

Note: all the simulations are under $TT\ 25^{\circ}C$

Please design a **single-ended operational amplifier** by using the folded-cascode circuit configuration with PMOS input stage as shown at Fig. 1. **Please make sure all the MOSFETs operate in saturation region.**

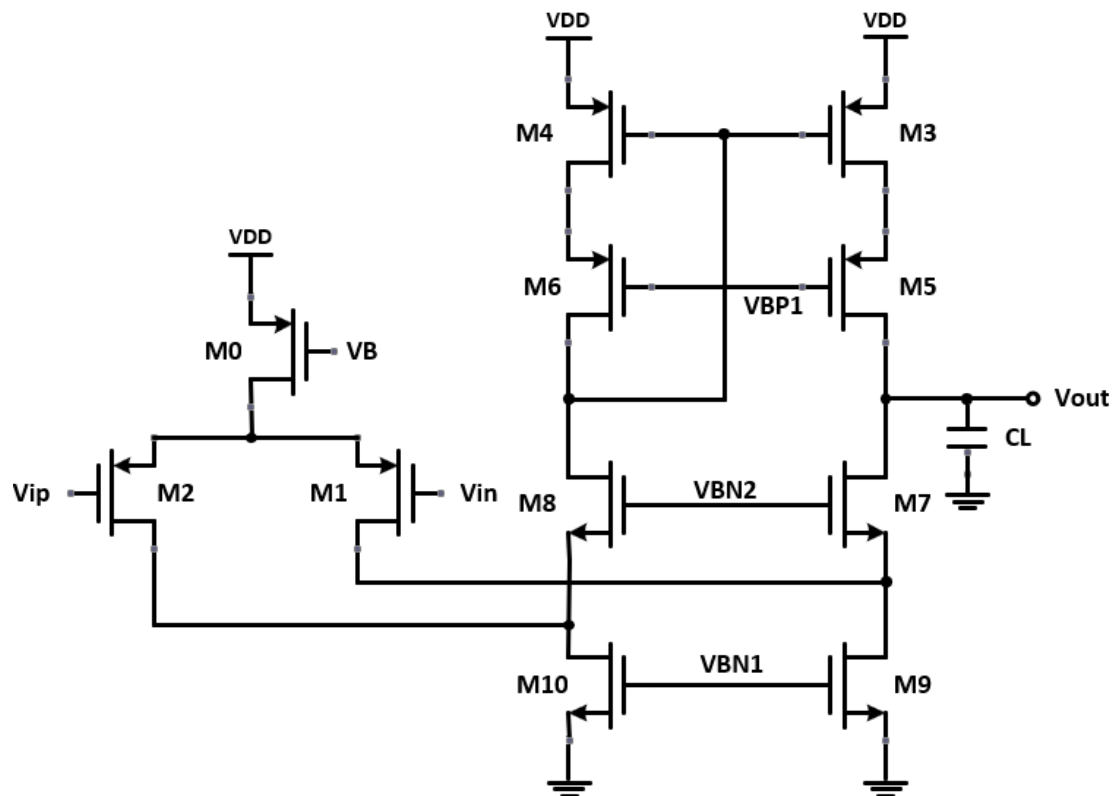


Fig. 1

This design is with output loading (CL) = 600fF, VDD = 1.8V, and input common mode voltage = 0.9V.

- You need to design the bias voltage (VB , $VBN1$, $VBN2$, $VBP1$) and device size (W/L) of $M0 \sim M10$ to make **DC gain larger than 65dB**, **unity gain frequency larger than 15MHz**, and **phase margin larger than 75°**. Please list all your device size, bias voltage and show your results. (10%)
- Please use .op command to print out the small signal parameters of active devices. Use the parameters to calculate the DC gain and check your calculation with the simulation results. (15%)
- Please simulate and plot the frequency response (magnitude and phase) of your design. Mark the DC gain, unity gain frequency, and phase margin on figure. (10%)

(d) Please simulate and plot the frequency response of your design. Use .pz to simulate and mark the first pole and second pole on this curve. (5%)

(e) Please input differential sinusoidal waveforms with 8mv linear range at 1MHz to estimate the harmonic distortion. Please use .four to simulate the THD performance. **The THD has to be less than 0.85% at 1MHz.** (10%)

(f) Please calculate the figure of merit (FoM) value as

$$= \frac{\text{Total current (uA)} \times \text{THD}(\%)}{\text{Gain (dB)} \times \text{Unity gain frequency (MHz)}} \times 1000$$

Try to find the best FoM of your design. (5%)

(g) Please fill the following table and discuss your design for best FoM. (15%+30%)

	Specification	This work
VDD	1.8V	
CL	600f	
Total current (uA)	Open for design	
DC gain (dB)	> 65	
Input common mode voltage	0.9V	
Output common mode voltage	Open for design	
Unity gain frequency (MHz)	> 15	
Phase margin (°)	> 75	
THD (%)	< 0.85	
FoM	As small as possible	

Result examples

```
dcgain_in_db= 70.1235 DC gain 1.0000
              from= 1.0000 to= 100.0000g
dcgain= 3.2076k at= 1.0000
              from= 1.0000 to= 100.0000g
unity_frequency= 15.0299x Unity gain frequency
phase=-104.9129
phase_margin= 75.0871 Phase margin
```

**** voltage sources

```
subckt
element 0:vbn1 0:vbn2 0:vbn3 0:vbn4 0:vbn5 0:vbn6
volts 1.2000 700.0000m 550.0000m 1.1000 1.8000 900.0000m
current 0. 0. 0. 0. -10.2326u 0.
power 0. 0. 0. 0. 18.4187u 0.
```

