

**Written Test**  
**TSTE80,**  
**Analog and Discrete-time Integrated Circuits**

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Date	January 11, 2003
Time:	8 - 12
Max. no of points:	70; 40 from written test, 15 for project, and 15 for assignments.
Grades:	30 for 3, 42 for 4, and 56 for 5.
Allowed material:	All types of calculators except Lap Tops. All types of tables and handbooks. The textbook Johns & Martin: Analog Integrated Circuit Design
Examiner:	Lars Wanhammar.
Responsible teacher:	Robert Hägglund. Tel.: 0705 - 48 56 88.
Correct (?) solutions:	Solutions and results will be displayed in House B, entrance 25 - 27, 1st floor.

**Good Luck!**

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**Student's Instructions**

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The CMOS transistor operation regions, small signal parameters, and noise characteristics are found on the last page of this test.

Generally, do not just answer yes or no to a short question. You always have to answer with figures, formulas, etc., otherwise no or fewer points will be given.

Basically, there are few numerical answers to be given in this test.

You may write down your answers in Swedish or English.

**NOTE: Exercise 6 is only for those that have taken the course before 2002, and have not handed in more than one assignment during the course.**

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**Exercise**

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## Transistor formulas and noise

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### CMOS transistors

#### Current formulas and operating regions

Cut-off:

$$V_{GS} < V_T \quad I_D \approx 0$$

Linear:

$$V_{GS} - V_T > V_{DS} > 0 \quad I_D \approx \frac{\mu_0 C_{ox}}{2} \cdot \frac{W}{L} \cdot (2(V_{GS} - V_T) - V_{DS}) \cdot V_{DS}$$

Saturation:

$$0 < V_{GS} - V_T < V_{DS} \quad I_D \approx \frac{\mu_0 C_{ox}}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_T)^2 \cdot (1 + \lambda V_{DS})$$

#### Small-signal parameters

Linear region:

$$g_m \approx \mu_0 C_{ox} \cdot \frac{W}{L} \cdot V_{DS} \quad g_{ds} \approx \mu_0 C_{ox} \cdot \frac{W}{L} \cdot (V_{GS} - V_T - V_{DS})$$

Saturation region:

$$g_m = \frac{dI_D}{dV_{GS}} \approx \sqrt{2\mu_0 C_{ox} \frac{W}{L} I_D} \quad g_{ds} = \frac{dI_D}{dV_{DS}} \approx \lambda I_D$$

### Circuit noise

#### Thermal noise

The thermal noise spectral density at the gate of a CMOS transistor is

$$\frac{\overline{v^2}}{\Delta f} = \frac{8kT}{3} \cdot \frac{1}{g_m}$$

#### Flicker noise

The flicker noise spectral density at the gate of a CMOS transistor is

$$\frac{\overline{v^2}}{\Delta f} = \frac{K}{WLC_{ox}f}$$