FINAL EXAM

ECE 2040

NAME:

MAJOR:

INSTRUCTIONS

This is an open book exam. You are allowed to use your calculators and MATLAB.

This is a take-home exam (due date: December 9 2023, by 11:59 PM). You will have 10 days to work on it.

Upload your completed exam to canvas.

LATE SUBMISSIONS ARE NOT ALLOWED.

Please note that solutions similar to those of other students in the class will NOT be graded.

Problem 1**.** Mark the following statements as either **True** or **False**

(a) **True** or **False**: An LC circuit (with a DC source) is an oscillatory circuit.

(b) **True** or **False**: A circuit response may grow, rather than decay exponentially with time.

(c) **True** or **False**: The time constant of an RC circuit is $\tau = \frac{1}{RC}$ while the time constant of an RL circuit is $\tau = \frac{L}{R}$.

(d) **True** or **False**: Kirchhoff's current and voltage laws hold in a frequency domain representation of an RLC circuit with a DC source.

(e) **True** or **False**: The decay constant α in an **overdamped** system can also be referred to as a **damping factor** or a **damping coefficient**.

(f) **True** or **False**: The overall gain of two contiguous connected or concatenated summing amplifiers is equal to product of gain of each amplifier.

(g) **True** or **False**: A noninverting amplifier is an op am circuit producing an output voltage that is a negative, scaled replica of the input voltage.

(h) **True** or **False**: Impedances in parallel share a common voltage.

(i) **True** or **False**: An attenuator is a passive device that affect it input power such that the output power is less than the input power. If the aforestated fact is true, then this type of passive device can be fabricated from a network of resistors.

(j) **True** or **False**: Two voltage sources/supplies have $+5$ V, and -5 V terminals only. If these devices are connected such that the -5 V terminal from device 1 is connected to the $+5$ V terminal from device 2 then the device combination can be considered as a three terminal device with the *common ground* being the joint terminals.

(k) **True** or **False**: The capacitor does not allow sudden changes in voltage.

(l) **True** or **False**: The voltage applied to a 212 mH inductor in a circuit can be denoted as $\mathrm{v(t)} = 15\mathrm{e}^{-5\mathrm{t}}$ V. The current in the circuit is $11.27\mathrm{e}^{-10\mathrm{t}}$ A.

(m) **True** or **False**: An inductor works as an open circuit if the circuit is power by a DC source.

(n) **True** or **False**: A capacitor can be used in place of a resistor in a circuit with a high frequency input AC source.

(o) **True** or **False**: The insulating medium between the two plates of capacitor is know as a capacitive medium.

(p) When the input voltage difference is small in magnitude, the operational amplifier behaves as ____
  (i) Non-linear device
  (ii) Complex device
  (iii) Linear device
  (iv) Bipolar device

(q) The condition for a Non-inverting amplifying circuit to function in linear region operation is ____
  (i) $(R_s + R_f)/R_s < |V_{CC}/V_g|$
  (ii) $(R_s + R_f)/R_s \neq |V_{CC}/V_g|$
  (iii) $(R_s + R_f)/R_s > |V_{CC}/V_g|$
  (iv) $(R_s + R_f)/R_s = |V_{CC}/V_g|$

(r) All the rules and laws of D.C. circuit also apply to A.C. circuit containing
  (i) Capacitance only
  (ii) Inductance only
  (iii) Resistance only
  (iv) all the above

