Third SPICE Exercise

Fundamentals Of Electronics - a.a. 2018-2019 - University of Padua (Italy)

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Contents

Chapter 1

Differential amplifier with MOS current source

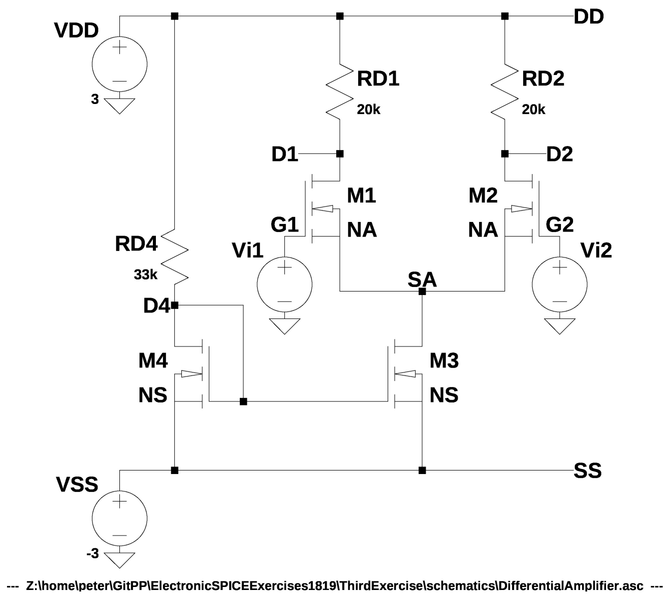

Figure 1.1: Differential amplifier with MOS current source

Data:

$$V_t = 0.5V \tag{1.1}$$

$$K'_n = \mu_n C_{ox} = 200 \frac{\mu A}{V^2} \tag{1.2}$$

$$\lambda = 0 \tag{1.3}$$

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 20 \tag{1.4}$$

$$\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 5 \tag{1.5}$$

$$R_{D_1} = R_{D_2} = 20k\Omega \tag{1.6}$$

$$R_{D_4} = \frac{30}{1000} \cdot 1097752\Omega = 32.93k\Omega \simeq 33k\Omega \tag{1.7}$$

$$V_{DD} = 3V \tag{1.8}$$

$$V_{SS} = -3V \tag{1.9}$$

1.1 MOSFET current mirror source - Analytic solution

1.1.1 MOSFET M_4

V_{D_4SS}

The transistor M_4 has a short circuit between its drain and its gate, so the transistor works in saturation mode and the voltage between the drain and the gate are the same of the voltage between the gate and the source. The current I_{D_4} could be calculated as:

$$I_{D_4} = \frac{1}{2}K'_n\left(\frac{W}{L}\right)_4(V_{D_4SS} - V_t)^2 \tag{1.10}$$

Other expression of the current I_{D_4} could be calculated using the LKT:

$$V_{DD} - R_{D_4}I_{D_4} - V_{D4SS} - V_{SS} = 0 \implies I_{D_4} = \frac{V_{DD} - V_{D_4SS} - V_{SS}}{R_{D_4}} \tag{1.11}$$

Using the equations 1.20 and 1.11 it's possible calculating V_{D_4SS}:

$$\frac{1}{2}K'_n\left(\frac{W}{L}\right)_4(V_{D_4SS} - V_t)^2 = \frac{V_{DD} - V_{D_4SS} - V_{SS}}{R_{D_4}} \tag{1.12}$$

$$\frac{1}{2}\cdot 200\frac{\mu A}{V^2}\cdot 5\frac{\mu m}{\mu m}(V_{D_4SS} - 0.5V)^2 = \frac{3V - V_{D_4SS} - (-3V)}{33k\Omega} \tag{1.13}$$

$$500\frac{\mu A}{V^2}(V_{D_4SS} - 0.5V)^2 = \frac{6}{33}mA - \frac{1}{33k\Omega}V_{D_4SS} \tag{1.14}$$

$$500\frac{\mu A}{V^2}(V_{D_4SS}^2 - V_{D_4SS}\cdot V + 0.25V^2) = \frac{6}{33}mA - \frac{1}{33k\Omega}V_{D_4SS} \tag{1.15}$$

$$500\frac{\mu A}{V^2}\cdot V_{D_4SS}^2 + \left(-500\frac{\mu A}{V^2}V + \frac{1}{33k\Omega}\right)V_{D_4SS} + 500\frac{\mu A}{V^2}\cdot 0.25V^2 - \frac{6}{33}mA = 0 \tag{1.16}$$

