

## i Front Page

**UNIVERSITY OF OSLO**

**The Faculty of Mathematics and Natural Sciences**

**Written examination IN3170/4170**

**Spring 2023**

**Duaration: 7-Jun-2022 09:00 to 13:00**

**Permitted aids:**

**Everything on paper and approved calculator**

**It is important that you read this front page before you start.**

### **General information:**

- All non-electronic sources of information are allowed, as well as an approved calculator. If you reproduce a text from books, articles, etc., a reference to these sources must be provided to avoid suspicions of plagiarism. This also applies if a text is translated from other languages.

### **Information about hand drawings (Scantron):**

*In this question set you have the opportunity to answer with hand drawings (questions 8 'NP Domino Logic' and 9 'Exponential Decay Counter'). You use the handed out sketch sheets. It is possible to use several sheets per assignment. See instructions on how to fill in the sketch sheets in the link below the assignment overview.*

*You are not supposed to submit hand drawings for any other questions than question 8 and 9. You will NOT be given extra time to fill in the information boxes on the sketch sheets (assignment codes, candidate number, etc.)*

### **Lecture slides available as PDF:**

*See the link under the task bar! There you will find a PDF with all the lecture slides used in the lecture in 2023.*

### **File Uploads:**

Make sure to have all files uploaded **BEFORE** the exam time runs out! This concerns all the MATLAB functions and scripts in the tasks. It's useless if you create the files, but they remain on the computer and are not uploaded! So check in time!

### **Information on MATLAB functions and scripts:**

Some tasks ask for MATLAB functions or MATLAB scripts. These are MATLAB executables stored in files with the ending '.m'. The file name is specified in the task. Do not name your file anything else! You will need to upload these files as your result. They need to be correctly written and executable in MATLAB! MATLAB is installed on your machine, so you can verify your code. Note the directory MATLAB is working in, indicated at the top underneath the tool bar: that is where any new files will be stored and where MATLAB will be looking for the m-files to execute them. You may change that directory to a convenient location before you start working. Use the 'New->function/script' button in the tool bar to make new m-files.

*MATLAB functions* have to start with a function header of syntax '[outputArg1 outputArg2]=function FunctionName(inputArg1, inputArg2)', where the number of output and input arguments can vary. The function header is specified in the task. Do not use any other function header! The function needs to contain a command that assigns a final expression to all the output arguments before it ends. For this exam functions will usually contain just a series of assignments where a mathematical expression is assigned to a variable. Functions shall be used in tasks where one needs to find a general expression assigning a value to variables in dependency of other variables.

Example in a file test1.m:

```
function [y]=test1(x)
y=2*x
end
```

*MATLAB scripts* do not have a function header and are just a series of MATLAB commands that are executed when the name of the file is typed into a MATLAB window. For this exam also scripts will usually contain just a series of assignments where a mathematical expression or a value is assigned to a variable. Scripts shall be used in tasks with numerical endresults.

Example in a file test2.m where the final result shall be in 'y':

```
x=3
y=2*x
```

The syntax of some potentially useful functions:  $\log(x)$  is  $\ln(x)$ ,  $\log_{10}(x)$  is  $\log_{10}(x)$ ,  $\exp(x)$  is  $e^x$ , ... The imaginary number  $i$  is 'j' in MATLAB. A line starting with '%' is a comment.

## **i Task Overview**

### **Chapter 3.5 (only for IN4170-students!)**

#### **task 1: Peak rectifier (only for IN4170-students!)**

(MATLAB-script, file upload)

### **Chapter 5**

#### **task 2: Resistance Triode-region**

(MATLAB-function, file upload)

#### **task 3: Overdrive for same current in pMOS and nMOS**

(MATLAB-function, file upload)

### **Chapter 6/7**

#### **task 4: Current conveyor**

(MATLAB-function, file upload)

### **Chapter 8**

#### **task 5: Current mirror loaded differential pair**

(MATLAB-script, file upload)

### **Chapter 9**

#### **task 6: Phase Margin**

(MATLAB-script, file upload)

### **Chapter 15**

#### **task 7: Balance Transition Times**

(multiple choice)

