

# VE311 Homework 6

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## Problem 1.

For the common-mode gain, I wrote this SPICE circuit:

```
p1_1.cir
.TITLE Problem 1 - common mode gain

V1 2 0 SIN(0 5MV 1KHZ)
V2 4 0 SIN(0 5MV 1KHZ)
M1 3 2 1 1 NFET
M2 5 4 1 1 NFET
.MODEL NFET NMOS (KP=400U VTO=1)
RSS 1 7 62K
RD1 3 6 62K
RD2 5 6 62K
VDD 6 0 DC 15V
VSS 7 0 DC -15V

.TRAN 10NS 1MS
.MEASURE TRAN vpp1 PP V(2)
.MEASURE TRAN vpp2 PP V(3)
.MEASURE TRAN common_gain param='vpp2/vpp1'

.PROBE
.END
```

The result of common-mode gain is  $4.86588 \times 10^{-1}$ .

For the differential-mode gain, I wrote this SPICE circuit:

```

p1_2.cir
.TITLE Problem 1 - diff mode gain

V1 2 0 SIN(0 5MV 1KHZ)
V2 4 0 SIN(0 -5MV 1KHZ)
M1 3 2 1 1 NFET
M2 5 4 1 1 NFET
.MODEL NFET NMOS (KP=400U VTO=1)
RSS 1 7 62K
RD1 3 6 62K
RD2 5 6 62K
VDD 6 0 DC 15V
VSS 7 0 DC -15V

.TRAN 10NS 1MS
.MEASURE TRAN vpp1 PP V(2)
.MEASURE TRAN vpp2 PP par('(V(3)-V(5))/2')
.MEASURE TRAN diff_gain param='vpp2/vpp1'

.PROBE
.END

```

The result of differential-mode gain is  $1.81396 \times 10^1$ .

$$CMRR = \frac{1.81396 \times 10^1}{2 \cdot 4.86588 \times 10^{-1}} = 1.86395 \times 10^1$$

The differential-mode and common-mode input resistances are both  $+\infty$ .

## Problem 2.

(a) Suppose  $V_{BE} = 0.7 \text{ V}$ ,

$$I_E = \frac{V_{EE} - V_{BE}}{2R_{EE}} = \frac{18 \text{ V} - 0.7 \text{ V}}{2 \cdot 47 \text{ k}\Omega} \approx 0.184 \text{ mA}$$

$$I_C = I_E \frac{\beta_F}{\beta_F + 1} = 0.368 \text{ mA} \cdot \frac{100}{101} \approx 0.182 \text{ mA}$$

$$V_C = V_{CC} - I_C R_C = 18 \text{ V} - 0.364 \text{ mA} \cdot 50 \text{ k}\Omega \approx 8.9 \text{ V}$$

$$V_{CE} = V_C + V_{BE} = 9.6 \text{ V}$$

So the Q point is (0.184 mA, 9.6 V).

(b)

$$g_m = \frac{I_C}{V_T} = \frac{0.182 \text{ mA}}{0.025 \text{ V}} = 7.28 \text{ mS}$$

$$A_{dd} = -g_m R_C = -7.28 \text{ mS} \cdot 50 \text{ k}\Omega = -364$$

$$A_{cc} = -\frac{R_C}{2R_{EE}} = -\frac{50 \text{ k}\Omega}{2 \cdot 47 \text{ k}\Omega} \approx -0.53$$

$$CMRR = \frac{A_{dd}}{2A_{cc}} = \frac{-364}{2 \cdot -0.53} \approx 343$$

Differential-mode:

$$r_{id} = 2r_{\pi} = 2 \frac{\beta_F}{g_m} = \frac{2 \cdot 100}{7.28 \text{ mS}} \approx 27.5 \text{ k}\Omega$$

$$r_{od} \approx 2R_C = 100 \text{ k}\Omega$$

Common-mode:

$$r_{ic} = \frac{r_{\pi}}{2} + (\beta_F + 1)R_{EE} = \frac{\beta_F}{2g_m} + (\beta_F + 1)R_{EE} = \frac{100}{2 \cdot 7.28 \text{ mS}} + 101 \cdot 47 \text{ k}\Omega \approx 4.75 \text{ M}\Omega$$

$$r_{oc} \approx R_C = 50 \text{ k}\Omega$$

For the common-mode gain, I wrote this SPICE circuit:

```
p2_1.cir
.TITLE Problem 2 - common mode gain

V1 2 0 SIN(0 5MV 1KHZ)
V2 4 0 SIN(0 5MV 1KHZ)
Q1 3 2 1 QMOD
Q2 5 4 1 QMOD
.MODEL QMOD NPN (BF=100)
REE 1 7 47K
RC1 3 6 50K
RC2 5 6 50K
VDD 6 0 DC 18V
VSS 7 0 DC -18V

.TRAN 10NS 1MS
.MEASURE TRAN vpp1 PP V(2)
.MEASURE TRAN vpp2 PP V(3)
.MEASURE TRAN common_gain param='vpp2/vpp1'

.PROBE
.END
```

The result of common-mode gain is  $5.25861 \times 10^{-1}$ .