$$0.5\frac{mA}{V^2}\cdot V_{D_4SS}^2 + \left(-0.5\frac{mA}{V^2}V + \frac{1}{33k\Omega}\right)V_{D_4SS} + 0.5\frac{mA}{V^2}\cdot 0.25V^2 - \frac{6}{33}mA = 0 \tag{1.17}$$

$$\left(0.5\frac{mA}{V^2}\right)V_{D_4SS}^2 + \left(-\frac{31}{66}\frac{mA}{V}\right)V_{D_4SS} + \left(-\frac{5}{88}mA\right) = 0 \tag{1.18}$$

$$V_{D_4SS_{1,2}} = \frac{-\left(-\frac{31}{66}\frac{mA}{V}\right) \pm \sqrt{\left(-\frac{31}{66}\frac{mA}{V}\right)^2 - 4\cdot\left(0.5\frac{mA}{V^2}\right)\cdot\left(-\frac{5}{88}mA\right)}}{2\cdot 0.5\frac{mA}{V^2}} = \begin{cases} 1.04784V \\ -0.10845V \quad \text{Not possible: } < \text{ of } V_t \end{cases} \tag{1.19}$$

I_{D_4}

Using the equation 1.20 and the result of the equation 1.19:

$$I_{D_4} = \frac{1}{2}\cdot 200\mu A/V^2\cdot 5\frac{\mu m}{\mu m}\cdot(1.04784V - 0.5V)^2 = 150.06433\mu A \tag{1.20}$$

1.1.2 MOSFET M_3

I_{S_A}

Using the result of the equation 1.19 and supposing that the work is on the saturation mode, it's possible calculating the drain current of the MOSFET M_3:

$$I_{SA} = \frac{1}{2}K'_n\left(\frac{W}{L}\right)_3(V_{D_4SS} - V_t)^2 \tag{1.21}$$

$$I_{SA} = \frac{1}{2}\cdot 200\mu A/V^2\cdot 5\frac{\mu m}{\mu m}\cdot(1.04784V - 0.5V)^2 = 150.06433\mu A \tag{1.22}$$

1.2 SPICE Operating Point analysis

```
* Differential Amplifier
*****************************************************************************
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*                                                                               *
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* http://creativecommons.org/licenses/by-sa/4.0/ or send a letter to Creative   *
* Commons, PO Box 1866, Mountain View, CA 94042, USA.                           *
*****************************************************************************

* Parameters
.param RD = 20k
.param VG1 = 0
.param VG2 = 0

* NMOS models
.model NA NMOS VT0=0.5 KP=200u LAMBDA=0 W=4.00u L=0.20u
.model NS NMOS VT0=0.5 KP=200u LAMBDA=0 W=1.25u L=0.25u

* Resistances
RD1 DD D1 {RD}
RD2 DD D2 {RD}
RD4 DD D4 33k

* Transistors
M1 D1 G1 SA SA NA
M2 D2 G2 SA SA NA
M3 SA D4 SS SS NS
M4 D4 D4 SS SS NS

* Voltage sources
VDD DD 0 3
VSS SS 0 -3
Vi1 G1 0 {VG1}
Vi2 G2 0 {VG2}

* Analysis
.op

.END
```

```
        --- Operating Point ---

V(dd):       3                 voltage
V(d1):       1.49935           voltage
V(d2):       1.49935           voltage
V(d4):       -1.95216          voltage
V(g1):       0                 voltage
V(sa):       -0.693691         voltage
V(g2):       0                 voltage
V(ss):       -3                voltage
Id(M4):      0.000150065       device_current
Ig(M4):      0                 device_current
Ib(M4):      -1.05784e-012     device_current
Is(M4):      -0.000150065      device_current
Id(M3):      0.000150065       device_current
Ig(M3):      0                 device_current
```

```
Ib(M3):    -2.31631e-012    device_current
Is(M3):    -0.000150065     device_current
Id(M2):    7.50327e-005     device_current
Ig(M2):    0                device_current
Ib(M2):    -2.20304e-012    device_current
Is(M2):    -7.50327e-005    device_current
Id(M1):    7.50327e-005     device_current
Ig(M1):    0                device_current
Ib(M1):    -2.20304e-012    device_current
Is(M1):    -7.50327e-005    device_current
I(Rd4):    0.000150065      device_current
I(Rd2):    7.50327e-005     device_current
I(Rd1):    7.50327e-005     device_current
I(Vi2):    0                device_current
I(Vi1):    0                device_current
I(Vss):    0.000300131      device_current
I(Vdd):    -0.000300131     device_current
```