

Analog CMOS Integrated Circuit Design Cheat Sheet

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Model of MOS Transistors

Process parameters (n, V_{TH}, KP, V_E):

$$t_{OX} = \frac{L_{min}}{50} \quad (1)$$

$$t_{si} = \sqrt{\frac{2\epsilon_{si}(\Phi - V_{BD})}{qN_B}} \quad (2)$$

$$C_{OX} = \frac{\epsilon_{OX}}{t_{OX}} \quad (3)$$

$$C_D = \frac{\epsilon_{si}}{t_{si}} \quad (4)$$

$$KP = \mu C_{OX} \quad (5)$$

$$\beta = KP \frac{W}{L} \quad (6)$$

$$Q_{dep} = \sqrt{4q\epsilon_{si}|\Phi_F|N_{sub}} \quad (7)$$

$$V_{TH0} = \Phi_{MS} + 2\Phi_F + \frac{Q_{dep}}{C_{OX}} \quad (8)$$

$$V_{TH} = V_{TH0} + \gamma(\sqrt{|2\Phi_F| + V_{BS}} - \sqrt{|2\Phi_F|}) \quad (9)$$

$$n = \frac{\gamma}{\sqrt{|2\Phi_F| + V_{BS}}} = 1 + \frac{C_D}{C_{OX}} \quad (10)$$

In linear region:

$$I_{DS} = \beta[(V_{GS} - V_{TH})V_{DS} - \frac{1}{2}V_{DS}^2] \quad (11)$$

$$R_{on} = \frac{1}{\beta(V_{GS} - V_{TH})} \quad (12)$$

Channel-Length modulation in saturation region:

$$K' = \frac{KP}{2n} \quad (13)$$

$$\lambda = \frac{1}{V_E L} \quad (14)$$

$$I_{DS} = K' \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS}) \quad (15)$$

$$r_o = \frac{\partial V_{DS}}{\partial I_{DS}} \approx \frac{1}{\lambda I_{DS}} = \frac{V_E L}{I_{DS}} \quad (16)$$

Saturation region has three distinctive regions: weak-inversion (exponential region), strong-inversion, and velocity saturation.

Value Examples In 0.35μm Process Nodes

Names	Symbols	Values
dielectric constant of sub-silicon	ϵ_{si}	1 pF/cm
dielectric constant of gate-oxide	ϵ_{OX}	0.34 pF/cm
electron charge	q	1.6×10^{-19} C
minium channel length	L_{min}	0.35 μm
width of gate-oxide	t_{OX}	0.1 nm
width of depletion layer	t_{si}	7 nm
junction built-in voltage	Φ	0.6 V
drain-bulk voltage	V_{BD}	-3.3V
gate-oxide capacitance	C_{OX}	0.5 μF/cm ²
depletion layer capacitance	C_D	0.1 μF/cm ²
bulk doping level	N_B	4×10^{17} cm ⁻³
P type mobility rate	μ_p	250 cm ² /Vs
N type mobility rate	μ_n	600 cm ² /Vs
N type KP	KP_n	300 μA/V ²
	n	1.2...1.5
	$ 2\Phi_F $	0.6 V
	γ	0.5...0.8 V ^{1/2}
N type K'	K'_n	100 μA/V ²
P type K'	K'_p	40 μA/V ²
	V_{GSTt}	70 mV
	v_{sat}	10 ⁷ cm/s
	θL	0.2 μm/V

Weak-Inversion

$$I_{DS} = I_{D0} \frac{W}{L} e^{\frac{V_{GS}}{n \frac{KT}{q}}} \quad (17)$$

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \frac{I_{DS}}{n \frac{KT}{q}} \quad (18)$$

strong-inversion

Ignore channel-length modulation:

$$I_{DS} = K' \frac{W}{L} (V_{GS} - V_{TH})^2 \quad (19)$$

$$g_m = \frac{2I_{DS}}{V_{GS} - V_{TH}} \quad (20)$$

Transition Point Between Weak-Inversion and Strong-Inversion

The voltage and current at transition point between weak-inversion and strong-inversion:

$$V_{GSt} = 2n \frac{KT}{q} + V_{TH} \quad (21)$$

$$I_{DS t} \approx K' \frac{W}{L} (2n \frac{KT}{q})^2 \quad (22)$$

EKV model, a smooth model for weak-inversion and strong-inversion regions:

$$I_{DS} = K' \frac{W}{L} (V_{GS} - V_{TH})^2 [\ln(1 + e^{\frac{V_{GS}}{V_{GSt}}})]^2 \quad (23)$$

Let:

$$v = \frac{V_{GS}}{V_{GSt}} \quad (24)$$

$$i = \frac{I_{DS}}{I_{DS t}} = [\ln(1 + e^v)]^2 \quad (25)$$

then,

$$v = \ln(e^{\sqrt{i}} - 1) \quad (26)$$

$$V_{GS} - V_{TH} = V_{GSTt} \ln(e^{\sqrt{i}} - 1) \quad (27)$$

where:

$$V_{GSTt} = V_{GSt} - V_{TH} = 2n \frac{KT}{q} \quad (28)$$

When $v = 1$, $i = 1$, we also have:

$$I_{DS t} = K' \frac{W}{L} (V_{GSt} - V_{TH})^2 \quad (29)$$

Velocity Saturation

$$I_{DS} = WC_{OX} v_{sat} (V_{GS} - V_{TH}) \quad (30)$$

$$g_m = WC_{OX} v_{sat} \quad (31)$$

Transition Point Between Strong-Inversion and Velocity Saturation

A smooth model for strong-inversion and velocity saturation regions:

$$I_{DS} = \frac{K' \frac{W}{L} (V_{GS} - V_{TH})^2}{1 + \theta(V_{GS} - V_{TH})} \quad (32)$$

where:

$$\theta = \frac{\mu}{2n v_{sat} L} \quad (33)$$

θL is constant:

$$\theta L = \frac{\mu}{2n v_{sat}} \quad (34)$$

$$g_{m, sat} = WC_{OX} v_{sat} = \frac{K' W}{\theta L} \quad (35)$$

The voltage and current at transition point between strong-inversion and velocity saturation:

$$V_{GSt} = \frac{1}{\theta} + V_{TH} = 2nL \frac{v_{sat}}{\mu} + V_{TH} \quad (36)$$

$$I_{DS t} = K' W L (2n \frac{v_{sat}}{\mu})^2 \quad (37)$$

Operational-Amp: Biasing Circuits

[illegible]