The intermediate node, we consider a first order transistor model as follows. In the triode region and in strong inversion, the drain current of an MOS transistor can be written [5-7] as

\[ I_D = \frac{W}{L} \mu_n C_{ox} \left( \frac{V_g - V_T}{2} \right)^n \left[ (V_g - V_T)^2 - (V_g - V_D)^2 \right] \]  

where all voltages are referred to the substrate. \( \mu_n \) is the effective mobility, which in the usual approximations for long-channel devices depends only on the gate voltage [1,6]. The pinch-off voltage [5-7] is given by

\[ V_P = \frac{V_{GS} - V_T}{n} \]  

The undefined symbols in eqns. 1 and 2 have their usual meanings [5,6]. For the series connection of transistors (Fig. 1), assuming that the drain currents of \( M_D \) and \( M_S \) are equal and that the two transistors have the same width and length, we obtain

\[ (V_g - V_X)^2 = \frac{1}{2} (V_P - V_D)^2 + \frac{1}{2} (V_P - V_S)^2 \]  

from the application of eqn. 1 for both transistors. On the verge of saturation of the transistor \( M_D \), \( V_P \approx V_D \); therefore, eqn. 3 reduces to

\[ V_X \approx \frac{V_{GS} - V_T}{n} \left( 1 - \frac{1}{\sqrt{2}} \right) + \frac{V_D}{\sqrt{2}} \]  

In this work we have used eqn. 4 to determine \( V_{gs}, V_D \), and \( n \).

**Results and discussion:** To test the above method of parameter extraction, measurements for the series connection (Fig. 1) of two identical (\( W = 6 \mu m, L = 5 \mu m \)) N-channel transistors from a 2\( \mu m \) CMOS technology have been performed.

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**Fig. 1** Series association of transistors

**Fig. 2** Experimental intermediate node voltage \( V_x(V_D) \) characteristics for \( V_D = 1, 2, 3 \) and 5V and \( V_S = 0 \)

**Fig. 3** Experimental intermediate node voltage \( V_D(V_S) \) and square root of drain current \( I_D(V_S) \) for \( V_D = V_S \) and \( V_S = 0 \)

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**References**

$V_d(V_G)$ curves to the $X$-axis are 499 and 762 mV, respectively. The determination of $V_T$ from the $V_d(V_G)$ curve is direct because this plot is linear for values of $V_G$ larger than, say, 2 V. The determination of $V_T$ from the $I_d(V_G)$ curve, however, is not precise because of the mobility dependence on the transversal field, which depends on $V_G$. It should be noted here that the extraction of the threshold voltage from the $V_d(V_G)$ curve does not depend on the value of the effective carrier mobility. The slope factor $n$ is easily determined from the gradient of the $V_d(V_G)$ curve, which is equal to $(1-1/n^2)/n$, according to eqn. 4. In our case, the gradient is 0.256; hence, $n = 1.14$.

Fig. 4 shows $V_d(V_G)$ curves. The slope of the curves for low values of $V_G$, i.e., for strong inversion operation, is $-1/n^2$, according to eqn. 4. The value of the pinch-off voltage for any value of $V_G$ is determined by the intersection of the tangent to the curve $V_d(V_G)$ for low $V_G$ and the straight line $V_X = V_G$, according to eqn. 4.

![Fig. 4 Experimental intermediate node voltage $V_d(V_S)$ characteristics for $V_G = 1, 2, 3, 4,$ and $5$ V with $V_D = V_T$](image)

**Conclusion:** We have proposed a direct method to determine the MOS transistor parameters that are related to the channel charge without using current measurements. We have used information provided by the voltage at the intermediate node of the series connection of transistors in order to determine the zero bias threshold voltage, the pinch-off voltage and the slope factor. The voltage measurements presented in this work together with the drain current measurement can be used to precisely determine the effective mobility dependence on the gate voltage.

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