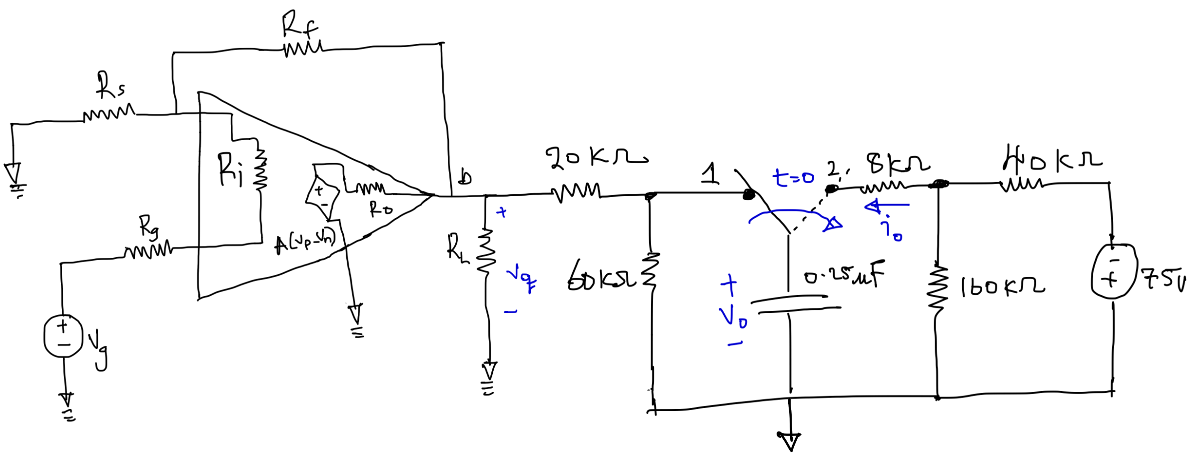


Fig. 1.

(s) The circuit shown in Fig. 1 stems from the concatenation of a realistic (non-ideal) non-inverting operational amplifier model and an RC circuit. The switch in the circuit has remained in position 1 for a long time. At $t = 0$, the switch moves to the position 2. If $R_s = 1000\ \Omega$, $R_f = 3000\ \Omega$, $R_g = 1000\ \Omega$, $R_i = 75\ \text{M}\Omega$, $R_o = 50\ \Omega$, $A = 10^5$ and $V_g = 10$ V. If
(a) $V_0(t) = -60 + 90e^{-100}t$ for $t \geq 0$
(b) $i_0(t) = -2.25e^{-100t}$ for $t \geq 0^+$

Check the consistency of the solutions (for $V_0(t)$ and $i_0(t)$) by deriving $V_0(t)$ from $i_0(t)$.

(t) Lauren Yao and Koby Dunn have been best friends since middle school. However, a recent argument about a circuit problem has put a strain on their friendship. The bone of contention is as follows:

An A.C. voltage impressed across a pure resistance of 3.5 *Ohms in parallel with a pure inductance of impedance of* 3.5 *Ohms. The weight of the current (i.e., value of current is one component relative to the other) in the aforementioned passive components is in question.*

If the current through the pure resistance and inductance are denoted as I_{R} and I_{L}, respectively.

(i) **Lauren** claims that $I_{\mathrm{R}} > I_{\mathrm{L}}$
(ii) **Koby** claims that $I_{\mathrm{R}} < I_{\mathrm{L}}$
(iii) **Roger** (paper vendor down their street) claims that $I_{\mathrm{R}} = I_{\mathrm{L}}$
(iv) **Mr Johnshon** (their neighbor) claims that none of the above answers are correct.

Help settle the dispute by stating the right answer.

Problem 2**a.** The parameters for the circuit shown in Fig. 2 are $R_a = 100\,\text{K}\Omega$, $R_1 = 500\,\text{K}\Omega$, $C_1 = 0.1\,\mu$F, $R_b = 25\,\text{K}\Omega$, $R_2 = 100\,\text{K}\Omega$ and $C_2 = 1\,\mu$F. The power supply voltage for each op amp is $\pm$6V. The signal voltage (V_g) for the cascaded integrating amplifiers jumps from 0 to 250 mV at $t = 0$. No energy is stored in the feedback capacitors at the instant the signal is applied.

(i) Derive an algebraic expression for the output voltage V_0 as a function of the input voltage V_g.
(ii) Derive the characteristic equation and solve for its roots.
(iii) Find the numerical expression of the differential equation for V_0.
(iv) Find $V_0(t)$ for $t \geq 0$.
(v) Find the numerical expression of the differential equation for V_{01}.
(vi) Find $V_{01}(t)$ for $t \geq 0$.

