Name:__________________________________ UT EID:__________ Instructor_____________________

ECE 302 **Please answer ALL questions**

100 points total.

Fall 2024, Midterm Exam III **Time: 600-800 PM**

21 Nov. 2024

PLEASE ATTEMPT ALL PROBLEMS AND SHOW ALL WORK!

WRITE ALL EXAM SOLUTIONS IN THE SPACES PROVIDED ON THE EXAM SHEETS.

YOU MAY USE THE BACK OF EACH PAGE FOR SCRATCH, BUT ONLY THE FRONT SIDES WILL BE SCANNED AND GRADED.

No class notes, books, homework assignments, or other materials are allowed. You may use a calculator for the exam. Any calculator that does not have phone/communication/photo capability is allowed. Your calculator's memory should not have any information or programs that are not allowed for use on the exam. You have 120 minutes from the start of the exam to complete the exam.
NOTES: Unless otherwise stated, you may assume all numerical quantities given in the exam problems are known to 3 significant figures, and calculate your answers accordingly. You must show all of your work to receive credit. If you need to make an assumption to answer a question, state it explicitly.

Instructions for turning in your exam:

After completing your exam, you may turn on your phones

0) Please write your EID on every page of the exam
1) Log in to Gradescope and find MT3 or Midterm III
2) For each problem:
a. If your response is within the space for the answer, you should choose the option to have Gradescope take a picture of your page. You should scan all pages of this exam booklet including the first page and any blank pages in the correct order. Gradescope will automatically assign your answers to each question according to the template.

b. If your response does not fit in the space for the answer and you used extra sheets, you must take pictures of each page with your camera app and choose the option to upload the solution. You will need to assign the answer for each question in Gradescope.

3) DOUBLE CHECK YOUR SUBMISSION
4) Turn in your paper exam to the proctor (this will be used as a reference)

Q1. (25 points)

a) (11 points) Fig. 1-1 is a circuit schematic of a CMOS inverter. $V_{DD} = 2$ V, $V_{IN} = 0.4$ V. For the PMOS operating in the linear region, we have W/L=100, $\mu_p C_{ox} = 100\ \mu A/V^2$, $V_T = -0.3$ V; for the NMOS operating in saturation region, we have W/L = 40, $\mu_n C_{ox} = 200\ \mu A/V^2$, $V_T = 0.3$ V. Please calculate the current into the ground, labeled **I** in the circuit schematic, and output voltage V_{OUT}.

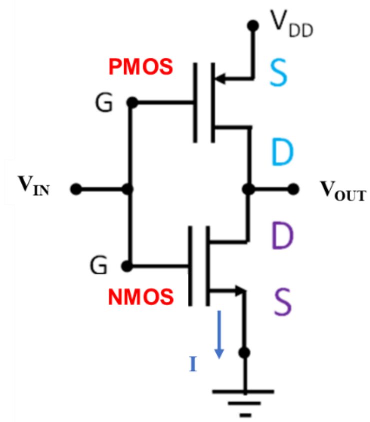


Fig. 1-1

b) Fig. 1-2 is a circuit consisting of 2 PMOS and 2 NMOS FETs. labeled 1 through 4. The PMOS has the threshold voltage = -0.1 V. The NMOS has the threshold voltage = +0.1 V. V_{DD} = 2 V. Assume that if a transistor is on, it is in the linear region.

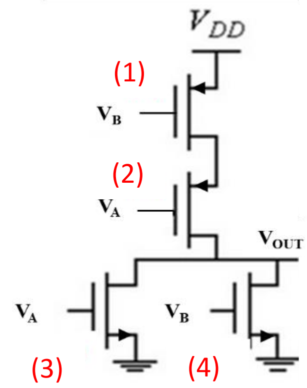


Fig. 1-2

i. (3 points) If $V_A = 0$ and $V_B = 0$, what is V_{GS} of FET (1)? Is it on? Justify your answer.

ii. (3 points) If $V_A = 0$ and $V_B = 0$, what is V_{GS} of FET (4)? Is it on? Justify your answer.

iii. (8 points) If V_A and V_B can be either set to 0 V or V_{DD}, for what combinations of V_A and V_B is the output high (close to V_{DD})? For what combinations of V_A and V_B is the output low (close to 0 V)? Please write your answers as a table with columns V_A, V_B and V_{out}. (8 points)

Q2 (25 points)

a) (12 points) What are the real and imaginary parts of the complex numbers below?

