Front Page

UNIVERSITY OF OSLO

The Faculty of Mathematics and Natural Sciences

Written examination IN3170/4170

Spring 2025

Duaration: 12-Jun-2025 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.
- A PDF file of the lecture's compendium (issue 1.4) is available as a resource-link at the bottom of the page.

Information about hand drawings (Scantron):

The answer for questions 4 and 5 are hand drawings. 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 questions 4 and 5*. You will NOT be given extra time to fill in the information boxes on the sketch sheets (assignment codes, candidate number, etc.) The sheets shall be handed in at a desk in the exam room after you are done with the exam.*

Lecture slides available as PDF:

See the link under the task bar! There you will find the lecture script (issue 1.4) as a PDF.

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 assignes 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 symbolic 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 $\ln(x)$, log10(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.

Table of Content

Note that all questions correctly answered give 1 point. So its a very good idea to start with the ones you think are easiest. It is also a very good idea to read through this overview once more at the end and to make sure that no question has simply been forgotten. **Remember to upload the MATLAB-functions and MATLAB-scripts!**

Part I: Models

question 1: Intrinsic Gain with Different Bias Currents
(MATLAB-script file upload for numerical result, 1 point)

Part II: Linear Circuit Analysis

question 2: Transfer Function
(MATLAB-function file upload for symbolic expression, 1 point)

Part III: Digital Circuits

question 3: Quadrouple Inverter Digital Buffer
(MATLAB-function file upload for symbolic expression, 1 point)
question 4: NP Domino logic
(hand drawing, 1 points)
question 5: Finite State Machine as State Transition Graph
(hand drawing, 1 points)

Part IV: Analog Circuits

question 6: Double Cascode Current Mirror
(MATLAB-function file upload for symbolic expression, 1 point)
question 7: Input Resistance and Capacitance
(MATLAB-script for numerical result, file upload, 1 point)
question 8: Common Mode Rejection Ratio
(MATLAB-script for numerical result, file upload, 1 point)

1 Intrinsic Gain with Different Bias Currents

Use the process parameters below and an nFET with width $W = 2\mu\mathrm{m}$ and length $0.3\mu\mathrm{m}$! What is its characteristic current I_S (use IS as variable name in MATLAB) as used in the EKV model?

Furthermore, biasing it with large signal currents (ignoring channel length modulation effects, i.e. these are what the compendium calls I'_D) Id1=1e-9, Id2= 1e-7, Id3=1e-5, Id4= 1e-3, what are its intrinsic gains A01, A02, A03, A04 for each of those currents?

Use the appropriate strong or weak inversion equation in each case! Source and bulk are both shorted to Gnd. Use these parameters (always pay close attention to the units, e.g. milli-, micro-, etc.):

$U_T = 23\mathrm{mV}, \mu C_{ox} = 300\mu\frac{\mathrm{A}}{\mathrm{V}^2}, Vt = 0.5\mathrm{V}, \mathrm{Vdd} - \mathrm{Vss} = 2.5\mathrm{V}, \lambda L = 0.05\frac{\mu\mathrm{m}}{\mathrm{V}}, n = 1, W = 2\mu\mathrm{m}, L = 0.3\mu\mathrm{m}$

Upload a matlab script that assignes the results to the variables

IS= ...

A01= ...

A02= ...

A03 = ...

A04= ...