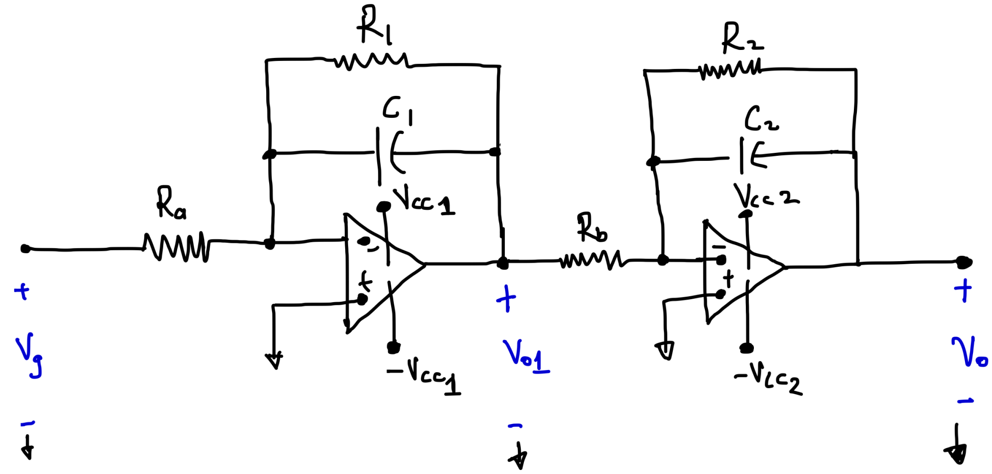


Fig. 2. Cascaded Integrating Amplifiers with RC Feedback Link.

Problem 2**b.** Repeat Problem 2a with the feedback resistors R_1 and R_2 removed.

Problem 3**.** The n-type metal oxide semiconductor (MOSFET) transistor (see Fig. 3) is a three-terminal component that serves as a building block for almost all digital electronic devices.

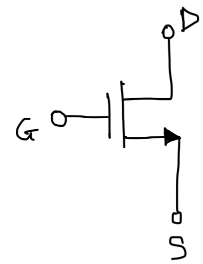


Fig. 3. MOSFET (NMOS) with terminals labeled as Gate (G), Source (S) and Drain (D)

The n-type MOSFET (NMOS) has two operation modes namely (i) triode mode, and (ii) saturation mode i.e., active mode. A large scale equivalent circuit model for the NMOS in the saturation mode is shown in Fig. 4.

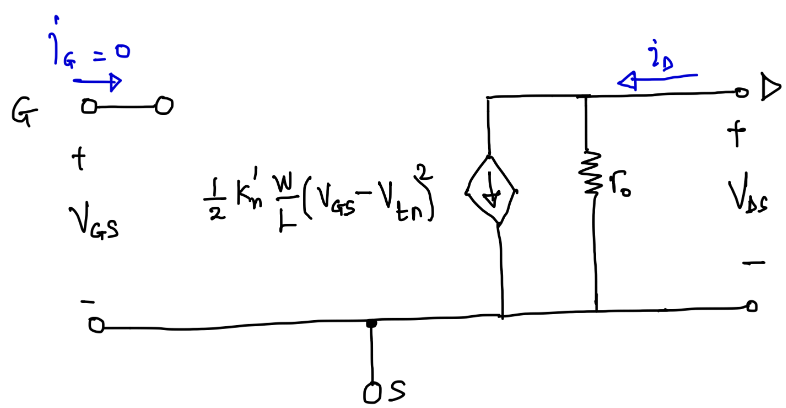


Fig. 4. Large-signal equivalent circuit model of the n-channel MOSFET in saturation.