### **Dynamic Logic**

#### **task 8: NP Domino Logic**

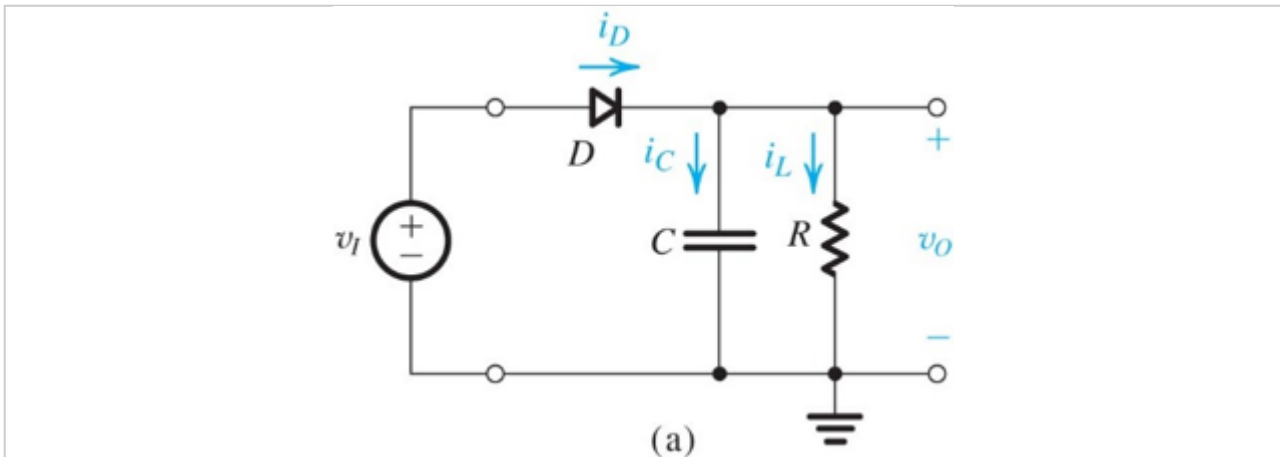
(hand drawing)

### **Sequential Logic**

#### **task 9: Exponential Decay Counter**

(hand drawing)

# 1 Peak Rectifier (only for IN4170!!!)



A peak rectifier as illustrated in the figure has an input peak voltage  $V_p = 1\text{V}$  at frequency  $f = 25\text{kHz}$ , a load capacitance  $C = 10\text{nF}$ , and a load resistance  $R = 200\text{k}\Omega$ . The diode used has a threshold voltage of  $V_D = 200\text{mV}$ , and its resistance drops immediately from infinity to zero when this threshold is exceeded.

Submit a MATLAB script in file 'PeakRectifier.m' that assigns the ripple amplitude  $V_r$  on the output to variable 'Vr'.



Upload your file here. Maximum one file.

All file types are allowed. Maximum file size is 2 GB

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Maximum marks: 1

## 2 Resistance Triode-region

An NMOS transistor is operated in the triode region with drain source voltage close to zero  $V_{DS} \approx 0V$ . Find the expressions for its drain resistance  $r_{DS}$  in dependency of  $k_n$  and overdrive voltage  $V_{OV}$  for both strong AND weak inversion. (If relevant, assume the slope factor  $n = 1$ .) Implement these two expression as a MATLAB function with the header 'function [r\_ds]=drainresistance(V\_ov,k\_n)' in file 'drainresistance.m'. Distinguish the strong and weak inversion case with:

```
if V_ov>0
    r_ds= <your strong inversion expression>;
else
    r_ds= <your weak inversion expression>;
end;
```



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Maximum marks: 1

### 3 Overdrive for same current in pMOS and nMOS

A nMOS and a pMOS of the same dimensions in the same technology have different carrier mobilities and thus  $k_n = 2.2 * k_p$ . If they both are operated in saturation mode/in the active region and in strong inversion/above threshold, what must the overdrive voltage of the pMOS  $V_{OVp}$  be as a function of the overdrive voltage of the nMOS  $V_{OVn}$  if they both should conduct the same current? (Ignore any channel length modulation effects or slope factor, i.e.  $\lambda = 0$  and  $n = 1$ !)

Submit a MATLAB function with header 'function [V\_OVp]=pMOSOverdrive(V\_OVn)' in file 'pMOSOverdrive.m' that computes  $V_{OVp}$  from  $V_{OVn}$ .