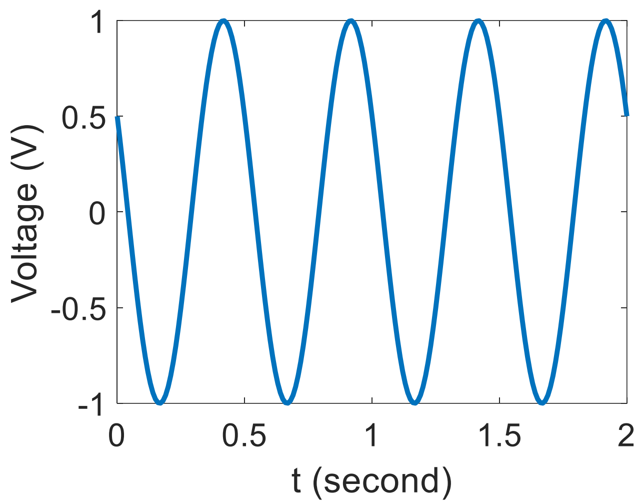
$$z_1 = \frac{x+yj}{2x-yj}$$

$$z_2 = e^{j\theta} + 2e^{-j\theta}$$

$$z_3 = (1+2j) \times e^{j(\theta+\frac{\pi}{2})}$$

$$z_4 = \left(\frac{1}{\sqrt{2}} - \frac{j}{\sqrt{2}}\right)^n$$

b) (9 points) Based on the plot below, write down the corresponding cosine function. What is the frequency, amplitude, and phase of the voltage signal? If another voltage signal has the same frequency and amplitude, but a phase lag of $\pi/3$ with respect to the original signal, write down this voltage signal function and plot it in the same figure below.



Signal function:

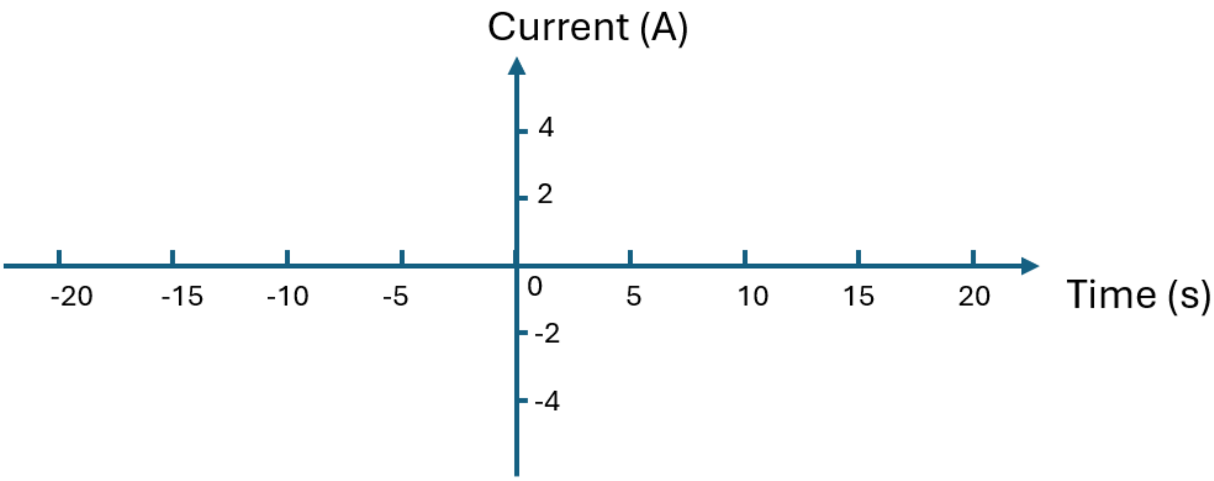
Frequency:

Amplitude:

Phase:

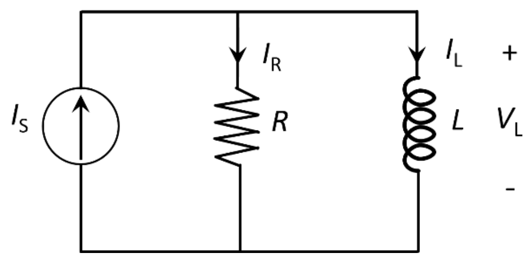
New signal function:

c) (4 points) Consider a current signal with a cosine waveform. The frequency is 0.1 Hertz, the amplitude is 2 A, and initial phase is $+\pi/2$. Write down this current signal and plot this current signal in the time domain.



Q3 (25 points)

Consider the circuit shown below.