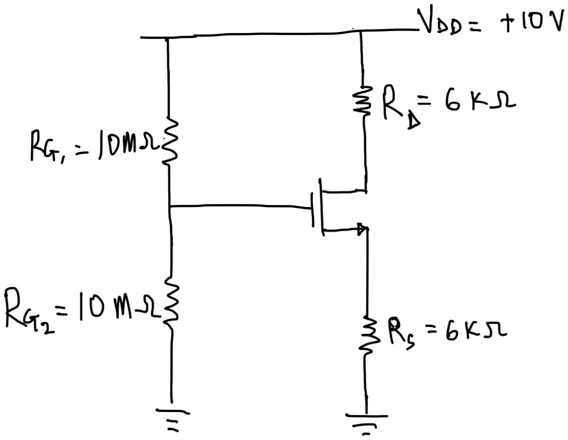
In the circuit above, $r_0 \approx \left[\frac{di_{\mathrm{D}}}{dv_{\mathrm{DS}}}\right]^{-1}_{V_{\mathrm{GS}}=\mathrm{constant}}$ while the drain current $i_{\mathrm{D}} = \frac{1}{2}k_{\mathrm{n}}' \frac{W}{L}\left(V_{\mathrm{GS}} - V_{\mathrm{tn}}\right)^2$.

There are rules guiding the operation of an NMOS transistor.

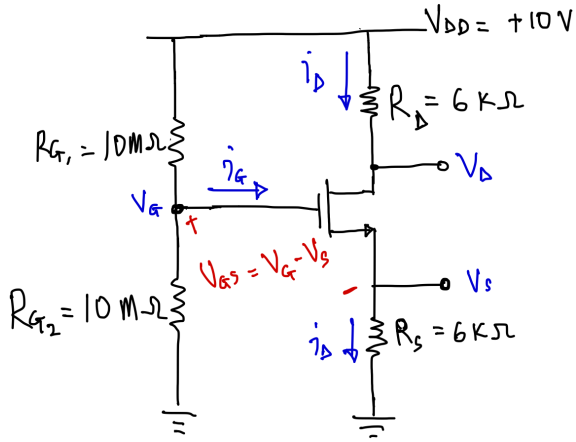
(i) **RULE** 1**:** The NMOS will operate in the saturation (active) mode if the drain voltage (V_D) is greater than the difference between the gate voltage (V_G) and the threshold voltage (V_{tn}) i.e. $V_D > V_G - V_{tn}$.

(ii) **RULE** 2**:** The source voltage (V_S) must not exceed the gate voltage (V_G). A situation where $V_S > V_G$ implies that the transistor is inactive i.e., cut off.

Using the rules stated above, analyze the active circuit shown in Fig. 5(b) – annotated version of Fig. 5(a). Find the voltages (V_S, V_D, V_{GS}) at all nodes and the current i_D. Let $V_{tn} = 1$ V, $i_G = 0$ A, and $k_n'(W/L) = 1\,\text{mA/V}^2$.



(a)



(b)

Fig. 5. (a) Original circuit (b) circuit with additional details

Problem 4**a.** The sinusoidal current source in the circuit shown in Fig. 6 produces the current $i_s = 8\cos 200000t$ A.

(a) Construct the frequency-domain equivalent circuit.

(b) Find the steady-state expression for v, i_1, i_2, and i_3.

