EE 332: Devices and Circuits II

Course Review & Examples for the Final Exam

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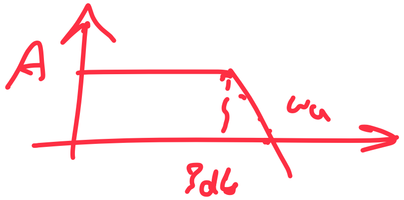
ELECTRICAL & COMPUTER ENGINEERING

What did we learn?

- MOS basics and modeling
  - I/V char, parasitics, small-signal, body-effect, channel length mod, …
- Single-stage Amp (CS, CG, SF + Cascode) 4 types
- Differential Pair (DM vs. CM, single-ended vs. diff, …)



- Frequency response (Poles/zeros, Bode Plot, Miller approx., GBW)
- Current Mirrors & Biasing 1/RC $A_o \times \omega_{3db} = 1 \times \omega_u$
- Feedback (loop-gain, voltage-voltage fb, …) & OpAmps Vs. OTA
- Noise (Definition & Characterization, Thermal Noise, etc.)

4kTR

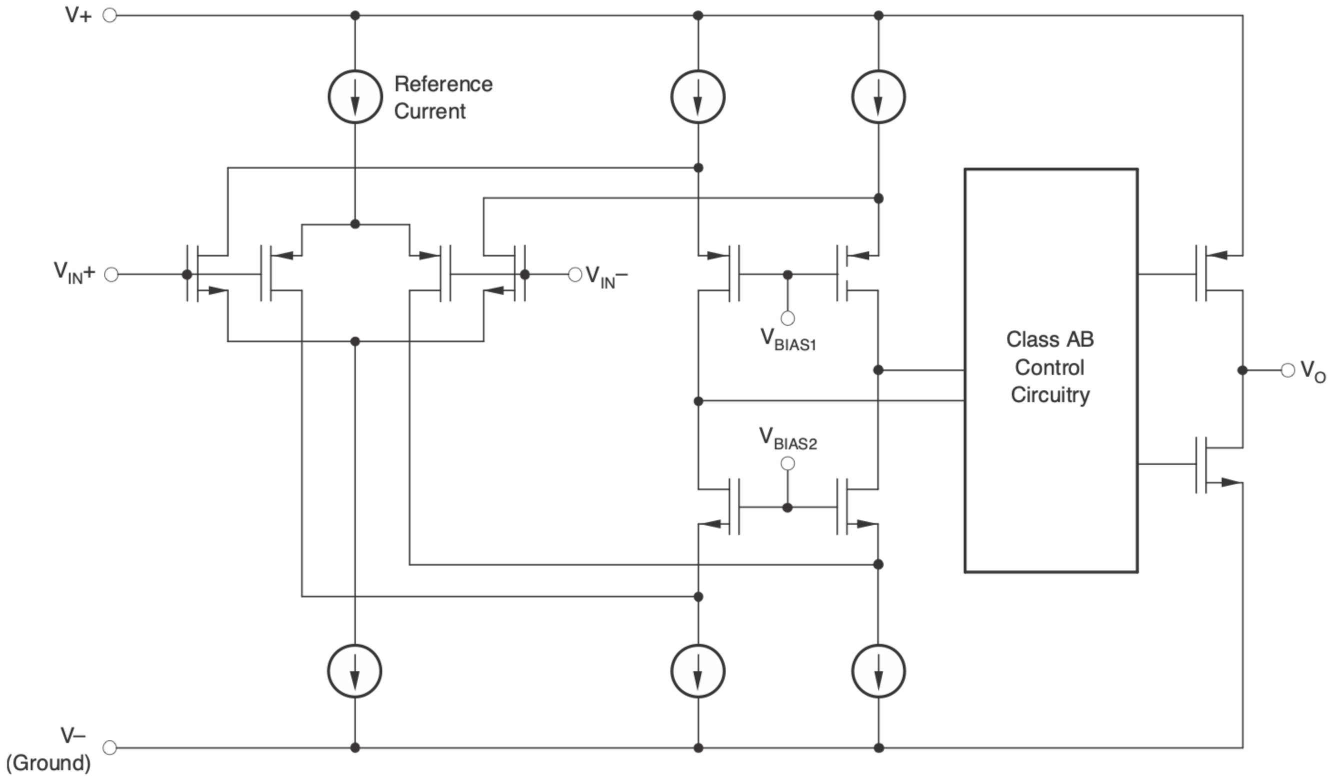
PSD,

Why did we learn?