**Upload your file here. Maximum one file.**

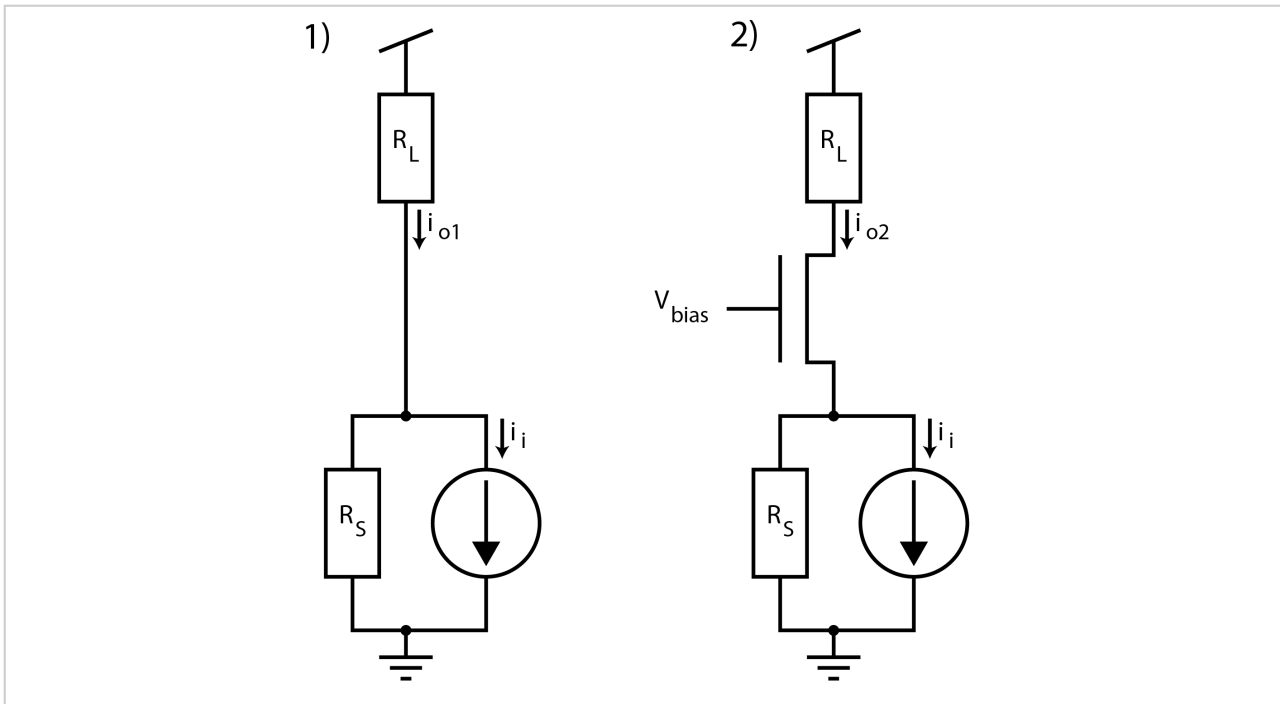
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Maximum marks: 1

## 4 Current conveyor



Imagine you have a current source that should provide a current to a load, e.g. a motor or a heating element, as illustrated by the circuit schematics 1). As you increase the current  $i_i$ , much of that current does not drive the load  $R_L$  but is 'wasted' through the source's internal resistance  $R_S$ . The Circuit 2) tries to improve that situation by interposing a common gate (CG) stage (can also be regarded as a cascode transistor) between the source and the load. Here this CG stage has the function of a current conveyor, increasing the percentage of the source current actually ending up driving the load, i.e. less current being wasted on the source's internal resistance. This becomes evident if you derive expressions (Do this!) for the small signal (!) current gains for the two situations,  $A_{i1} = \frac{i_{o1}}{i_i}$ ,  $A_{i2} = \frac{i_{o2}}{i_i}$ , as functions of the four variables  $R_S, R_L, g_m, r_o$ .

