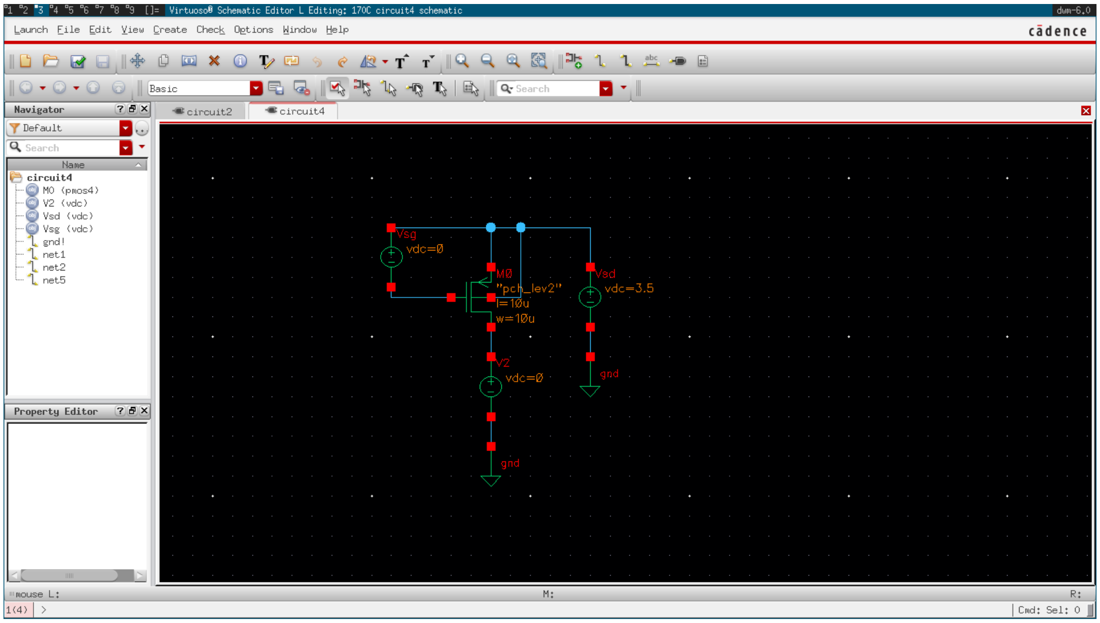

Figure 1: Circuit for Simulation 4

The results for Simulation 4 are similar to Simulation 2, except a PMOS is used instead of an NMOS. The definition $g_{sd} = \frac{\partial I_D}{\partial V_{SD}}$ is used instead.

