

In the CMOS circuit shown in Fig. 1, the device parameters are:  $\mu_n C_{ox} = 50 \mu A/V^2$ ,  $\mu_p C_{ox} = 16 \mu A/V^2$ ,  $\gamma_n = \gamma_p = 0$ ,  $\lambda_n = \lambda_p = \lambda = 0.02$  (1/V),  $V_{tn} = -V_{tp} = V_t = 1V$ . The supply voltage is  $V_{DD} = 5V$ . The two input voltages have DC bias components  $V_{I1}$ ,  $V_{I2}$ , and the signal components  $v_{i1}$ ,  $v_{i2}$ . The device sizes  $W/L$  in  $\mu m/\mu m$  are shown in Fig. 1. State the approximations you made in solving the problem.

- a) For  $V_{I1} = V_{I2} = 1.4V$ , resistance  $R$  is selected so that all devices operate in the active mode. Find the DC bias currents  $I_1$ ,  $I_2$ ,  $I_3$ ,  $I_R$ , and the DC bias voltages  $V_a$ ,  $V_b$ . Find  $R$ .
- b) For  $V_{I1} = V_{I2} = 1.4V$  and  $R$  found in (a), find the range of the output voltages  $V_{Omin} < V_O < V_{Omax}$ , such that all devices operate in the active mode.
- In parts (c) and (d) of the problem, you can assume that the circuit operates at the point found in (a), and that  $V_O$  is such that all devices are active.
- c) Find the parameters  $g_{m1}$ ,  $r_{ds1}$ ,  $g_{m2}$ ,  $r_{ds2}$ , in the small-signal models of the devices M1 and M2.
- d) Find the small-signal output  $v_o$  as a function of the small-signal inputs  $v_{i1}$ ,  $v_{i2}$ . Find the output resistance  $R_{out}$ .
- e) If  $V_{I1} = 5V$  and  $V_{I2} = 0V$ , and  $R$  is as found in (a), determine operating modes of all devices. Justify your answers.

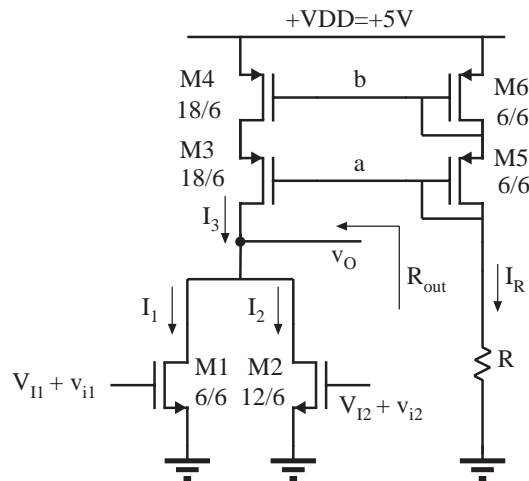


Figure 1: