Supplementary Material for

Organic and Amorphous-Metal-Oxide Flexible Analogue Electronics

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SI 1 Impact of contact resistance on transconductance

Here we present the derivation of Equations (2.12–2.13), which provide a basic model for the impact of contact resistance on transconductance in a TFT.

The starting point is Equation (2.6), which we report here for the reader's convenience:

$$I_{DS,sat} \cong \frac{1}{2+\gamma}\mu C_I \ \frac{W}{L}\left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)^{2+\gamma}(1+\lambda V_{DS}).$$

It is useful to define here the parameter

$$K := \mu C_\mathrm{I} \ \frac{W}{L}(1+\lambda V_{DS}),$$

which allows us to rewrite the drain current in saturation as

$$I_{DS,sat} = \frac{1}{2+\gamma} \cdot K \cdot \left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)^{2+\gamma}. \tag{SI1}$$

Differentiating Equation (SI1) and arranging the terms in $\partial I_{DS,sat}/\partial V_{GS}$ on the left-hand side leads to:

$$\frac{\partial I_{DS,sat}}{\partial V_{GS}} \cdot \left(1 + K \cdot \left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)^{1+\gamma} \cdot R_c\right)$$
$$= K \cdot \left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)^{1+\gamma}.$$

From Equation (SI1) also follows that:

$$K \cdot \left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)^{1+\gamma}$$
$$= (2+\gamma) \cdot \frac{I_{DS,sat}}{\left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)}.$$

Therefore, we have:

$$\frac{\partial I_{DS,sat}}{\partial V_{GS}} \cdot \left(1 + (2+\gamma) \cdot \frac{I_{DS,sat}}{\left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)} \cdot R_c\right)$$
$$= (2+\gamma) \cdot \frac{I_{DS,sat}}{\left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right)}.$$

By rearranging the equation above, we obtain:

$$\frac{\partial I_{DS,sat}}{\partial V_{GS}} \cdot \left(\left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right) + (2+\gamma) \cdot I_{DS,sat} \cdot R_c\right)$$
$$= (2+\gamma) \cdot I_{DS,sat} \tag{SI2}$$

$$\frac{\partial I_{DS,sat}}{\partial V_{GS}} \cdot \left((V_{GS} - V_T) + (1+\gamma) \cdot I_{DS,sat} \cdot R_c\right) = (2+\gamma) \cdot I_{DS,sat}.$$

Directly from the definition of transconductance, this leads to Equation (2.12)

$$g_m = \frac{(2+\gamma) \cdot I_{DS,sat}}{V_{GS} - V_T + (1+\gamma) \cdot I_{DS,sat} \cdot R_c}.$$

As for Equation (2.13), it can be directly derived from Equation (2.6) (Equation (SI1)) and Equation (2.12) (Equation (SI2)). From Equation (SI1) follows that:

$$\left(\frac{1}{K}\right)^{\frac{1}{2+\gamma}} \left((2+\gamma) \cdot I_{DS,sat}\right)^{\frac{1}{2+\gamma}} = \left(V_{GS} - I_{DS,sat} \cdot R_c - V_T\right). \tag{SI3}$$

Plugging in Equation (SI3) into Equation (SI2), we obtain:

$$g_m \cdot \left(\left(\frac{1}{K}\right)^{\frac{1}{2+\gamma}} \left((2+\gamma) \cdot I_{DS,sat}\right)^{\frac{1}{2+\gamma}} + (2+\gamma) \cdot I_{DS,sat} \cdot R_c\right)$$
$$= (2+\gamma) \cdot I_{DS,sat}.$$

We can rewrite this equation as

$$g_m \cdot \left(\frac{1}{K}\right)^{\frac{1}{2+\gamma}} \cdot \left((2+\gamma) \cdot I_{DS,sat}\right)^{\frac{1}{2+\gamma}} \cdot \left(1 + \frac{(2+\gamma) \cdot I_{DS,sat} \cdot R_c}{\left(\frac{1}{K}\right)^{\frac{1}{2+\gamma}} \cdot \left((2+\gamma) \cdot I_{DS,sat}\right)^{\frac{1}{2+\gamma}}}\right) = (2+\gamma) \cdot I_{DS,sat},$$

from which

$$g_m \cdot \left(1 + \frac{(2+\gamma) \cdot I_{DS,sat} \cdot R_c}{\left(\frac{1}{K}\right)^{\frac{1}{2+\gamma}} \cdot \left((2+\gamma) \cdot I_{DS,sat}\right)^{\frac{1}{2+\gamma}}}\right) = \frac{(2+\gamma) \cdot I_{DS,sat}}{\left(\frac{1}{K}\right)^{\frac{1}{2+\gamma}} \cdot \left((2+\gamma) \cdot I_{DS,sat}\right)^{\frac{1}{2+\gamma}}}$$

or

$$g_m \cdot \left(1 + \sqrt[(2+\gamma)]{K \cdot [(2+\gamma) \cdot I_{DS,sat}]^{1+\gamma}} \cdot R_c\right) = \sqrt[(2+\gamma)]{K \cdot \, [(2+\gamma) \cdot I_{DS,sat}]^{1+\gamma}}. \tag{SI4}$$

We now return to Equation (2.11), which gives the transconductance with zero contact resistance, g_{m0}, for a given current $I_{DS,sat}$. Under the hypothesis of negligible channel-length modulation, Equation (2.11) can be conveniently rewritten as:

$$g_{m0} = \sqrt[(2+\gamma)]{\frac{W}{L} \cdot \mu \cdot C_I \cdot [(2+\gamma) \cdot I_{DS,sat}]^{1+\gamma}} = \sqrt[(2+\gamma)]{K \cdot \, [(2+\gamma) \cdot I_{DS,sat}]^{1+\gamma}}. \tag{SI5}$$

Comparing Equations (SI4) and (SI5), we obtain

$$g_m \cdot (1 + g_{m0} \cdot R_c) = g_{m0},$$

which is equivalent to Equation (2.13).