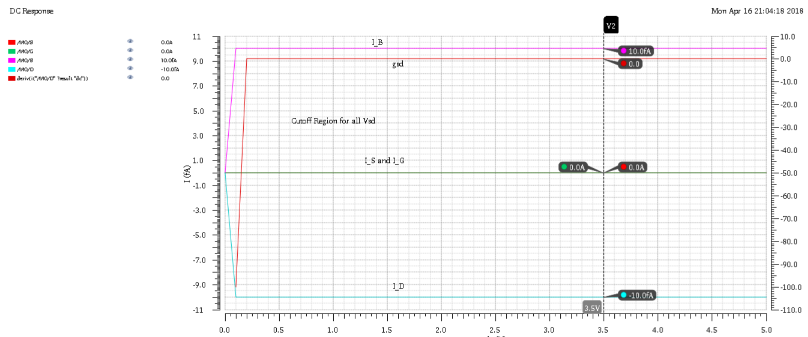

Figure 2: PMOS I_D versus V_{SD} when $V_{SG} = 0$V

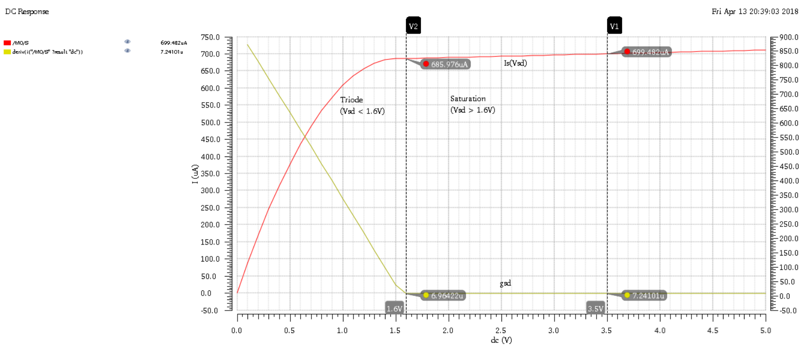

Figure 3: PMOS I_D versus V_{SD} when $V_{SG} = 2.5$V

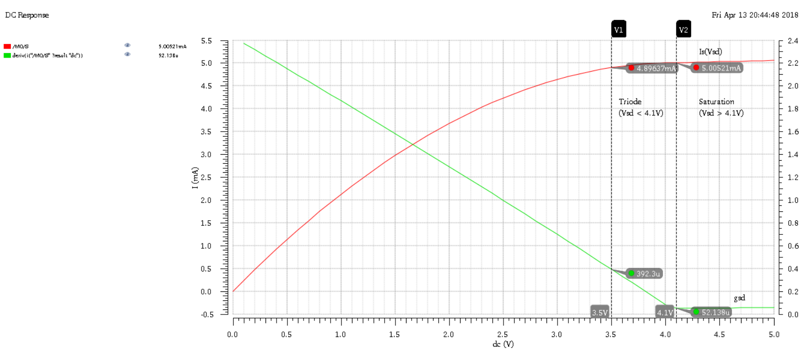

Figure 4: PMOS I_D versus V_{SD} when $V_{SG} = 5.0$V

Table 1: Simulation 4 Results

Vgs [V]	gsd from Simulation Curves [uA / V]	gsd from DC Operating Point Simulation [mA / V]
0	0	0
2.5	7.24	7.249
5.0	392.3	361.6

λ for the NMOS and PMOS can be calculated from the given data. Two samples are already taken for each transistor: the current at the edge of saturation and triode I_{D1} and the current at $V_{DS} = 3.5$V (or V_{SD} in the case of a PMOS). Consider the transistor at $V_{GS} = 2.5$V (or V_{SG} in the case of a PMOS). It operates in saturation at this V_{DS} (or V_{SD} value). Therefore, its current is given by $I_D = I'_D(1 + \lambda V_{DS})$ (or V_{SD} in the case of a PMOS). So, λ can be determined from a system of equations. The equations are written for the NMOS, but extrapolating to the PMOS is trivial by simply replacing V_{DS} with V_{SD}:

$$I_{D1} = I'_D(1 + \lambda V_{DS1}) \tag{1}$$

$$I_{D2} = I'_D(1 + \lambda V_{DS2}) \tag{2}$$

Solving equations (1) and (2) for λ yields:

$$\lambda = \frac{I_{D2} - I_{D1}}{I_{D1}V_{DS2} - I_{D2}V_{DS1}} \tag{3}$$

λ for each transistor is presented in table(2). The results are compared with the simulation models.

Table 2: Lambda Calculations for Transistors

	Calculated Lambda	Model-Specified Lambda	Percentage Error
NMOS	0.0051209300	0.0050000000	2.4186002719%
PMOS	0.0105371990	0.0100000000	5.3719898064%

A simpler approach can also be taken to determine λ. For processes with relatively long transistors, λ should not be very large. Because $\lambda = \frac{1}{V_A}$, where V_A is the Early voltage, this implies that V_A is quite large. So, long as V_{DS} (or V_{SD} in the case of a PMOS) is not very large relative to V_A ($V_{DS} << V_A$), the following approximation can be made:

$$I_D = I'_D(1 + \lambda V_{DS}) = I'_D(1 + \frac{V_{DS}}{V_A}) \approx I'_D \tag{4}$$

Therefore, $g_{ds} = \lambda I'_D \approx \lambda I_D$ for $V_A >> V_{DS}$ (or $V_A >> V_{SD}$ for a PMOS). So, *lambda* can also be approximated using $\lambda \approx \frac{g_{ds}}{I_D}$ (or g_{sd} in the case of a PMOS) provided that these assumptions about the transistor hold.