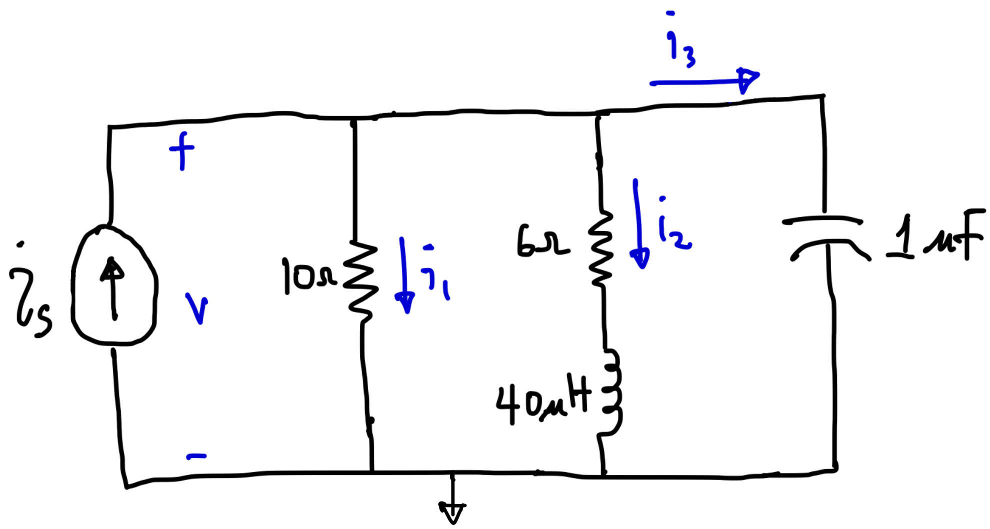


Fig. 6. RLC Network with sinusoidal current source.

Problem 4**b.** For the circuit shown in Fig. 7, find:

(i) The value of R_L that results in maximum power being transferred to R_L
(ii) Calculate the maximum power that can be delivered to R_L
(iii) When R_L is adjusted for maximum power transfer, what percentage of the power delivered by the 360 V source reaches R_L?

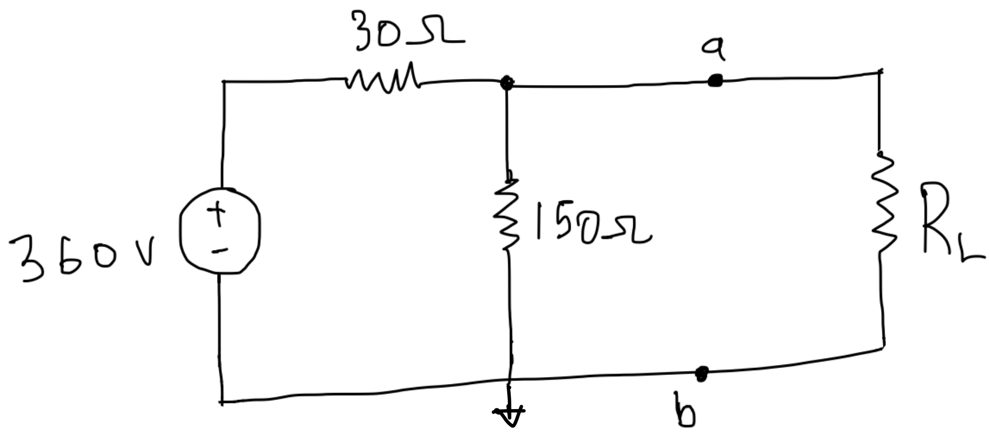
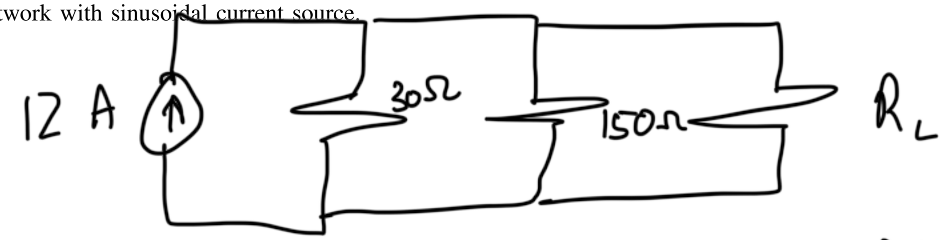
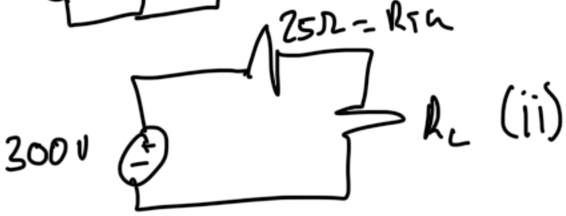


Fig. 7. RLC Network with sinusoidal current source.