- Analog circuit is an inevitable part of any electrical system!
  - Remember the world is analog!
- Now you can clearly appreciate the benefit of digital processors
  - You know where the noise is coming from!
- All the metrics you learned are fundamentals that any IC and embedded system designer should know …
  - Gain, Noise, Speed, …
- Techniques and circuit analysis are also essential for any IC designer
- Topics like feedback, noise, … are useful in Control, Signal processing, communications, etc.

COT Example (CMOS): TI OPAx355

8.2 Functional Block Diagram



1 Features

- Unity-Gain Bandwidth: 450 MHz
- Wide Bandwidth: 200 MHz GBW
- Low Noise: 5.8 nV/√Hz
- Excellent Video Performance
  - Differential Gain: 0.02%
  - Differential Phase: 0.05°
  - 0.1-dB Gain Flatness: 75 MHz
- Input Range Includes Ground
- Rail-to-Rail Output (within 100 mV)
- Low Input Bias Current: 3 pA
- Low Shutdown Current: 3.4 μA
- Enable and Disable Time: 100 ns and 30 ns
- Thermal Shutdown
- Single-Supply Operating Range: 2.5 V to 5.5 V
- *Micro*SIZE Packages

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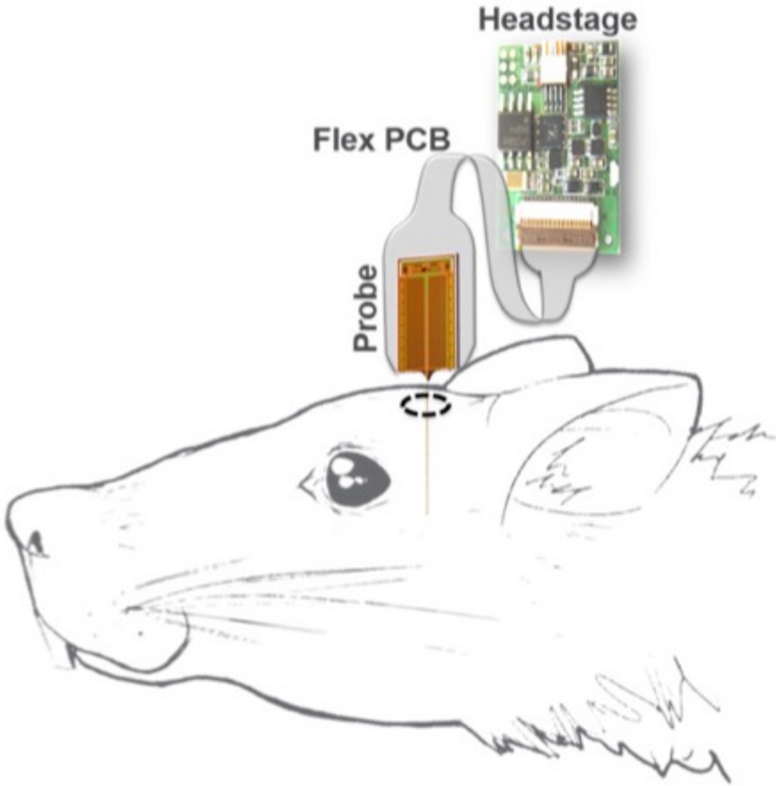
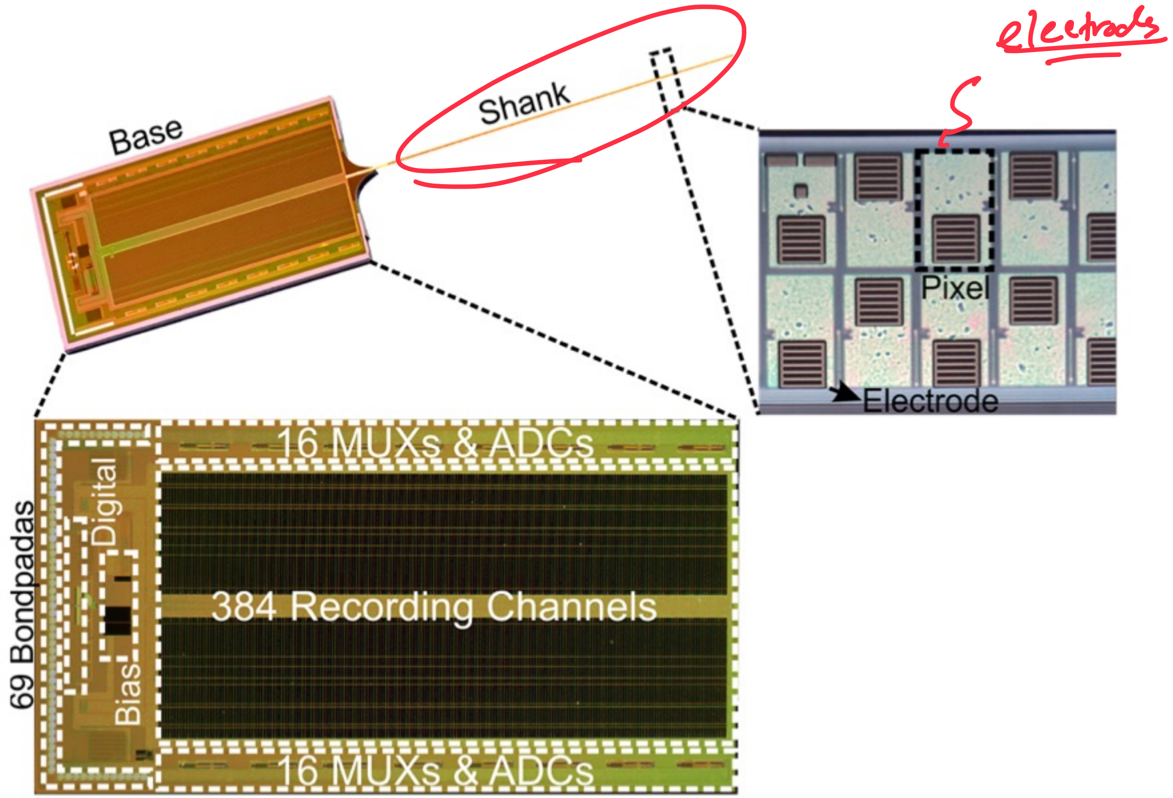
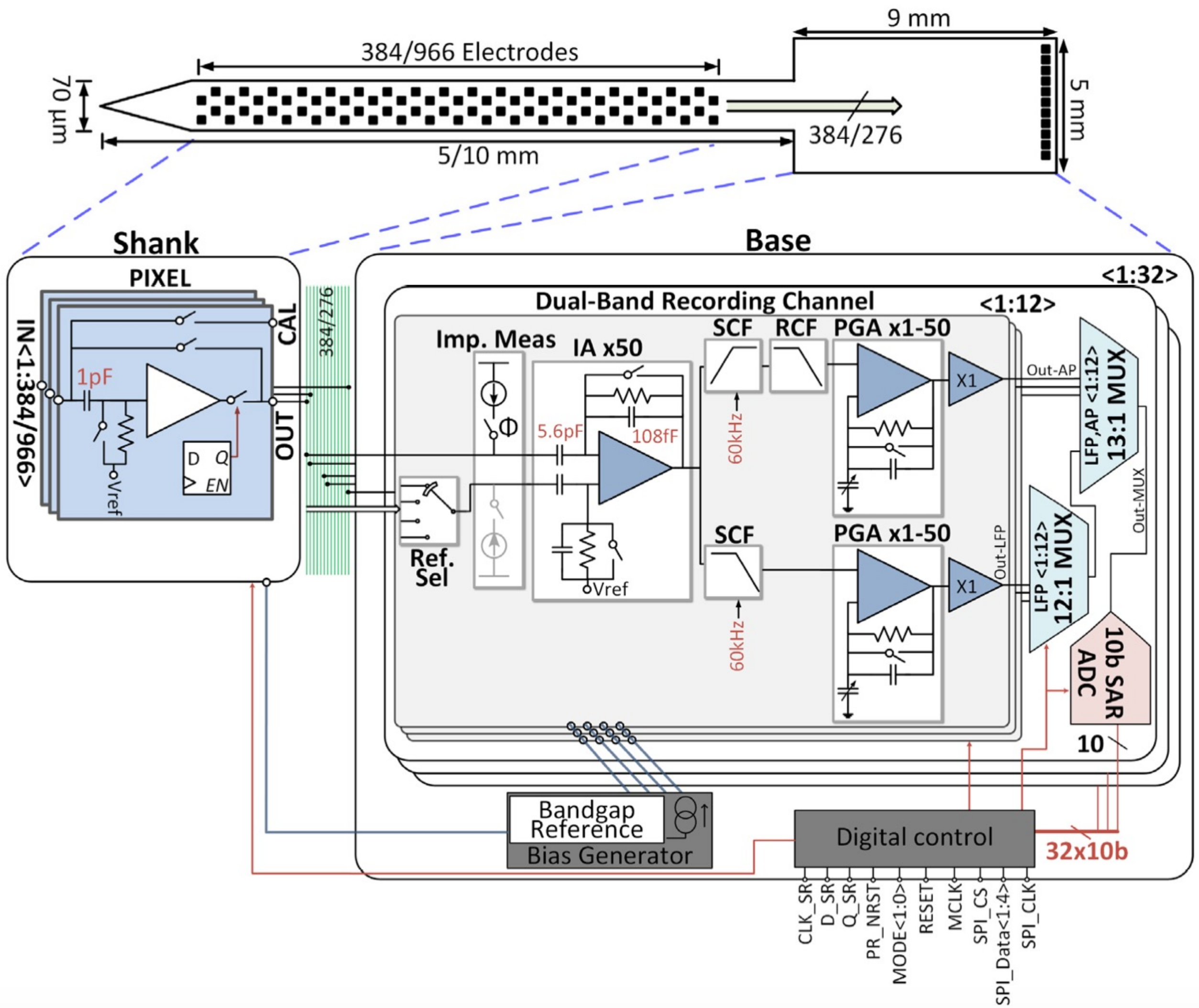
Modern Examples: Neuropixel