I_S represents a sinusoidal current source oscillating at frequency f, angular frequency $\omega = 2\pi f$.

a) (3 points) For $R = 1\ \Omega$, $L = 10\ \mu\text{H}$, calculate the impedance of the resistor and inductor separately at $f = 100$ Hz.

b) (3 points) For $R = 1\ \Omega$, $L = 10\ \mu\text{H}$, calculate the impedance of the resistor and inductor separately at $f = 1$ MHz.

c) (6 points) Calculate the transfer function I_L/I_S between the current phasor I_L and the current phasor I_S. Express your answer in terms of the variables R, L and ω in polar form.

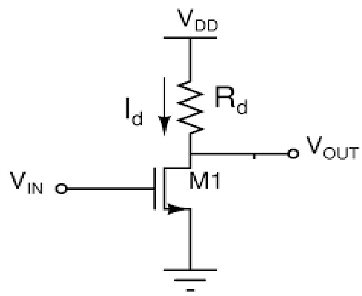
d) (2 points) For $R = 1\ \Omega$, $L = 10\ \mu\text{H}$, calculate the frequency at which the magnitude of the transfer function $|I_L/I_S| = 1/\sqrt{2}$. Express your answer in Hz.

e) (2 point) Does the transfer function I_L/I_S correspond to a low-pass filter or a high-pass filter? Justify your answer.

f) (4 points) Evaluate the transfer function I_L/I_S for $R = 1\ \Omega$, $L = 10\ \mu H$ at $f = 1$ MHz. Express the answer in polar form.

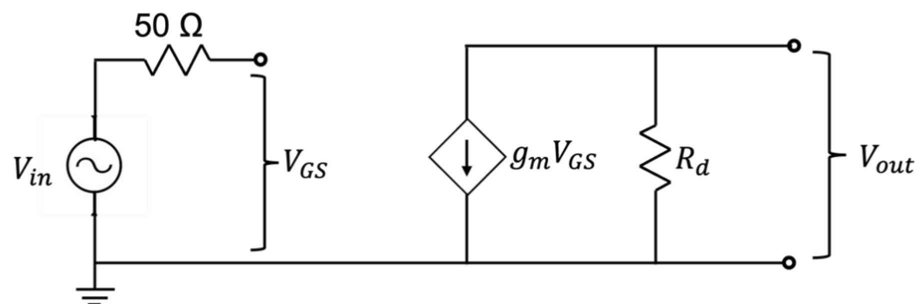
g) (5 points) If $I_S(t) = 2\cos(2\pi f\, t + 60°)$ mA is the time-domain signal from the current source, calculate $I_L(t)$ for $f = 1$ MHz. Express the answer in standard cosine form.

Q4 A common source amplifier (CS amp) circuit is shown below, made with an NMOS FET with threshold voltage $V_T = 2\ V$ that is assumed to be operating in its saturation regime. V_{in} is an AC input voltage, but it has a DC component of 2.5 V. When the circuit is operated with $V_{DD} = 6\ V$, the drain-source current of the FET is $I_d = 5\ mA$. The drain resistor $R_d = 500\ \Omega$.



a) (5 points) Calculate the small signal transconductance g_m from the DC operating point details.

b) (5 points) With the transistor modeled as a voltage-controlled current source, the circuit model of the CS amp is as shown below. **A load resistance $R_L = 2\ k\Omega$ is then added across the output (not shown).** It is observed that when the frequency of $V_{in} < 10\ kHz$, the CS amp circuit has constant voltage gain vs. frequency. What is the voltage gain of the circuit, and is it inverting or non-inverting?



c) (5 points) Using the absolute value of the voltage gain found in (b), express the circuit's gain in decibels (dB). Show your work to arrive at your solution.

d) (5 points) It is observed that when the frequency of $V_{in} > 10\ kHz$, the CS amp voltage gain rolls off at about -20 dB per decade. Draw the transfer function of the gain for the CS amp, with absolute value of the gain on the y axis in dB, and frequency in Hz on the x axis. Is it acting as a low pass filter or a high pass filter? Briefly justify your answer.

e) (3 points) What is the voltage gain of the CS amp at 1 MHz? Express your answer in both dB and linear scale.

f) (2 points) If the voltage output of the CS amp is measured by an oscilloscope, there will be additional capacitance from the oscilloscope. This can be modeled by adding a capacitor C_{scope} in parallel with R_L. Write an expression for the total complex impedance of R_d, R_L, and C_{scope}. Your expression should depend on the resistance and capacitance values as well as the frequency ω of the input signal.