(i) Maximum power transfer theorem states to deliver max power, $R_L = R_{Th}$

$\Rightarrow R_L = 25\ \Omega$



Problem 5**a.** The initial energy stored in the circuit in Fig. 8 is zero. At $t = 0$, a dc current source of 24 mA is applied to the circuit. The value of the resistor is $400\ \Omega$.

(a) What is the initial value of i_L?
(b) What is the initial value of di_L/dt?
(c) What are the roots of the characteristic equation?
(d) What is the numerical expression for $i_L(t)$ when $t \geq 0$?
(e) Find $i_L(t)$ for $t \geq 0$ if the resistor R in Fig. 8 is increased to $625\ \Omega$.
(f) Find $i_L(t)$ for $t \geq 0$ if the resistor R in Fig. 8 is increased to $500\ \Omega$.

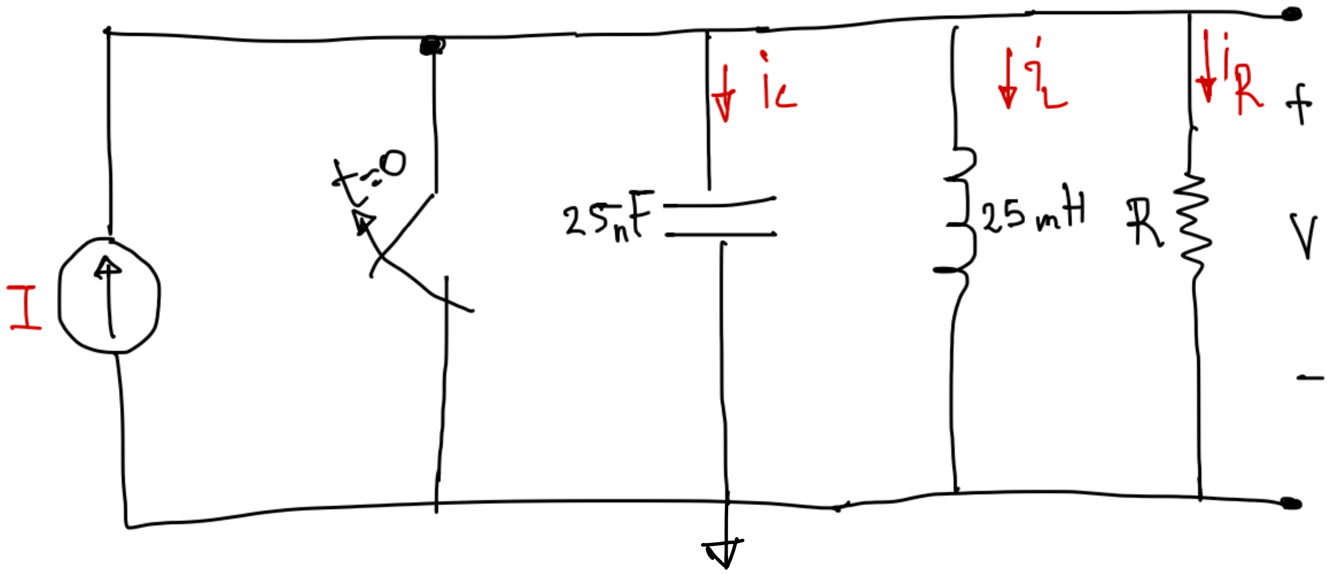


Fig. 8.

Problem 5**b.** Energy is stored in the circuit in Fig. 8 at the instant the dc current source is applied. If the resistance $R = 500\ \Omega$ and initial current in the inductor is 29 mA with the initial voltage across the capacitor being 50 V. Find

(i) $i_L(0)$
(ii) $di_L(0)/dt$
(iii) $i_L(t)$ for $t \geq 0$
(iv) $v(t)$ for $t \geq 0^+$.