Fully integrated silicon probes for high-density recording of neural activity [Nature 2017]
A Neural Probe with up to 966 Electrodes and up to 384 Configurable Channels in 0.13µm SOI CMOS [TBioCAS 2017]

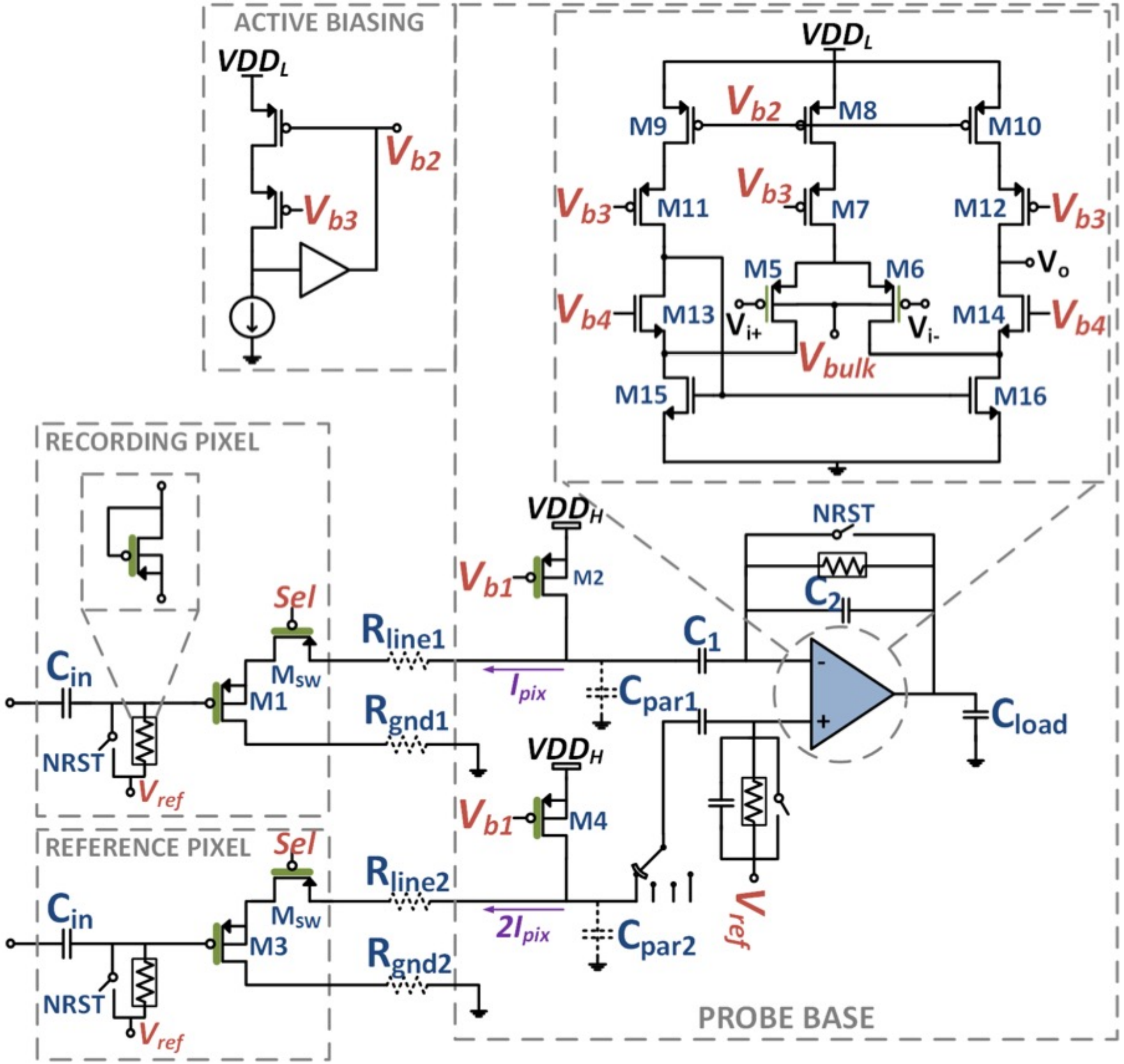
Modern Examples: Neuropixel



Extended Data Table 1 | Measured operating parameters of the 4 probe types reported (phase 3)

	Option 1	Option 2	Option 3	Option 4
Site Count	384	384	960	966
Channel count	384	384	384	276
Electrode type	Passive	Active	Passive	Active
Shank power (mW)	0	1.31	0	1.31
Base power (mW)	17.5			
Electrode area (μm^2)	144			
Crosstalk (at 1kHz)	< 5%			
Gain	selectable from 50 - 2500			
AP band high-pass corner (kHz)	selectable from 0.3 - 1.0			
AP band low-pass corner (kHz)	10			
LFP band high-pass corner (Hz)	0.5			
LFP band low-pass corner (Hz)	1000			
AP band sampling rate (kHz)	30			
LFP band sampling rate (kHz)	2.5			
AP band noise (µV r.m.s.)	5.7 ± 0.8	6.6 ± 0.8	5.5 ± 0.7	6.6 ± 2.5
LFP band noise (µV r.m.s.)	9.6 ± 5.8	13.0 ± 2.8	8.0 ± 2.5	10.2 ± 1.9

Modern Examples: Neuropixel



Examples for the Final Exam

Example 1

DM gain $= \frac{v_x}{v_{in_1}} \times \frac{v_{out_1}}{v_x}$

$-g_{m_1} \times (r_{o_1} || r_{o_3}) \times -g_{m_5} \times (r_{o_5} || r_{o_7})$

S.E C.M gain = ...