Total current

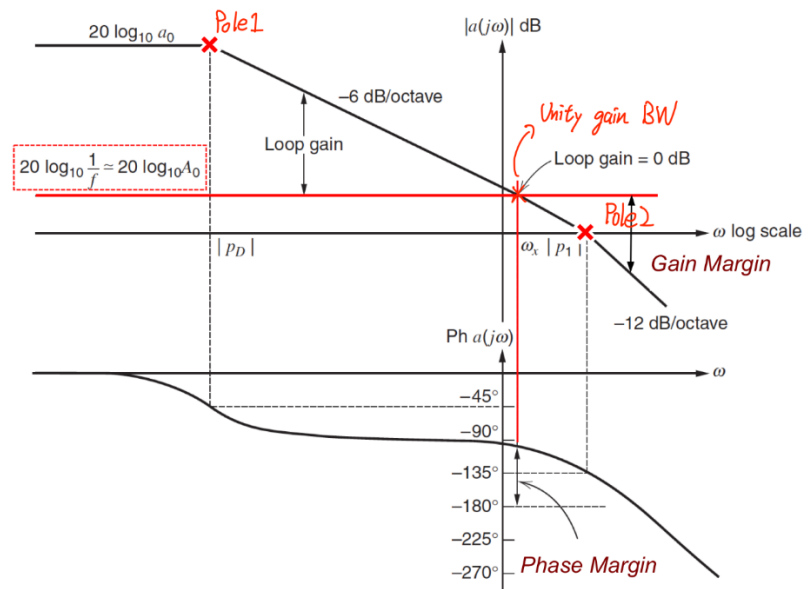
fourier components of transient response v(vout)
dc component = 1.3487

harmonic no	frequency (hz)	fourier component	normalized component	phase (deg)	normalized phase (deg)
1	1.0000x	121.9137m	1.0000	179.7440	0.
2	2.0000x	456.6967u	3.7461m	-95.1398	-274.8838
3	3.0000x	309.8281u	2.5414m	-91.2001	-270.9441
4	4.0000x	231.3345u	1.8975m	-88.6446	-268.3886
5	5.0000x	184.2653u	1.5114m	-88.0292	-267.7732
6	6.0000x	154.3273u	1.2659m	-87.9019	-267.6460
7	7.0000x	131.5347u	1.0789m	-87.2187	-266.9628
8	8.0000x	115.6348u	948.4976u	-87.3587	-267.1027
9	9.0000x	102.6788u	842.2256u	-86.5859	-266.3300

total harmonic distortion = **0.554546** percent **THD**

<補充説明> Phase margin

□ Bode Diagram



The key point to make phase margin better is to push further the second pole from the unity gain frequency.

For more detail, you can check Lecture 10 !!!

天梯分數計算方式

1. 得到天梯分數資格需滿足 $FoM < 6.5$

2. 天梯分數級距

1~2 名: 30 分

3~5 名: 25 分

6~10 名: 20 分

11~20 名: 15 分

21~30 名: 10 分

31 名以後: 5 分

3. 天梯表格連結:

https://docs.google.com/spreadsheets/d/1Ds97lnq0_m8mMIghyPJtGfywJy91g130/edit#gid=1062528342

! Do not fill these columns !				Fill your name				Fill your result			
RANK	Student Id	Name	FoM	Student Id	Name	FoM	Gain (dB)	Unity gain BW (MHz)	Current (uA)	THD (%)	
1	11200000X	TA	6.50E+0	11200000X	TA	6.50E+0	65	15.3848	10.0000	0.8500	
2	108011205			108011205							
3	109011116			109011116							
4	109011242			109011242							
5	109012029			109012029							
6	109012037			109012037							
7	109030032			109030032							
8	109031805			109031805							
9	109034051			109034051							
10	109061232			109061232							
11	110011101			110011101							
12	110011111			110011111							
13	110011114			110011114							
14	110011128			110011128							
15	110011134			110011134							
16	110011137			110011137							
17	110011144			110011144							
18	110011146			110011146							
19	110011149			110011149							
20	110011151			110011151							
21	110011205			110011205							
22	110011207			110011207							
23	110011208			110011208							
24	110011212			110011212							
25	110011213			110011213							
26	110011217			110011217							
27	110011220			110011220							
28	110011222			110011222							
29	110011231			110011231							
30	110011235			110011235							
31	110011241			110011241							
32	110011243			110011243							
33	110011247			110011247							
34	110011248			110011248							
35	110011249			110011249							
36	110011271			110011271							
37	110020002			110020002							
38	110020015			110020015							
39	110022102			110022102							

右表格輸入你的結果

Fill your name				Enter your student id				Do not fill these columns			
Fill your name				Enter your student id				Do not fill these columns			
Student Id	Name	FoM		Student Id	Name	FoM		Gain (dB)	Unity gain BW (MHz)	Current (uA)	THD (%)
11200000X	TA	6.50E+0		11200000X	TA	6.50E+0		65	15.3848	10.0000	0.8500
108011205				108011205							
109011116				109011116							
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109012029				109012029							
109012037				109012037							
109030032				109030032							
109031805				109031805							
109034051				109034051							
109061232				109061232							
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110011111				110011111							
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110011271				110011271							
110020002				110020002							
110020015				110020015							
110022102				110022102							

排名會顯示左邊

學號

名字(可隨便取)

填入你的結果