Submit a MATLAB function as file CurrentConveyor.m with function header:

```
function (Ai1, Ai2)=CurrentConveyor(RS,RL,gm,ro)
```

That computes  $A_{i1}$  and  $A_{i2}$  from the variables  $R_S, R_L, g_m, r_o$



**Upload your file here. Maximum one file.**

All file types are allowed. Maximum file size is **2 GB**

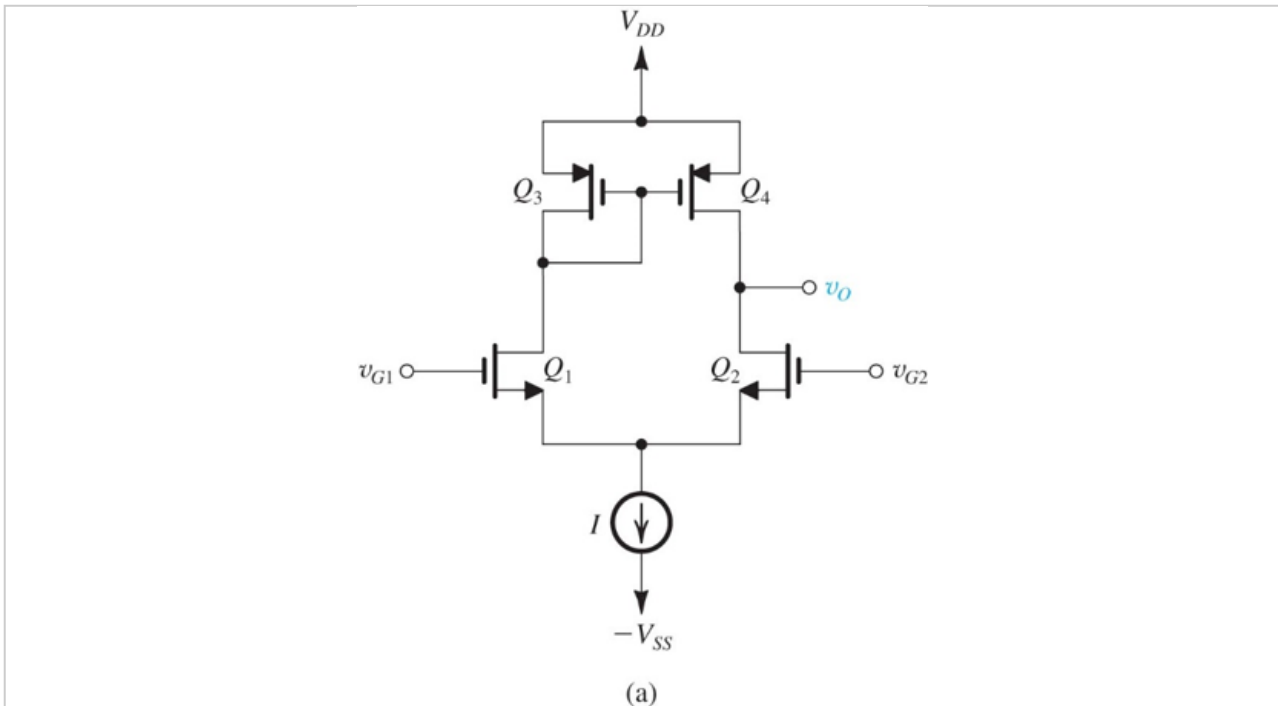
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Maximum marks: 1



## 5 Current mirror loaded differential pair



A current mirror loaded differential pair as illustrated in the figure without an external load resistance (i.e.  $R_L = \infty$ ) has an open circuit differential gain of  $A_d = 18 \frac{V}{V}$ . When an external load of  $R_L = 30k\Omega$  is connected, the gain is reduced to  $A_d = 12 \frac{V}{V}$ . What is the circuit's short circuit transconductance  $G_m = ? \frac{A}{V}$  and output resistance  $R_O = ? \Omega$ ?

Submit the answer as a MATLAB script in file Transamp.m. The script should assign the answer for  $G_m$  and  $R_O$  to MATLAB variables 'Gm' and 'RO' respectively.



Upload your file here. Maximum one file.

All file types are allowed. Maximum file size is 2 GB

Select file to upload

Maximum marks: 1

## 6 Phase Margin

The transfer function of a second order low pass filter has two poles, a known first pole  $\omega_{p1} = 100\text{Rad}$  and an unknown second pole  $\omega_{p2}$  and no zeros. Its DC gain  $A_{DC}$  is 42dB. It shall be used in a negative feedback configuration as introduced in the lecture with a feedback factor  $\beta = \frac{1}{10}$ . Its phase margin is  $60^\circ$ .

Determine the unity gain  $\omega_t$  of the loop  $A\beta$  (!) and the frequency in Rad of the second pole  $\omega_{p2}$  !

Upload a matlab script in file 'PhaseMargin.m' that assigns the results for respectively  $\omega_t$  and  $\omega_{p2}$  to variable 'wt' and 'wp2'!