For the differential-mode gain, I wrote this SPICE circuit:

```

p2_2.cir
.TITLE Problem 2 - diff mode gain

V1 2 0 SIN(0 5MV 1KHZ)
V2 4 0 SIN(0 -5MV 1KHZ)
Q1 3 2 1 QMOD
Q2 5 4 1 QMOD
.MODEL QMOD NPN (BF=100)
REE 1 7 47K
RC1 3 6 50K
RC2 5 6 50K
VDD 6 0 DC 18V
VSS 7 0 DC -18V

.TRAN 10NS 1MS
.MEASURE TRAN vpp1 PP V(2)
.MEASURE TRAN vpp2 PP par('(V(3)-V(5))/2')
.MEASURE TRAN diff_gain param='vpp2/vpp1'

.PROBE
.END

```

The result of differential-mode gain is  $3.47344 \times 10^2$ .

$$CMRR = \frac{3.47344 \times 10^1}{2 \cdot 5.25861 \times 10^{-1}} = 3.30262 \times 10^1$$

## Reference

The simulation can be run with the following command:

```

#!/bin/bash
ngspice -b -o p1_1.result p1_1.cir
ngspice -b -o p1_2.result p1_2.cir
ngspice -b -o p2_1.result p2_1.cir
ngspice -b -o p2_2.result p2_2.cir

```

The results are shown below

Circuit: Problem 1 - common mode gain

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: v2: no DC value, transient time 0 value used

Warning: v1: no DC value, transient time 0 value used

Initial Transient Solution

-----

Node	Voltage
----	-----
2	0
4	0
3	8.36573
1	-1.73145
5	8.36573
7	-15
6	15
vss#branch	0.000214009
vdd#branch	-0.000214009
v2#branch	0
v1#branch	0

No. of Data Rows : 100008

Measurements for Transient Analysis

vpp1	=	1.000000e-02	from=	0.000000e+00	to=	0.000000e+00
vpp2	=	4.865880e-03	from=	0.000000e+00	to=	0.000000e+00
common_gain	=	4.86588e-01				

CPU time since last call: 0.700 seconds.

Total CPU time: 0.700 seconds.

Total DRAM available = 7808.496094 MB.

DRAM currently available = 220.328125 MB.

Total ngspice program size = 3.952148 MB.

Resident set size = 2.176758 MB.

Shared ngspice pages = 1.367188 MB.

Text (code) pages = 1.324219 MB.

Stack = 0 bytes.

Library pages = 909.000 kB.

Circuit: Problem 1 - diff mode gain

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: v2: no DC value, transient time 0 value used

Warning: v1: no DC value, transient time 0 value used

Initial Transient Solution

-----

Node	Voltage
----	-----
2	0
4	0
3	8.36573
1	-1.73145
5	8.36573
7	-15
6	15
pa_00	0
bpa_00#branch	0
vss#branch	0.000214009
vdd#branch	-0.000214009
v2#branch	0
v1#branch	0

No. of Data Rows : 100008

Measurements for Transient Analysis

vpp1	=	1.000000e-02	from=	0.000000e+00	to=	0.000000e+00
vpp2	=	1.813960e-01	from=	0.000000e+00	to=	0.000000e+00
diff_gain	=	1.81396e+01				

CPU time since last call: 0.732 seconds.

Total CPU time: 0.732 seconds.

Total DRAM available = 7808.496094 MB.

DRAM currently available = 223.156250 MB.

Total ngspice program size = 3.953125 MB.

Resident set size = 2.122070 MB.

Shared ngspice pages = 1.352539 MB.

Text (code) pages = 1.324219 MB.

Stack = 0 bytes.

Library pages = 910.000 kB.

Circuit: Problem 2 - common mode gain

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: v2: no DC value, transient time 0 value used

Warning: v1: no DC value, transient time 0 value used

Initial Transient Solution

-----

Node	Voltage
----	-----
2	0
4	0
3	8.90485
1	-0.730129
5	8.90485
7	-18
6	18
vss#branch	0.000367444
vdd#branch	-0.000363806
v2#branch	-1.81902e-06
v1#branch	-1.81902e-06

No. of Data Rows : 100008

Measurements for Transient Analysis

vpp1	=	1.000000e-02	from=	0.000000e+00	to=	0.000000e+00
vpp2	=	5.258608e-03	from=	0.000000e+00	to=	0.000000e+00
common_gain	=	5.25861e-01				

CPU time since last call: 0.816 seconds.

Total CPU time: 0.816 seconds.

Total DRAM available = 7808.496094 MB.

DRAM currently available = 219.437500 MB.

Total ngspice program size = 3.952148 MB.

Resident set size = 2.166992 MB.

Shared ngspice pages = 1.408203 MB.

Text (code) pages = 1.324219 MB.

Stack = 0 bytes.

Library pages = 909.000 kB.

Circuit: Problem 2 - diff mode gain

Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

Warning: v2: no DC value, transient time 0 value used

Warning: v1: no DC value, transient time 0 value used

Initial Transient Solution

-----

Node	Voltage
----	-----
2	0
4	0
3	8.90485
1	-0.730129
5	8.90485
7	-18
6	18
pa_00	0
bpa_00#branch	0
vss#branch	0.000367444
vdd#branch	-0.000363806
v2#branch	-1.81902e-06
v1#branch	-1.81902e-06

No. of Data Rows : 100008

Measurements for Transient Analysis

vpp1	=	1.000000e-02	from=	0.000000e+00	to=	0.000000e+00
vpp2	=	3.473439e+00	from=	0.000000e+00	to=	0.000000e+00
diff_gain	=	3.47344e+02				

CPU time since last call: 0.776 seconds.

Total CPU time: 0.776 seconds.

Total DRAM available = 7808.496094 MB.

DRAM currently available = 180.914062 MB.

Total ngspice program size = 3.953125 MB.

Resident set size = 2.251953 MB.

Shared ngspice pages = 1.482422 MB.

Text (code) pages = 1.324219 MB.

Stack = 0 bytes.

Library pages = 910.000 kB.