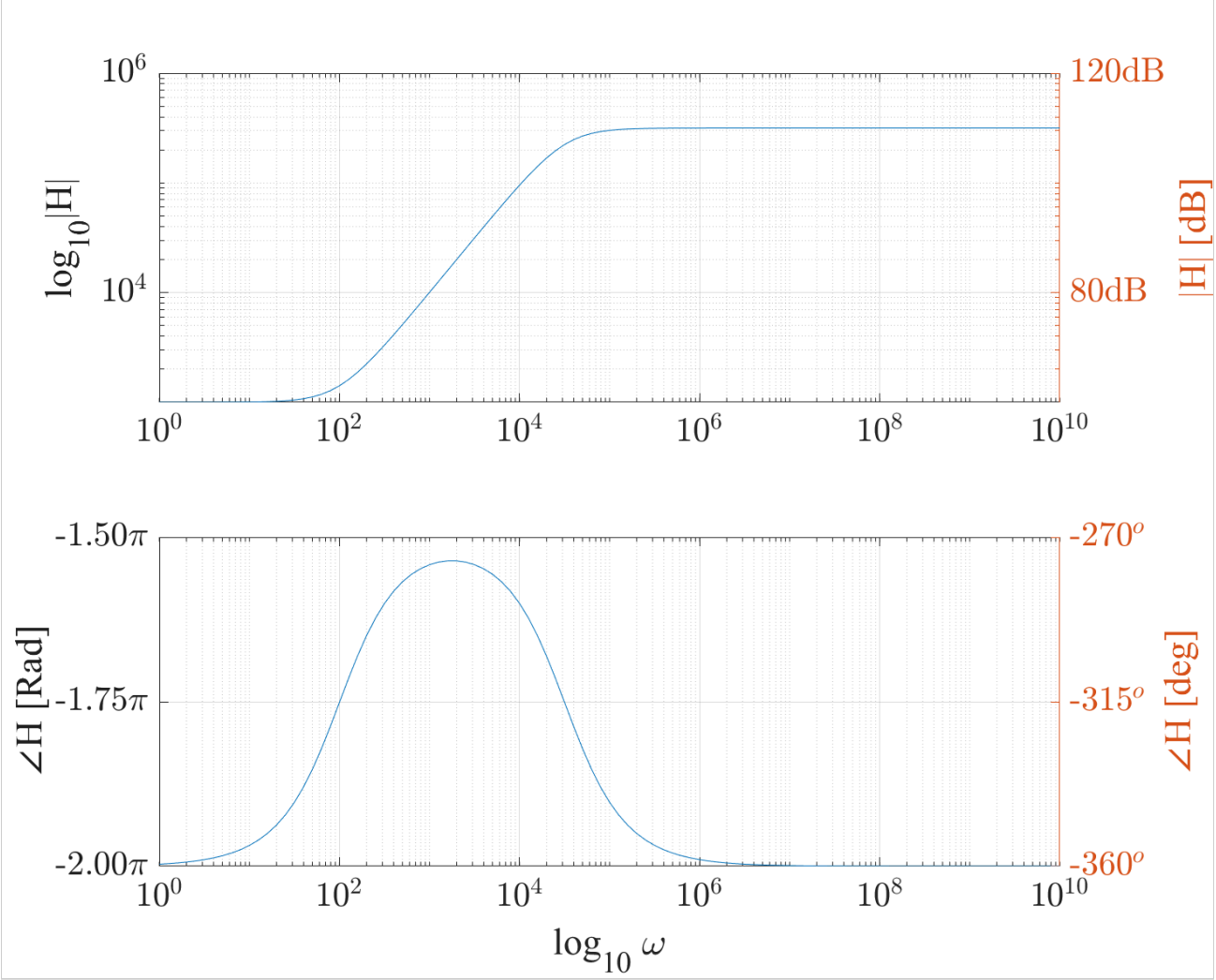
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Maximum marks: 10

2 Transfer Function



The Bode plot in the figure specifies a transfer function. Can you make a function H(s) in matlab of variable $s = j\omega$ that produces exactly that Bode plot?

Hint: a phase shift of -360^o (or -2π in Rad) corresponds to 0^o (or just 0 in Rad).

Submit your result as a MATLAB function in file "TransferFunction.m" with function header:

function [H]=TransferFunction(s)

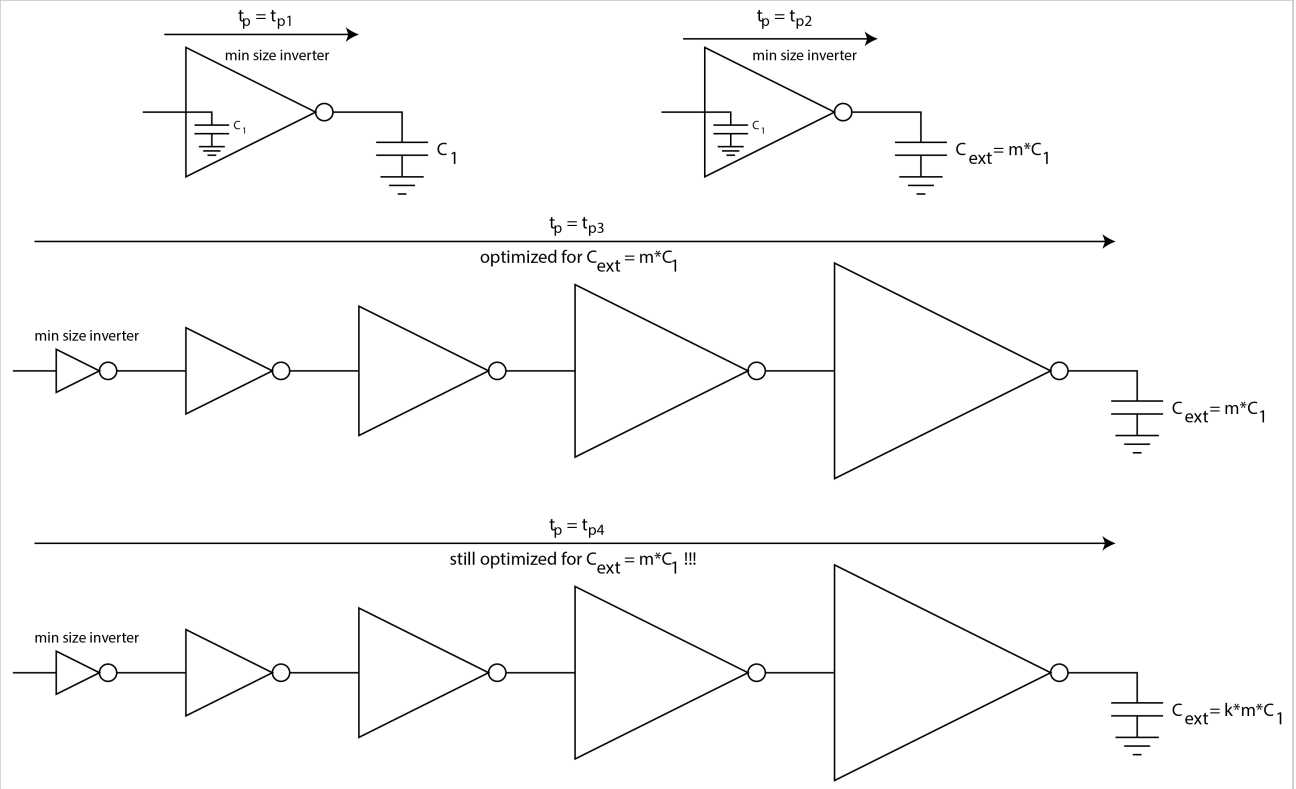
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Maximum marks: 10

3 Quadrouple Inverter Digital Buffer



Assume a typical minimum size inverter provides a signal to an off-chip capacitance. That off-chip capacitance C_{ext} is m times larger than the input capacitance C_1 of that typical minimum size inverter. If the inverter were to drive another inverter of the same size, it would suffer from a gate delay t_{p1} ('tp1' in MATLAB). Let us use the gate delay model where that inverter drives its output via an on-resistance Ron1 proportional to the inverters' width to length ratio, and let's take only gate input capacitances and the final capacitance Cext into account. In terms of m and t_{p1}, what is the gate delay t_{p2} (use 'tp2' in MATLAB) if the minimum inverter drives C_{ext}?

Now, when adding four inverters in series between the initial minimum size inverter and C_{ext} (so including the initial inverter, it will be 5!), to what value t_{p3} (use 'tp3' in MATLAB) can you reduce the delay t_{p2} when sizing the transistor widths of each of those additional four inverters optimally (then length remains the same for all transistors)?

And finally, it is not always possible to predict off-chip loads correctly. So lets assume that the prediction of C_{ext} is off by a factor k, i.e. C_{ext} is not m times bigger than C_1, but instead k*m times bigger. In that case, keeping the same sizing of the 4 inverters' transistors as optimized for m, what is the total gate delay t_{p4} (use 'tp4' in MATLAB)?

Submit the solution as a a Matlab function in a file PropagationDelay.m with the function header:

function [tp2,tp3,tp4]=PropagationDelay(tp1,m,k)

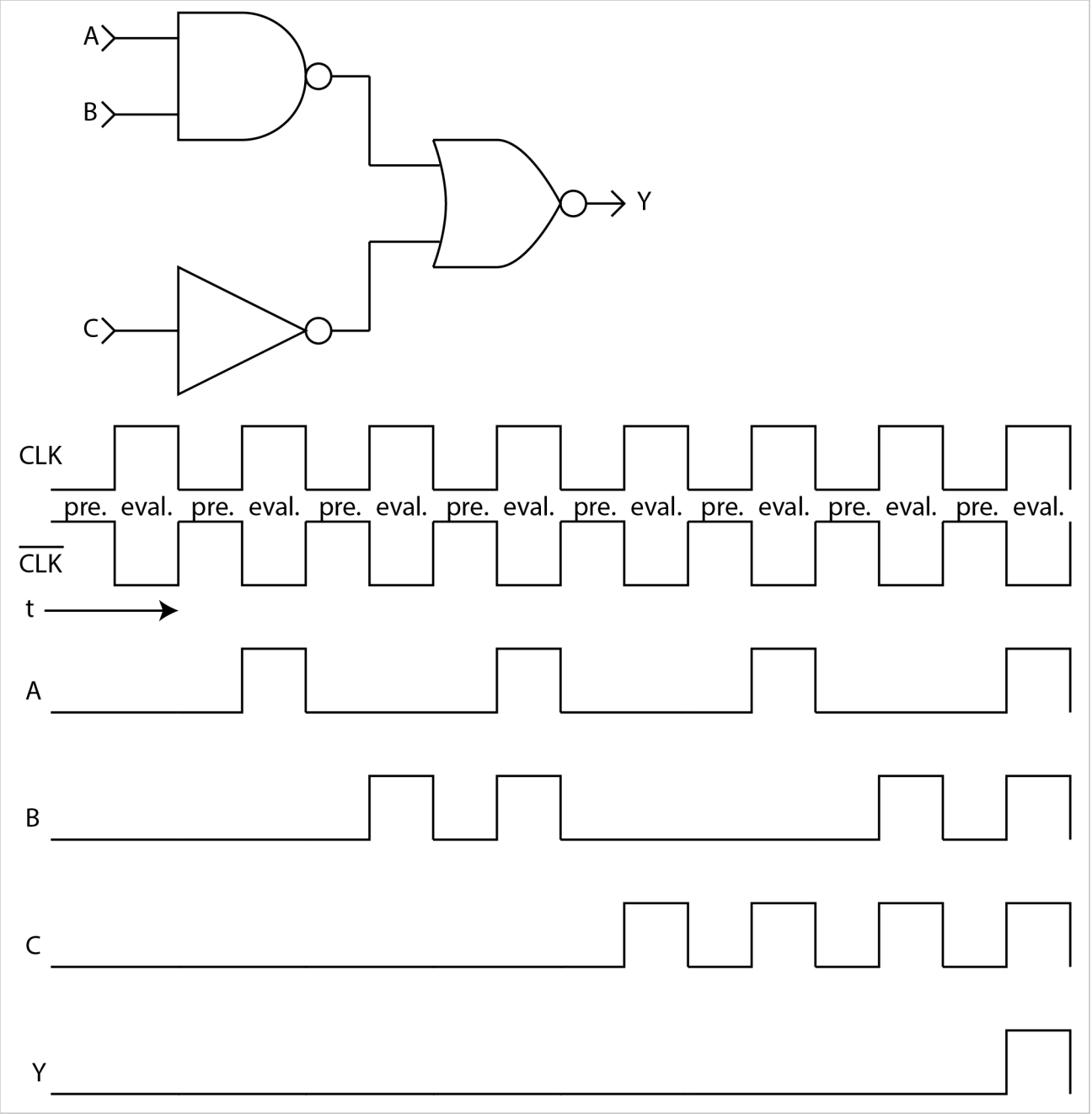
Upload your file here. Maximum one file.

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Maximum marks: 10

4 NP Domino Logic



Implement the combinational logic circuit in the illustration as **NP Domino dynamic logic** as a **transistor level schematics**, i.e. using nFETs and pFETs. Do NOT simplify but implement it using the three gates as indicated. The input traces come from appropriate NP Domino logic circuits too, as indicated in the signal traces below the schematic. That means they are in a default low (!) state during the **precharge phase** (marked as 'pre.' on the clock traces) Check the traces in the illustration! This default precharge state determines whether the first gates are N or P type. Then they assume their logic signal level during the **evaluation phase** (marked as 'eval.' in the figure). The traces undergo all possible combinations of the input signals. The correct output signal trace is also shown. You may use all the signals indicated in your schematics, i.e. the inputs as well as CLK and the inverted CLK, plus Vdd and Gnd as power rails.

Maximum marks: 10

5 Finite State Machine as State Transition Graph

Draw a synchronous state transition graph for a (Moore) finite state machine (FSM) that controls an automated car wash.

The user selects between two programs: 'Standard' and 'Delux' which are encoded as a binary **input signal P**, where P=0 corresponds to 'Standard' and P=1 to 'Delux'. This selection remains locked and unchanged after a washing sequence is started. There is also a **start signal 'S'** that is high when sufficient money has been inserted and a car is in position. Money will be deducted when a washing sequence starts.

The **outputs** of your FSM are active high binary variables **'W' for 'wash', 'D' for 'dry', and 'T' for a 'wax finish'**.

The sequenc for a 'Standard' wash is simply 'wash' and then 'dry', each for one 'clock cycle'.

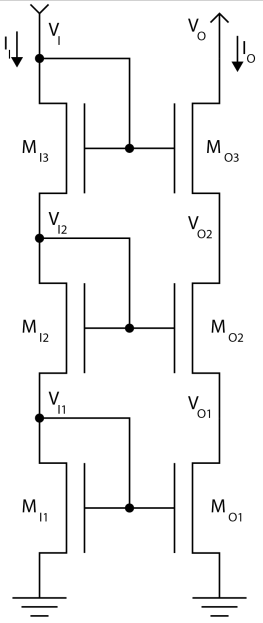
The sequence for the 'Delux' wash is a double 'wash', i.e. holding 'W' for two cycles, then a 'wax finish' for one cycle, and finaly a 'dry' cycle.

Hint: remember that the output signals need not be the same as the internal state registers but can be derived from them by combinational logic, *i.e. you can have the same outputs in different states.*

Mark each bouble with a unique state number (integer or binary) and the appropriate output signal states, and the state transition arrows with the appropriate conditions. Arrows with no conditions are used for unconditional transitions.

Maximum marks: 10

6 Double Cascode Current Mirror



The illustration shows a current mirror with two added casacode transistors, i.e. three nFETs in series on both the input and output branch. Deduce the maximum and minimum voltages for each of the nodes that keep all transistors in saturation (!!!) and conducting the same current when given the overdrive voltage Vov and threshold voltage Vt appropriate for the input current. All transistors are identical. **Assume strong inversion!** Report the voltages and voltage ranges as a matlab function in file CurrentMirrorVoltages.m with function header

function [ViMax, ViMin, Vi1Max, Vi1Min, Vi2Max, Vi2Min, VoMax, VoMin, Vo1Max, Vo1Min, Vo2Max, Vo2Min]=CurrentMirrorVoltages(Vov,Vt, Vdd)

Ignore any channel length modulation or back gate effect, i.e. n=1 and $\lambda = 0$. If the maximum for any of these voltages is not limited, simply assign Vdd as the upper limit for it, and if the minimum is not limited, assign zero to it. If any of these voltages has an exact value instead of a range, simply use the same expression for both the maximum an minimum value.