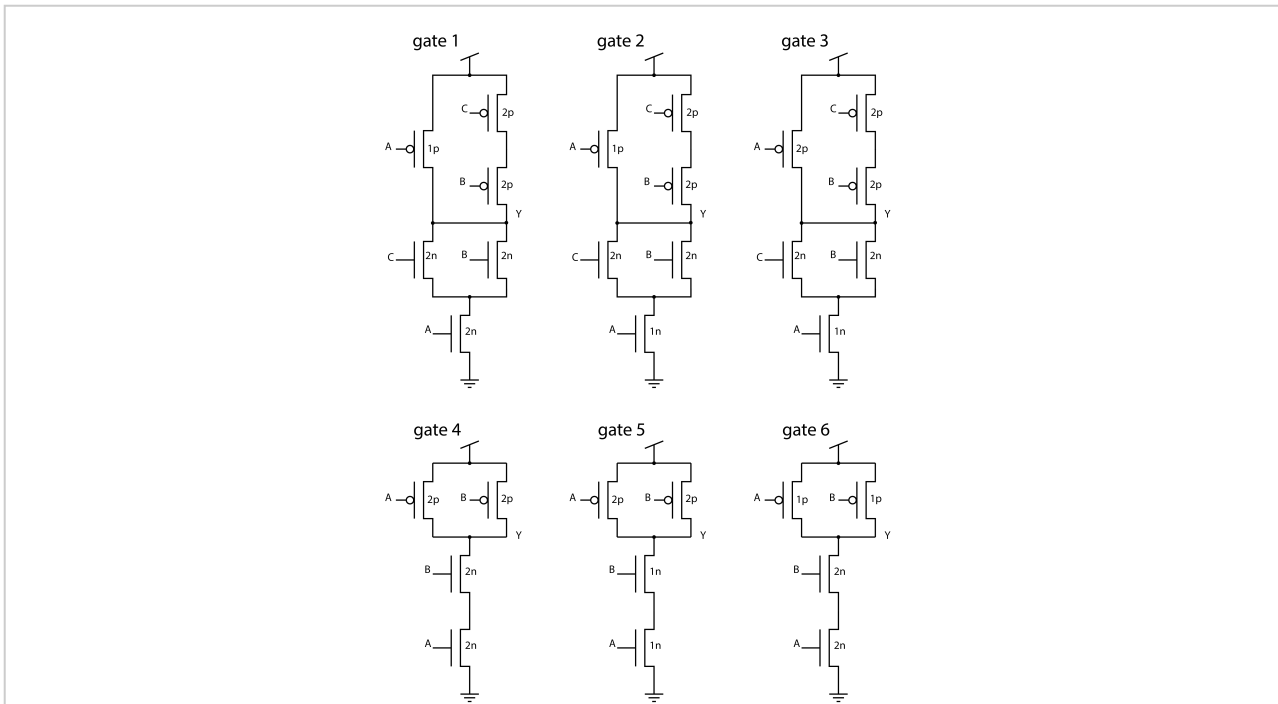
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All file types are allowed. Maximum file size is **2 GB**

