Third SPICE Exercise

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

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Chapter 1

Differential amplifier with MOS current source

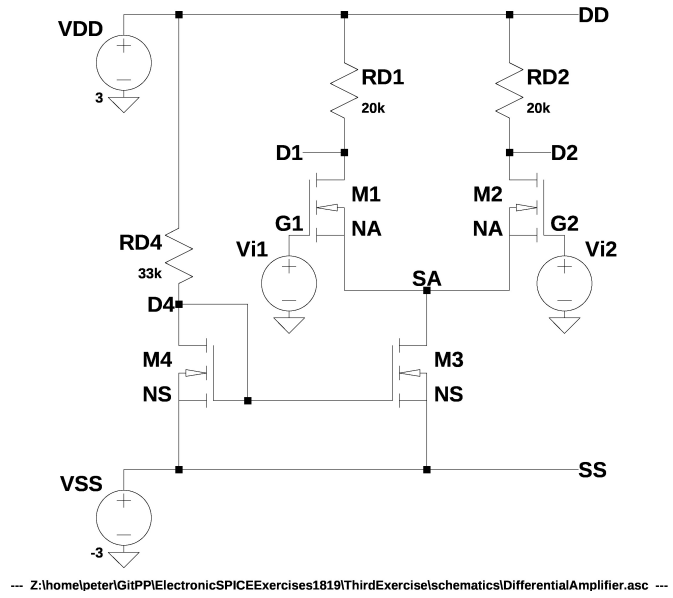

Figure 1.1: Differential amplifier with MOS current source

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 I_{D_4}

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

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

Other expression of the current I_{D_4} is:

$$I_{D_4} = \frac{V_{DD} - (V_{D_4} - V_{SS})}{R_{D_4}} \tag{1.11}$$

Using the equations 1.10 and 1.11 it's possible calculating V_{D_4}:

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

$$\frac{1}{2} \cdot 200\frac{\mu A}{V^2} \cdot 5\frac{\mu m}{\mu m}(V_{D_4} - (-3V) - 0.5V)^2 = \frac{3V - V_{D_4} + (-3V)}{33k\Omega} \tag{1.13}$$

$$500\frac{\mu A}{V^2}(V_{D_4} + 2.5V)^2 = -\frac{1}{33k\Omega} V_{D_4} \tag{1.14}$$

$$500\frac{\mu A}{V^2}(V_{D_4}^2 + 5V \cdot V_{D_4} + 6.25V) = -\frac{1}{33k\Omega} V_{D_4} \tag{1.15}$$

$$500\frac{\mu A}{V^2} \cdot V_{D_4}^2 + \left(500\frac{\mu A}{V^2} \cdot 5V + \frac{1}{33k\Omega}\right) V_{D_4} + 500\frac{\mu A}{V^2} \cdot 6.25V = 0 \tag{1.16}$$

$$0.5\frac{mA}{V^2} \cdot V_{D_4}^2 + \left(0.5\frac{mA}{V^2} \cdot 5V + \frac{1}{33k\Omega}\right) V_{D_4} + 0.5\frac{mA}{V^2} \cdot 6.25V = 0 \tag{1.17}$$

$$\left(0.5\frac{mA}{V^2}\right) V_{D_4}^2 + \left(2 \cdot \frac{35}{66}\frac{mA}{V}\right) V_{D_4} + \left(3 \cdot \frac{1}{8} mA\right) = 0 \tag{1.18}$$

$$V_{D_{4_{1,2}}} = \frac{-\left(2 \cdot \frac{35}{66}\frac{mA}{V}\right) \pm \sqrt{\left(2 \cdot \frac{35}{66}\frac{mA}{V}\right)^2 - 4 \cdot \left(0.5\frac{mA}{V^2}\right) \cdot \left(3 \cdot \frac{1}{8} mA\right)}}{2 \cdot 0.5\frac{mA}{V^2}} = \begin{cases} -0.44833V \\ -1.67288V \end{cases} \tag{1.19}$$

1.2 SPICE Operating Point analysis

```
* Differential Amplifier
*****************************************************************************
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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
```