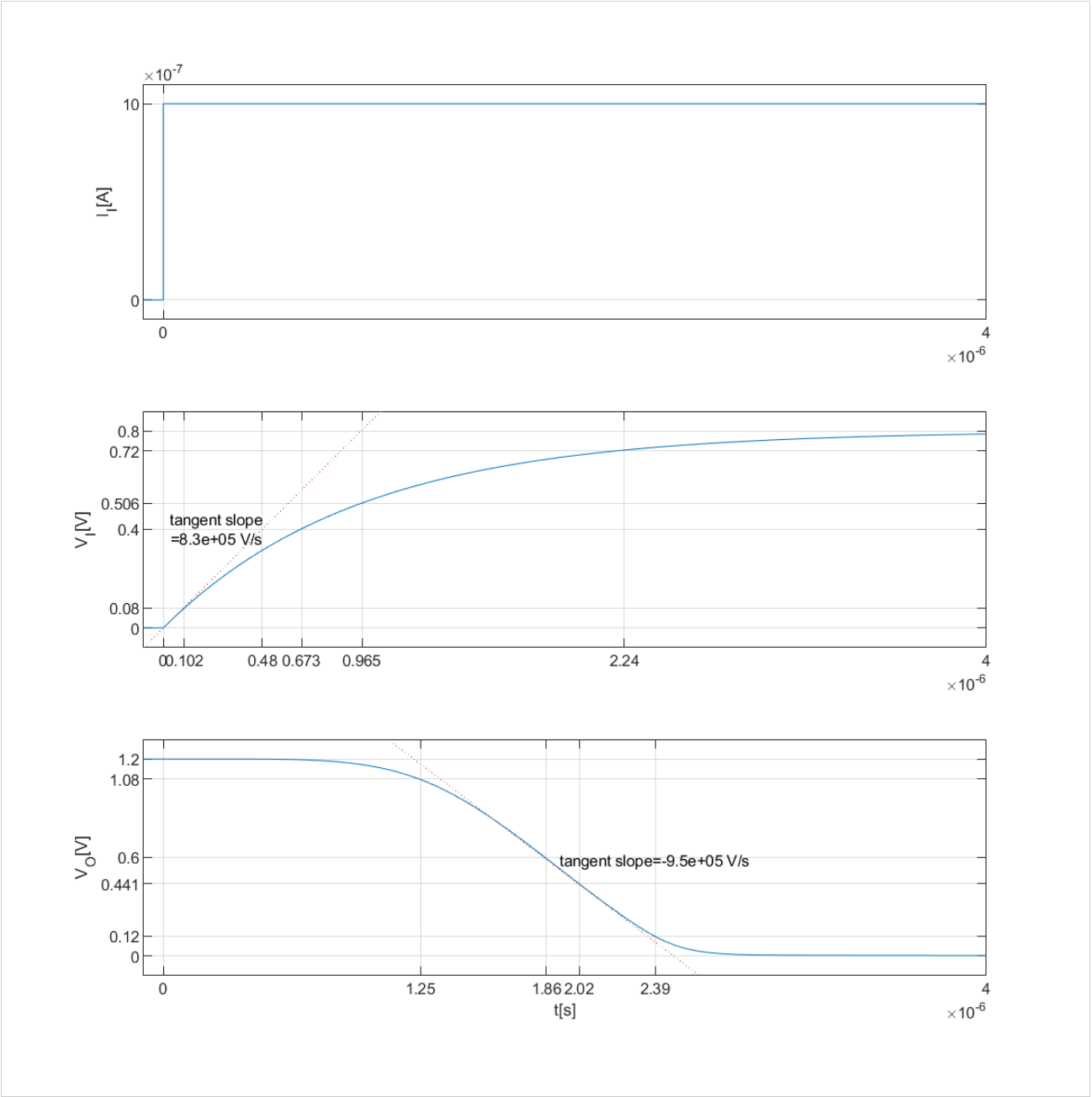
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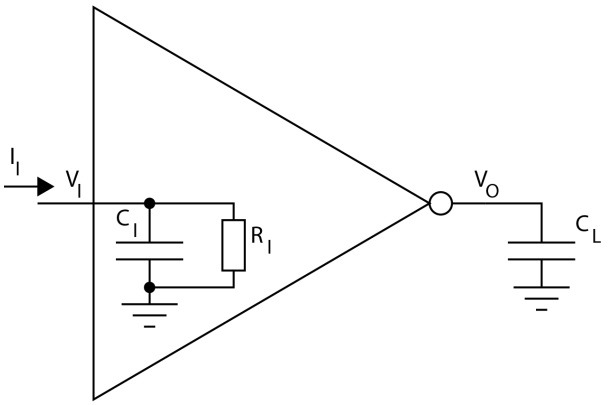
Maximum marks: 10

7 Input resistance and capacitance



Suppose you buy an inverter electronic circuit as a black box with supply pins and a pin for an input and output. So you do not exactly know, how the inverter is implemented inside that black box, similarly to lab 3. It might not even be a CMOS circuit, but functionally for DC inputs it does what it is supposed to do, i.e. it inverts a voltage input.