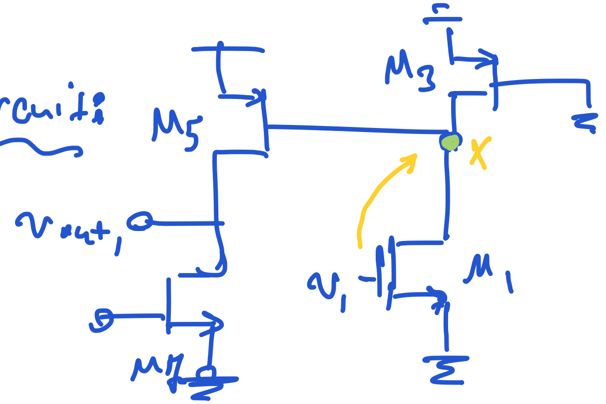
$$\frac{v_x}{v_{in_1}} = \frac{-g_{m_1} \times (r_{o_1} || r_{o_3})}{1 + g_{m_1} \times 2R_{SS}}$$

- Find/Draw: DM & CM half-circuit & gain, Swing

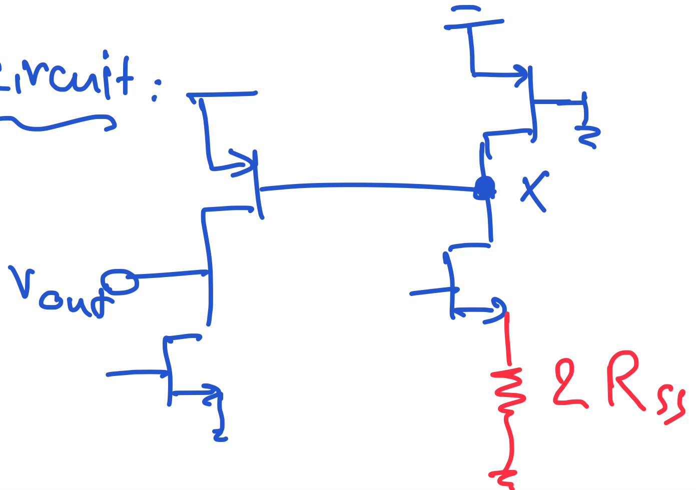
$V_{out\,max} \approx V_{DD} - V_{OD_5}$