 Select file to upload

Maximum marks: 1

## 7 Balance Transition Times



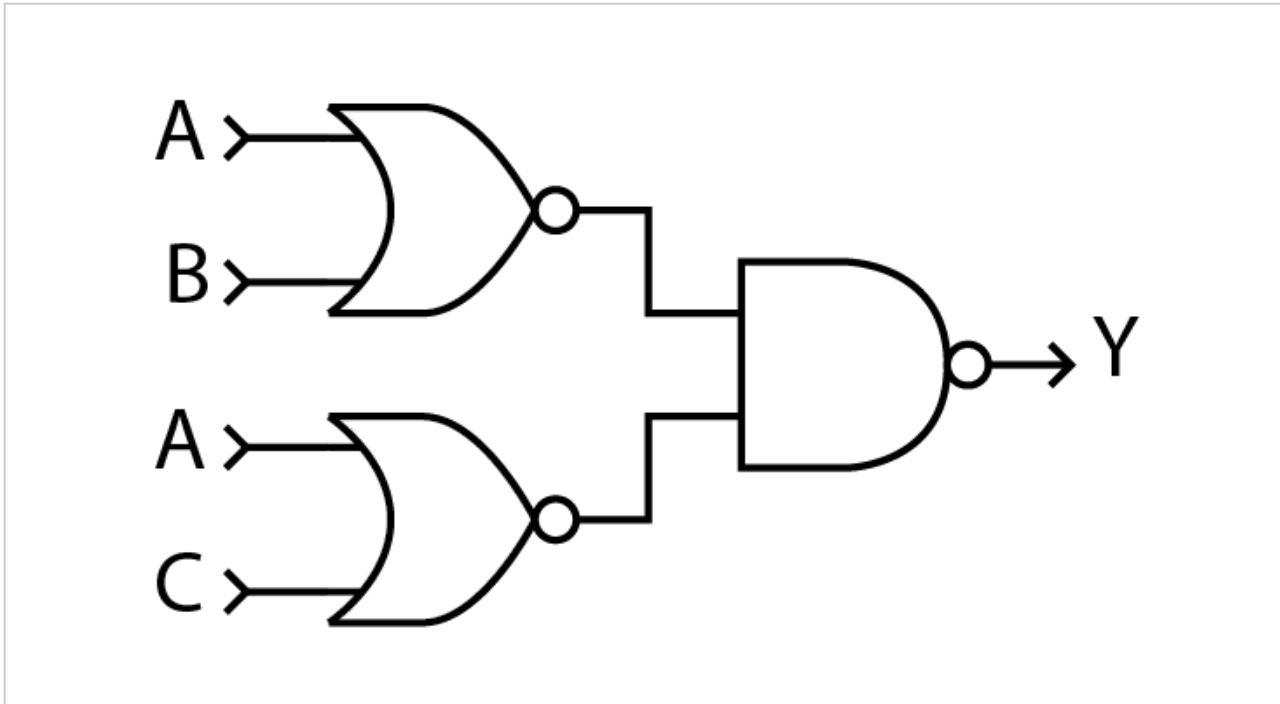
If an inverter in a certain CMOS technology has balanced transition times  $t_{THL} = t_{TLH}$  and when the width to length ratio for the pull down nFET is  $\frac{W_n}{L_n} = n$  and for the pull up pFET is  $\frac{W_p}{L_p} = p$ , which of the following logic gates are appropriately balanced, i.e. do have the same approximate current drive (i.e. neither less nor more) in both the HL and LH transitions as that inverter? The transistors do have the same lengths as the inverter's but their width is changed. The ratio  $x$  of their widths relative to the inverter's is indicated as  $xp$  and  $xn$  in the figure.

**Select one or more alternatives:**

- Gate 1
- Gate 2
- Gate 3
- Gate 4
- Gate 5
- Gate 6

Maximum marks: 1

## 8 NP Domino Logic



Re-implement the gate level schematics in the figure as NP domino logic schematic on transistor level (!), i.e. using pMOS and nMOS transistors as building blocks. Do not attempt to simplify the logic, but implement it 1:1 as NP domino logic with the same three gates. Let's define a clock signal  $\varphi$  and its inverse  $\bar{\varphi}$  and that  $(\varphi = 0) \Rightarrow$  **precharge** and  $(\varphi = 1) \Rightarrow$  **evaluation**. Make sure to use the same signal label as in the figure. Make a clear drawing! Unclear connections or hard to identify symbols will be cause for point deduction!

*In this exercise you shall answer with hand drawing that is to be scanned. Use your own sketch sheet (distributed). See instructions for filling in the sketch sheet in the link below the task bar.*

Maximum marks: 1

## 9 Exponential Decay Counter

Design the state transition graph for a synchronous Moore finite state machine implementing an exponential decay counter: The output 'O' of that counter shall be a binary 4 for the first clock cycle, turn to 2 the next clock cycle, then turn to 1 after a total two (!) clock cycles, and finally to 0 after another four (!) clock cycles. It shall hold 0 for another 8 clock cycles, before restarting the whole cycle at output 4 again. It shall have a reset input 'RES' which can set it back to the first state with output 'O=4' at the onset of the next clock cycle. Number your states with a state variable 'S'.

Make a clear drawing! Unclear connections between states or hard to identify expressions in the states and along the connections will be cause for point deduction!

*In this exercise you shall answer with hand drawing that is to be scanned. **Use your own sketch sheet (distributed)**. See instructions for filling in the sketch sheet in the link below the task bar.*

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Maximum marks: 1