In order to know what signal you need to provide from another circuit to its input, you want to characterize its input impedance. Unlike lab 3, you find out that a simple input capacitance alone is insufficient to model its input impedance. Instead, it looks like it behaves like there is in addition an input resistance in parallel with an input capacitance, as indicated in the schematic of the figure here:



To find values for the input capacitance C_I as well as for the input resistance R_I you apply an input step current and monitor the input voltage V_I and output voltage V_O. The supply rails are specified as 1.2V Vdd and 0V for Gnd and are connected.

The resulting signal traces are shown here.

The graphs indicate a few points and lines with values. Some of them will be helpful to solve the task, others might just be distractors.

Find the values for R_I(Ri in MATLAB-script) and C_I (Ci in MATLAB-script) and report them in a MATLAB script as variables Rin and Cin. The script shall be submitted in file:

"inputImpedance.m"

and contain statements that assign the correct numerical values to the variables

Ci=?
Ri=?

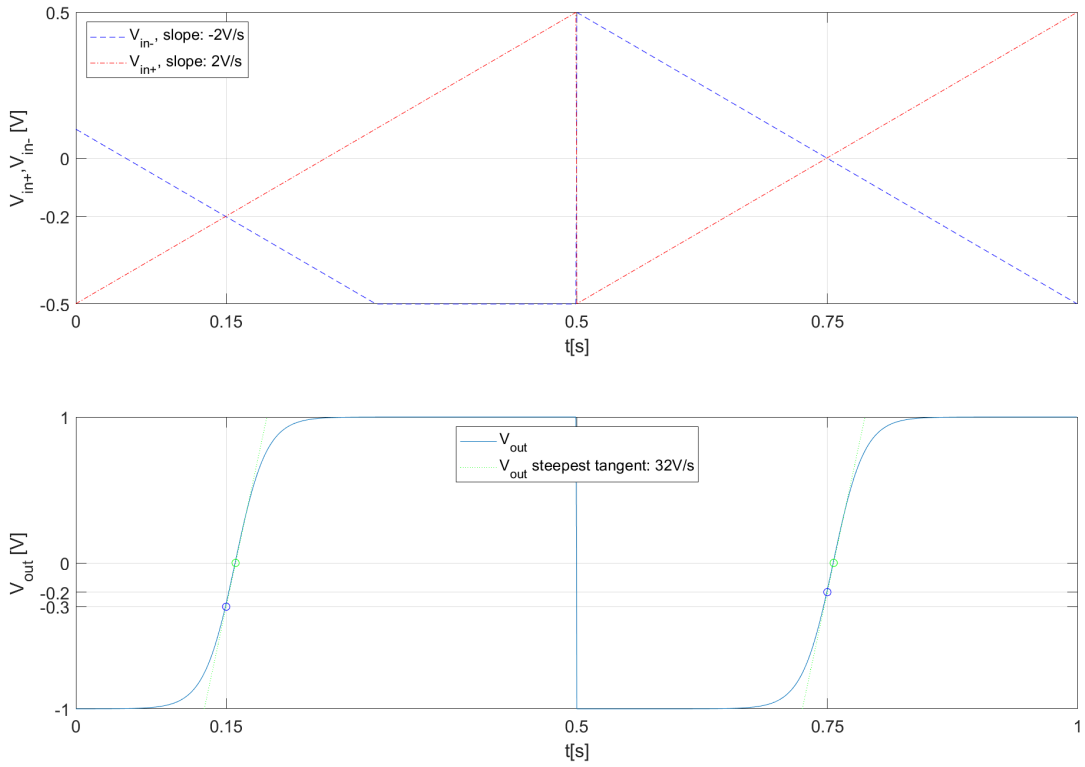
Upload your file here. Maximum one file.

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

Select file to upload

Maximum marks: 10

8 Common Mode Rejection Ratio



The figure shows the voltage traces from an experiment with a differntial amplifier. V_{in+} and V_{in-} are the differential inputs and V_{out} is the single ended output. The signals are slow enough to be well inside the pass band of the amplifier so there are no frequency effects and the observed behaviour is the amplifier's low frequency/DC behaviour.

From the graphs and the indicated time and voltage values, derive the small signal gain A, the common mode gain Acm, and the common mode rejection ratio CMRR in decibel (!).

Submit the result as a MATLAB-script in file "CMRR.m" that assignes the correct numerical values to variables:
A=?
Acm=?
CMRR=?
Use at least 3 significant digits!

Upload your file here. Maximum one file.

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

Select file to upload

Maximum marks: 10