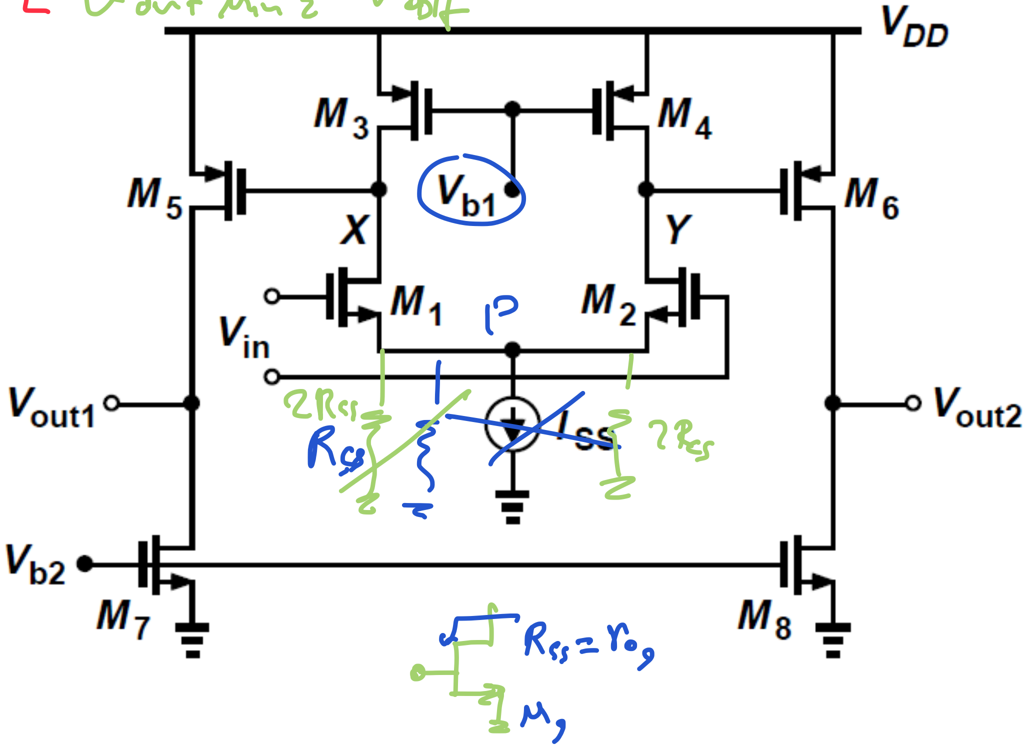
$V_{out\,min} \approx V_{OD7}$

D.M half-circuit:



C.M half-circuit:





Example 2

* Only assuming a dominant pole

D.M

- Find: Poles & Bode plots (C_L=1pF, C_{gs}=C_{gd}=1fF/um), 3db-bw, unity-gain bw

$\omega_x = \frac{1}{R_x C_x}$, $\omega_{out} = \frac{1}{R_{out} C_{out}}$

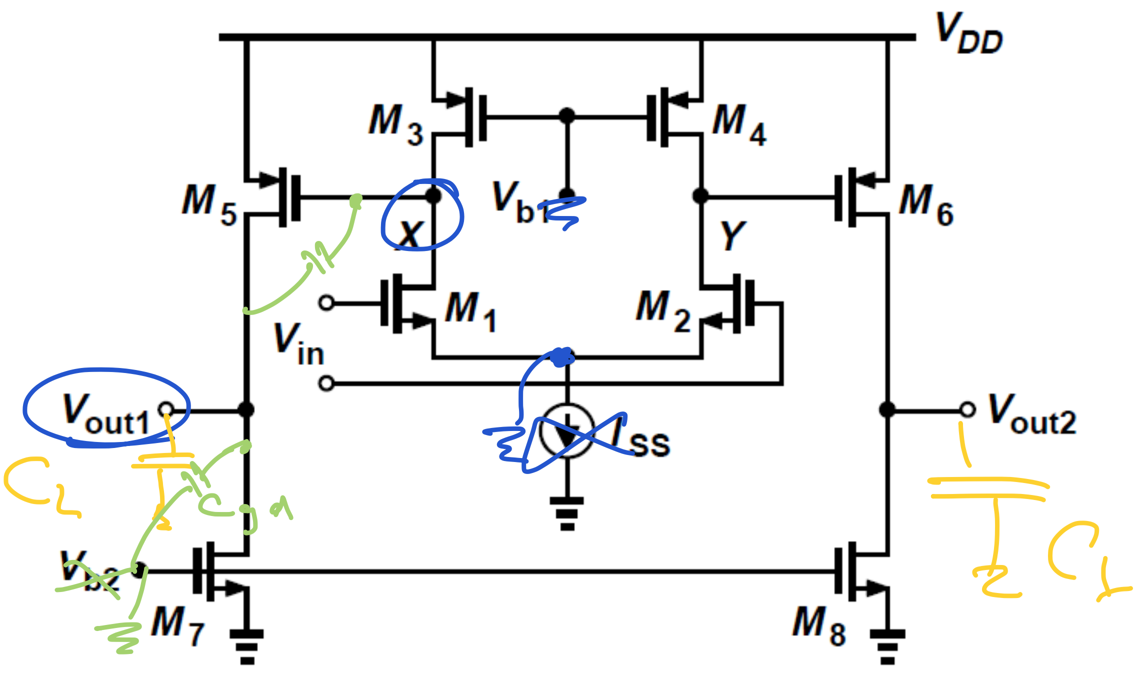
$r_{o7} \| r_{o1}$ $\qquad$ $r_{o5} \| r_{o7}$

