

Collection of Formulas

Analogue IC-design ETIN25



OBS!! Work in progress
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Preface

This collection of formulas is an unofficial formula sheet created by me, a student (Melker Rose E23), for the course Analogue IC-design (ETIN25) at LTH.

The primary purposes of creating this document were:

- To gather all relevant formulas in one convenient location for study and reference
- To enhance learning through the process of organizing and typesetting the material

Important notes:

- This is *not* an official document from the course administration, department, or faculty
- Although care has been taken to ensure accuracy and formulas are primarily sourced from official materials, the coursebook (**Gray, Hurst, Lewis, Meyer: Analysis and Design of Analog Integrated Circuits**, Fifth Edition. Wiley 2010.) and/or lecture slides, cross-referencing is recommended, as there may be errors or omissions
- This document is a work in progress and may be updated

I hope this collection of formulas proves useful.

Best of luck,

Melker Rose

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Active-Device Parameters

npn Bipolar Transistor Parameters

Large-Signal Forward-Active Operation

Collector current

$$I_C = I_S \exp \left(\frac{V_{be}}{V_T} \right) \quad (1)$$

Small-Signal Forward-Active Operation

Transconductance

$$g_m = \frac{qI_C}{kT} = \frac{I_C}{V_T} \quad (2)$$

Transconductance-to-current ratio

$$\frac{g_m}{I_C} = \frac{1}{V_T} \quad (3)$$

Input resistance

$$r_\pi = \frac{\beta_0}{g_m} \quad (4)$$

Output resistance

$$r_o = \frac{V_A}{I_C} = \frac{1}{\eta g_m} \quad (5)$$

Collector-base resistance

$$r_\mu = \beta_0 r_o \text{ to } 5\beta_0 r_o \quad (6)$$

Base-charging capacitance

$$C_b = \tau_F g_m \quad (7)$$

Base-emitter capacitance

$$C_\pi = C_b + C_{je} \quad (8)$$

Emitter-base junction depletion capacitance

$$C_{je} \simeq 2C_{je0} \quad (9)$$

Collector-base junction capacitance

$$C_\mu = \frac{C_{\mu 0}}{\left(1 - \frac{V_{BC}}{\psi_{0c}}\right)^{n_c}} \quad (10)$$

Collector-substrate junction capacitance

$$C_{cs} = \frac{C_{cs0}}{\left(1 - \frac{V_{SC}}{\psi_{0s}}\right)^{n_s}} \quad (11)$$

Transition frequency

$$f_T = \frac{1}{2\pi} \frac{g_m}{C_x + C_\mu} \quad (12)$$

Effective transit time

$$\tau_T = \frac{1}{2\pi f_T} = \tau_F + \frac{C_{je}}{g_m} + \frac{C_\mu}{g_m} \quad (13)$$

Maximum gain

$$g_m r_o = \frac{V_A}{V_T} = \frac{1}{\eta} \quad (14)$$

NMOS Transistor Parameters

Large-Signal Operation

Process transconductance parameter

$$k' = \mu C_{ox} \quad (15)$$

Drain current (active region)

$$I_D = \frac{k'}{2} \frac{W}{L} (V_{GS} - V_t)^2 \quad (16)$$

Early voltage

$$V_A = \frac{I_D}{\delta I_D / \delta V_{DS}} = L_{eff} \left(\frac{\delta X_d}{\delta V_{DS}} \right)^{-1} \quad (17)$$

Reciprocal of the Early voltage

$$\lambda = \frac{1}{V_A} \quad (18)$$

Drain current (active region) better

$$I_D = \frac{k'}{2} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS}) \quad (19)$$

Drain current (triode region)

$$I_D = \frac{k'}{2} \frac{W}{L} [2(V_{GS} - V_t)V_{DS} - V_{DS}^2] \quad (20)$$

Characteristic current

$$I_t = q X D_n n_{po} \exp \left(\frac{k_2}{V_T} \right) \quad (21)$$

Drain current (subthreshold region)

$$I_D = \frac{W}{L} I_t \exp \left(\frac{V_{GS} - V_t}{nV_T} \right) \left[1 - \exp \left(-\frac{V_{DS}}{V_T} \right) \right] \quad (22)$$

Threshold voltage

$$V_t = V_{t0} + \gamma \left[\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f} \right] \quad (23)$$

Threshold voltage parameter

$$\gamma = \frac{1}{C_{ox}} \sqrt{2q\varepsilon N_A} \quad (24)$$

Oxide capacitance

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = 3.45 \text{ fF}/\mu\text{m}^2 \quad \text{for } t_{ox} = 100 \text{ \AA} \quad (25)$$

Small-Signal Operation (Active Region)

Top-gate transconductance

$$g_m = \frac{\delta I_D}{\delta V_{GS}} = k' \frac{W}{L} (V_{GS} - V_t) = \sqrt{2I_D k' \frac{W}{L}} \quad (26)$$

Transconductance-to-current ratio

$$\frac{g_m}{I_D} = \frac{2}{V_{GS} - V_t} \quad (27)$$

Body-effect transconductance

$$g_{mb} = \frac{\gamma}{2\sqrt{2\phi_f + V_{SB}}} g_m = \chi g_m \quad (28)$$

Channel-length modulation parameter

$$\lambda = \frac{1}{V_A} = \frac{1}{L_{\text{eff}}} \frac{dX_d}{dV_{DS}} \quad (29)$$

Output resistance

$$r_o = \frac{1}{\lambda I_D} = \frac{L_{\text{eff}}}{I_D} \left(\frac{dX_d}{dV_{DS}} \right)^{-1} \quad (30)$$

Effective channel length

$$L_{\text{eff}} = L_{\text{down}} - 2L_d - X_d \quad (31)$$

Maximum gain

$$g_m r_o = \frac{1}{\lambda} \frac{2}{V_{GS} - V_i} = \frac{2V_A}{V_{GS} - V_i} \quad (32)$$

Source-body depletion capacitance

$$C_{sb} = \frac{C_{s0}}{\left(1 + \frac{V_{SB}}{\psi_0}\right)^{0.5}} \quad (33)$$

Drain-body depletion capacitance

$$C_{db} = \frac{C_{db0}}{\left(1 + \frac{V_{DB}}{\psi_0}\right)^{0.5}} \quad (34)$$

Gate-source capacitance

$$C_{gs} = \frac{2}{3} W L C_{ox} \quad (35)$$

Transition frequency

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{sd} + C_{gb})} \quad (36)$$

Transconductance

$$G_m = \left. \frac{i_o}{v_i} \right|_{v_o=0} \quad (37)$$

Input resistance (with test source)

$$R_i = \left. \frac{v_t}{i_t} \right|_{v_o=0} \quad (38)$$

Output resistance (with test source)

$$R_o = \left. \frac{v_t}{i_t} \right|_{v_i=0} \quad (39)$$

Maximum gain

$$|A_v|_{max} = G_m R_o \quad (40)$$

Example example

$$A = \frac{B}{C} \quad (41)$$

$$(42)$$

Example
example

$$A = \frac{B}{C} \quad (43)$$

(44)

Example
example

$$A = \frac{B}{C} \quad (45)$$

(46)

Example
example

$$A = \frac{B}{C} \quad (47)$$

(48)

Example
example

$$A = \frac{B}{C} \quad (49)$$

(50)