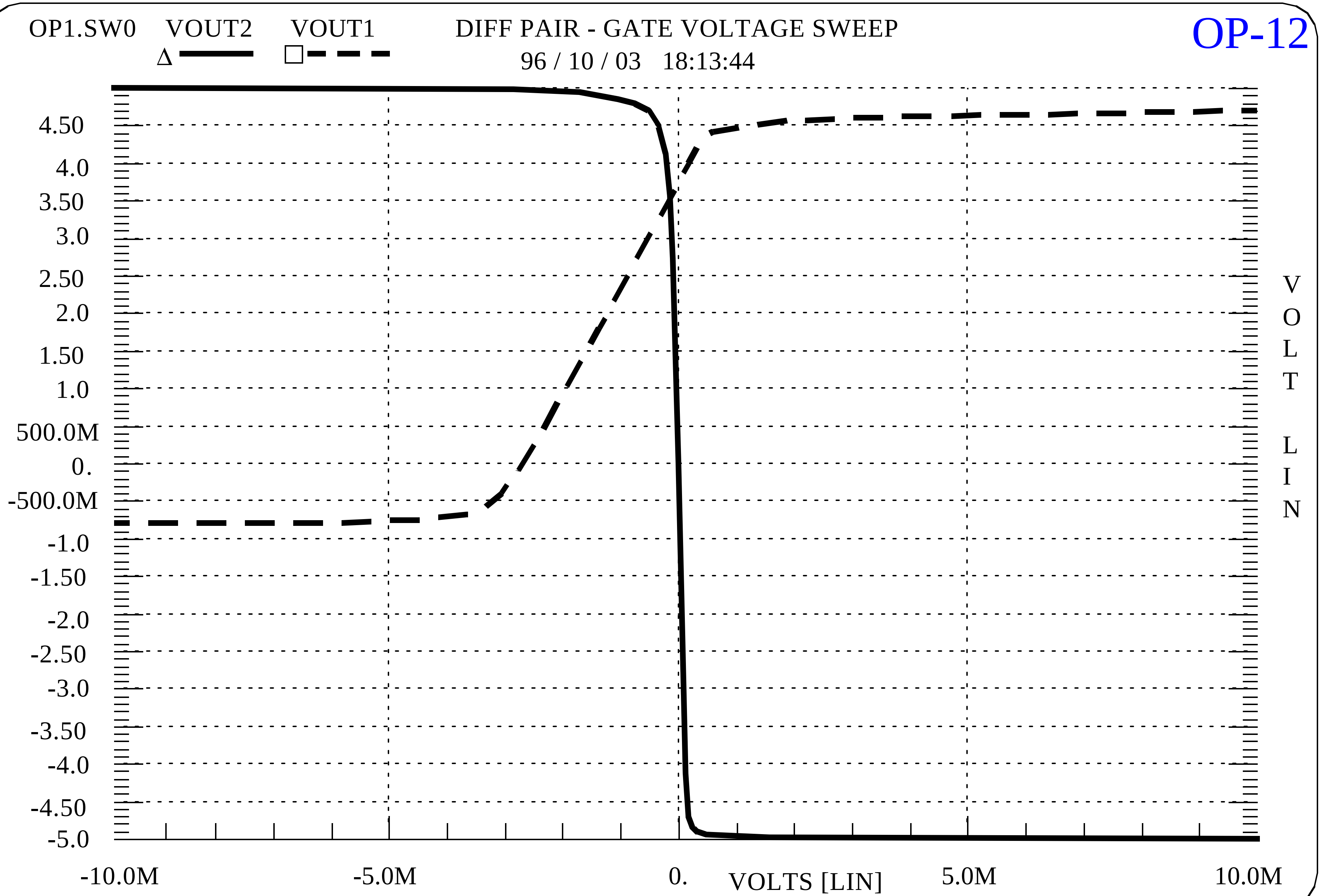
Empty Slide

You could use a level shifter



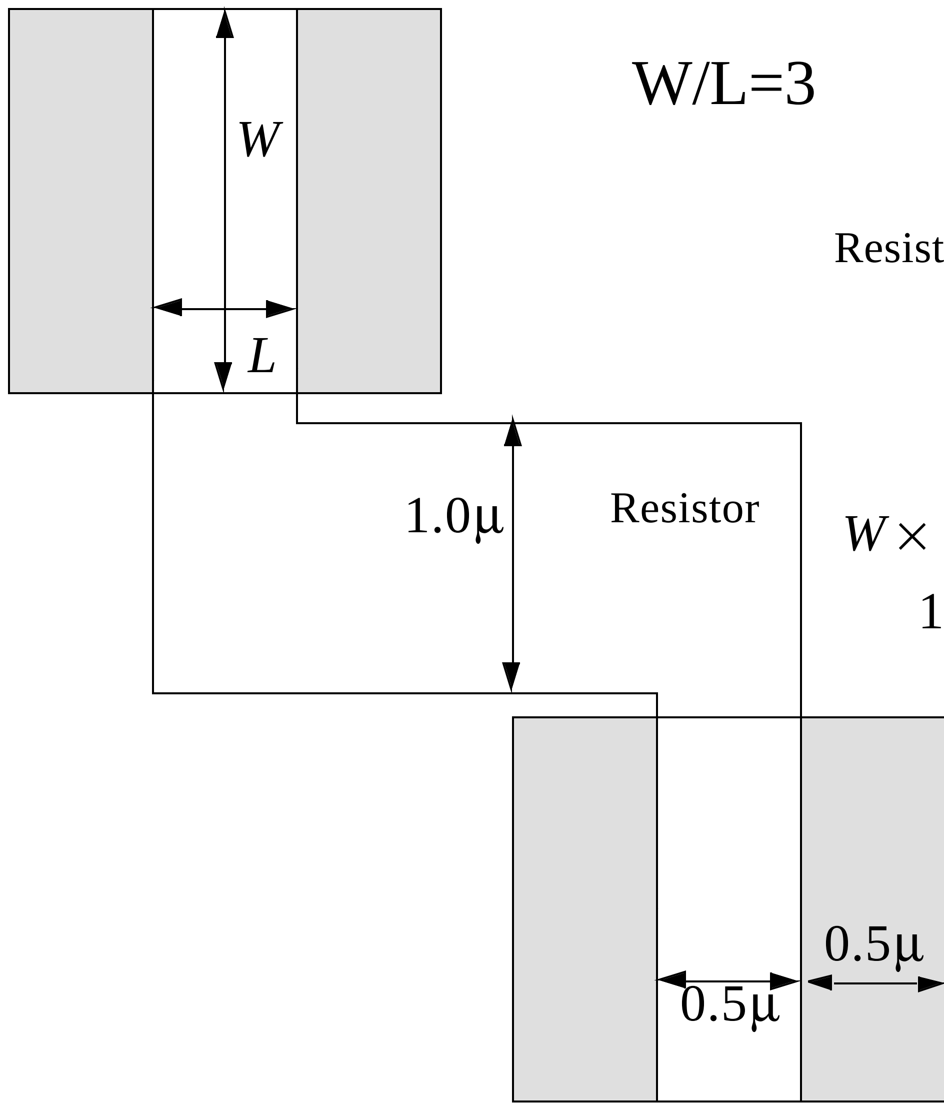
How to connect these?

OP-12


OP1.SW0
VOUT2
VOUT1
DIFF PAIR - GATE VOLTAGE SWEEP
96 / 10 / 03 18:13:44
4.50
4.0
3.50
3.0
2.50
2.0
1.50
1.0
500.0M
0.
-500.0M
-1.0
-1.50
-2.0
-2.50
-3.0
-3.50
-4.0
-4.50
-5.0
-10.0M
-5.0M
0.
VOLTS [LIN]
5.0M
10.0M
VOLT LIN

Area Calculation (L=.5 micron minimum channel Length)