$C_{out} = C_L + C_{gd7} + C_{gd5}$

$(W/L) \times L$

$W_7 \times \frac{1fF}{\mu m}$

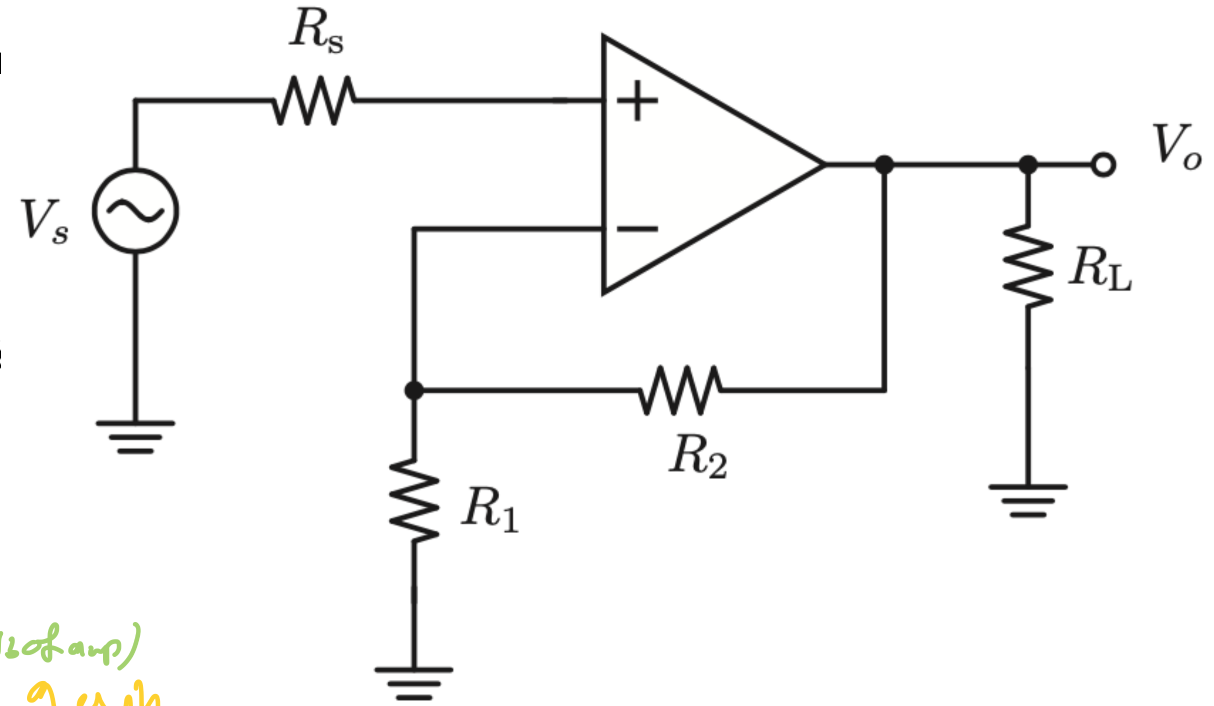
in μm



Example 3

An op-amp is configured to provide gain (V_O/V_S) of 5V/V a $R_L = 1k\Omega$ load. Model the op-amp with the followi parameters:

- $R_{in} = \infty$ (ideal)
- $R_{out} = 0$ (ideal)
- $A_0 = 100$ (not infinite)
- $f_0 = 10MHz$ (not ideal: finite 3dB-bandwidth frequency



Find:

- R2/R1 ?
- Gain error
- Bandwidth & Unity frequency
- If OpAmp's Rout = 100ohm -> find closed loop Rout?

$\omega_{3db} = \omega_{3db}$ of opAmp $\times (1+\beta A)$

remains the same! $(A_0 \times \omega_{3db}$ of amp$)$

gain error

$R_{out} = 100\Omega/(1+\beta A)$

$$\frac{A_0}{1+\beta A_0} \approx \frac{1}{\beta}\left(1-\frac{1}{\beta A}\right)$$

loop gain

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Example 3

Example 4

- Find bias currents, gain, input and output resistance.

$I_D \longrightarrow g_m \ \& \ r_o$