Exercise 3

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26.09.2019

Problem 1

1a)

Note that:

$$V_x = V_g \cap V_s = 0 \cap V_{eff} = V_{gs} - V_{tn}$$

This gives:

$$V_x = V_{gs} = (V_{gs} - V_{tn}) + V_{tn} = V_{eff} + V_{tn}$$

1b)

We know from 1a) that $V_{ds} > V_{eff}$ and $V_{gs} > V_{tn}$ This means the transistor works in the active region and is turned on. We further assume that all currents are static, this means $V_{gs} = 0$ for the right hand transistor.

We know that:

$$V_{eff} = \sqrt{\frac{2I_d}{\mu_n C_{ox} \frac{W}{L}}} \approx 0,126V$$

$$V_x = V_{eff} + V_{tn} \approx 0,576V > V_{tn}$$

Note that $V_{eff} > 0$, this means the transistor is indeed turned on and all expressions are valid.

1c)

We know the voltage on both sides of the resistor (V_{dd} and V_x) and the current through (I_d). This means:

$$R = \frac{V_{dd} - Vgs}{I_d} = 122k\Omega$$

The circuit was simulated in SPICE with the following code:

```
.include p18_model_card.inc
*.include p18_cmos_models_ff.inc
*.include p18_cmos_models_ss.inc
.include p18_cmos_models_tt.inc
```

```
VDD 1 0 1.8
R1 1 2 122000
MN1 2 2 3 3 NMOS
MN2 1 2 0 0 NMOS

Vtest 3 0 0

.op
```

With the following result:

```
AIM-Spice Version 2019.100  (Built on Aug 27 2019)


Parsing circuit...

Running simulation...

Operating point information:
v(1) = 1.8 V
v(2) = 0.669717 V
v(3) = 0 V
v(mn2.drain) = 1.79994 V
v(mn2.source) = 6.39596e-05 V
v(mn1.drain) = 0.669654 V
v(mn1.source) = 6.28141e-05 V
i(vtest) = 9.26461e-06 A
i(vdd) = -1.86982e-05 A


Simulation completed successfully!
```

This verifies the calculations above.

1d&e)

We did the simulations in the same way as in 1c) with the following results:

	ff	ss	tt
I_d	$13,5745\mu A$	$9,8615\mu A$	$11,6506\mu A$
r_{ds}	$233,0k\Omega$	$637,0k\Omega$	$382,5k\Omega$

1f)

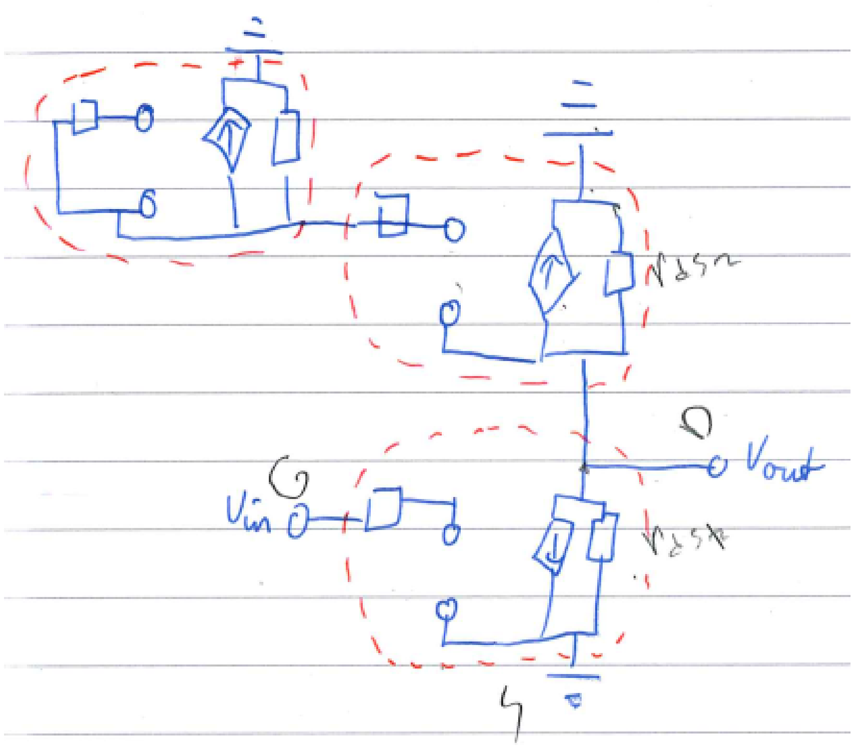
Because the R_{ds} works as a voltage divider, the great change in resistance will have a profound impact on how the amplifier behaves and how much current can be delivered from the system.

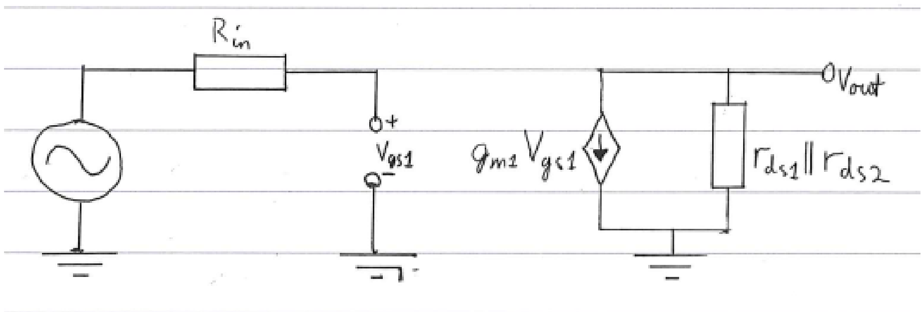
Problem 2

2a)

We will use the small-signal analysis eqivalent of a PMOS and a NMOS to analyze the circuit. We know that a NMOS (and PMOS for that matter) can be modelled as a current source in paralell with a resistance. When M_2 is combined with M_1, then we see that the gain A for the circuit in figure 2 is given as: $A_v = \frac{V_out}{V_in} = -g_{m1}R_2 = -g_{m1}(r_{ds1}||r_{ds2})$

This goes well with the fact that M_1 and M_2 are wired in paralell relative to ground. The following drawings illustrate the thought process.





2b)

It is known from the book:

$$g_m = \frac{2I_D}{V_{eff}}$$

Since we work on the same transistor M1 we can write:

$$\frac{g_{m,M1}}{I_{D,M1}} = \frac{2}{V_{eff}}$$

We can find V_{GS} as follows:

$$V_{GS} = V_{tn} + \frac{I_{D,M1}}{2g_{m,M1}} = 0.5V$$

2c)

We found with AIM-spice that if $\frac{W}{L} = 2.525$ the transconductance becomes $250,03\mu S$.

2d)

It is known that:

$$r_{ds,M1}||r_{ds,M2} = \frac{r_{ds,M1} * r_{ds,M2}}{r_{ds,M1} + r_{ds,M2}}$$

Since they are equal:

$$r_{ds,M1}||r_{ds,M2} = \frac{r_{ds}^2}{2r_{ds}} = \frac{r_{ds}}{2}$$