W/L=3

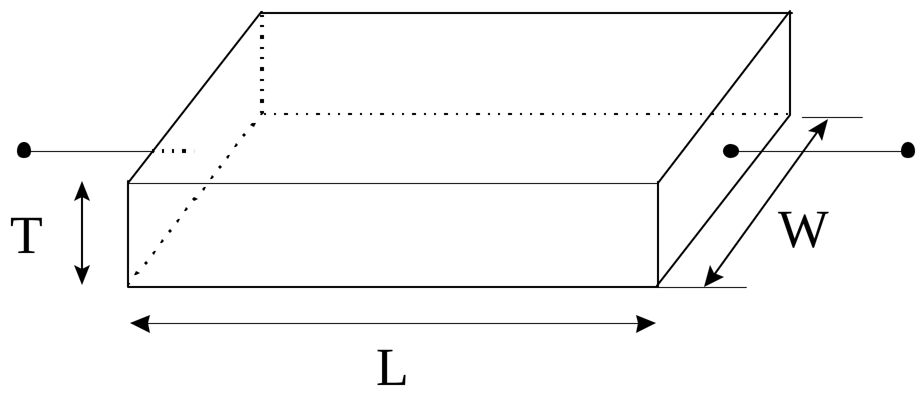


Resistor Area = # of squares * 1.0 μ^2

$$W \times \langle L + 1\mu^2 \rangle \approx TransistorArea$$

$$1.5\mu \times (0.5 + 1) = 2.25\mu^2$$

Sheet Resistance

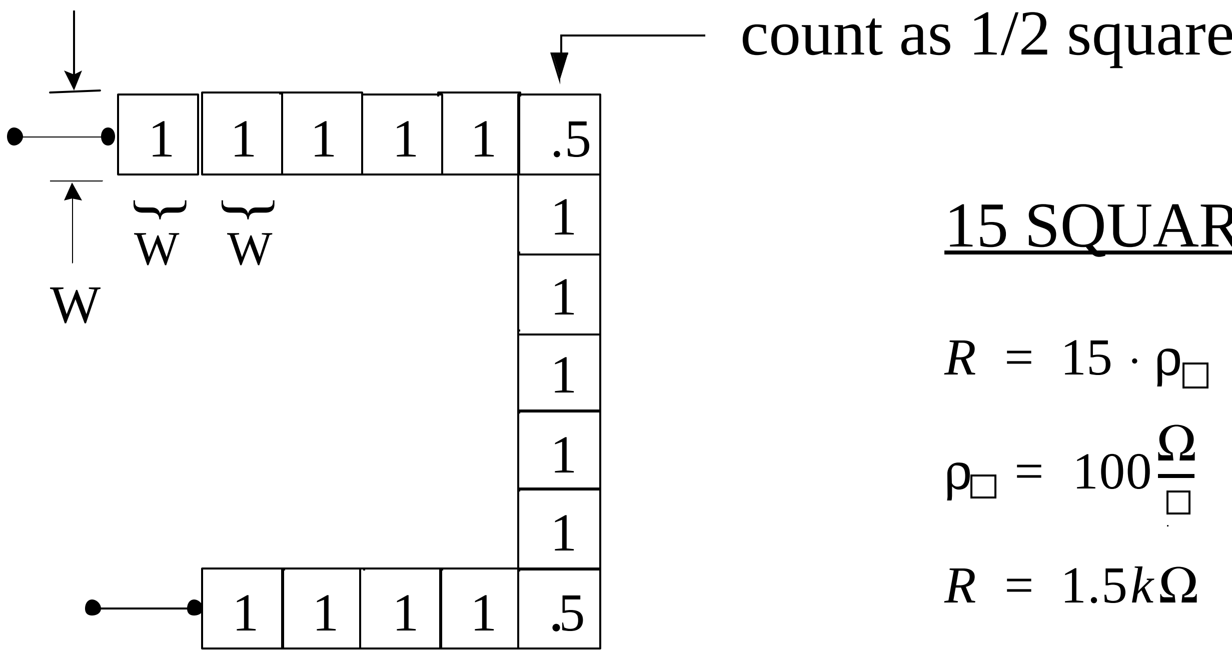


$$\text{Conductance} = \frac{1}{Resistance} = \frac{W \cdot T}{L} \cdot \sigma \quad \left[\frac{mhos}{cm^3}\right]$$

$$R = \frac{L}{W} \cdot \underbrace{\rho_\square}_{ohms/\square} \qquad \rho_\square = \sigma \cdot T$$

Sheet Resistance (Cont.)

TOP VIEW



15 SQUARES

$$R = 15 \cdot \rho_{\square}$$

$$\rho_{\square} = 100\frac{\Omega}{\square}$$

$$R = 1.5k\Omega$$