Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
Cambridge, MA 02139

Unified Engineering
Fall 2004

Problem Set #6

Due Date: Tuesday, October 19, 2004 at 5pm

	Time Spent (minutes)
T1	
T2	
T3	
S7	
S8	
S9	
Study Time	

Name: ________________

UNIFIED ENGINEERING Fall 2004

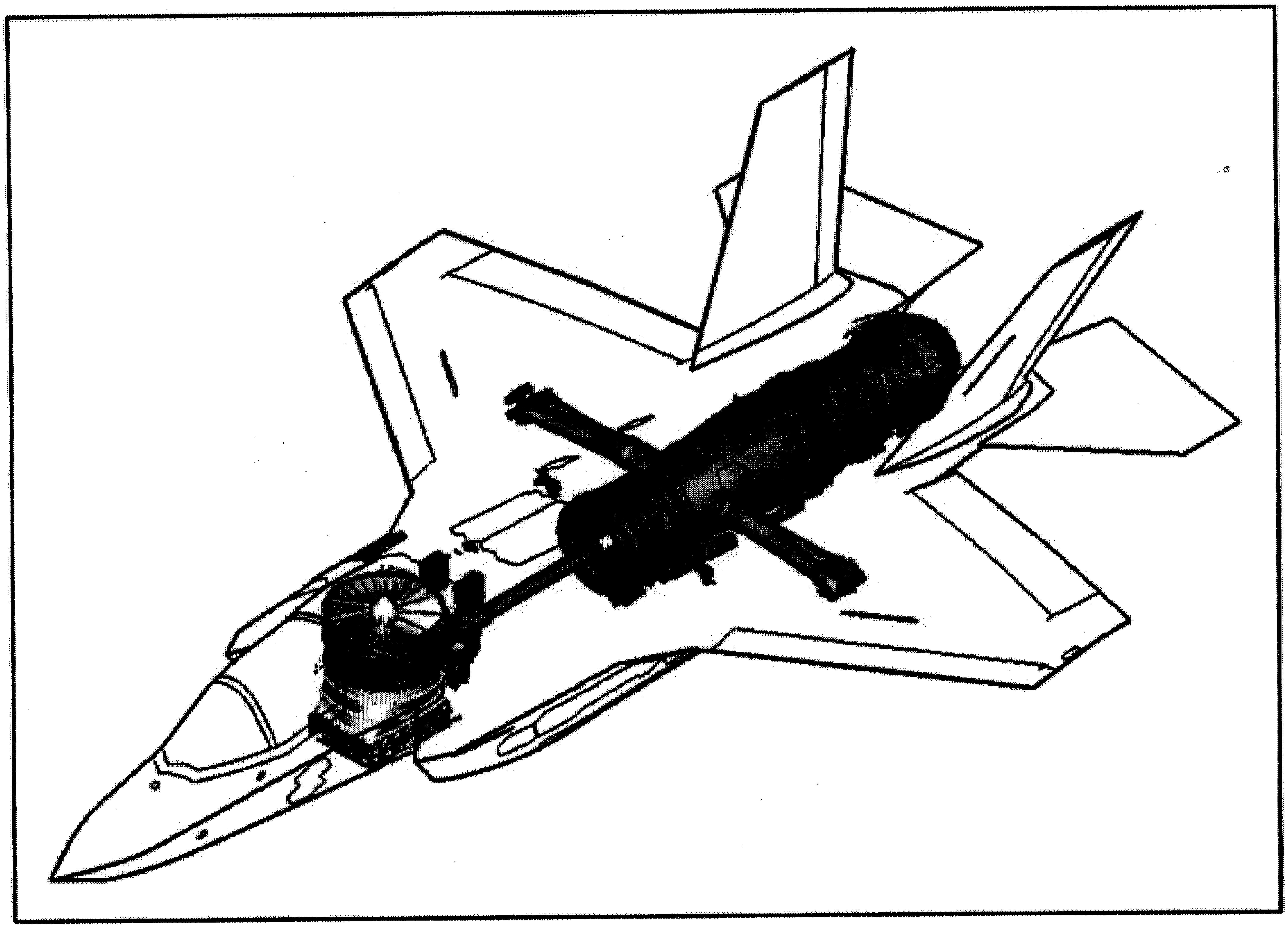
Ian A. Waitz

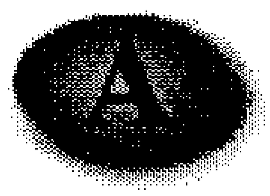
Problem T1. (Unified Thermodynamics)

Below is a schematic of the engine for the Joint Strike Fighter (JSF). A lift fan (directly behind the cockpit) is driven by a shaft from the main engine to provide vertical take-off and landing capability. The exhaust nozzle on the main engine can also swivel 90 degrees to point directly down. The inlet for the main engine is split, with half of the flow coming in either side of the cockpit, flowing through a y-shaped duct (with the shaft running through it) that wraps around the lift fan and meets in the center of the aircraft. There are also two small roll-control jets that exit the main engine aft of the compressor.

Describe the exchanges of energy (internal, potential, kinetic, chemical) and conversions of heat and work for this system. Start with the fuel and air being mixed in the combustor and the airplane on the ground. End with the airplane hovering at some distance above the ground.

(LO#1, LO#2, LO#3)





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Problem T2 (Unified Thermodynamics)

An electric motor draws 3 A from the 12 V battery shown below. After 50 seconds of operation the 100 kg piston is raised a distance of 0.1m. The area of the piston, which can be considered to move without friction, is 0.05 m^2, and the atmospheric pressure is P_{atm} = 105 N/m2.

a) What is the work input to the gas from the motor during the 50 s period?

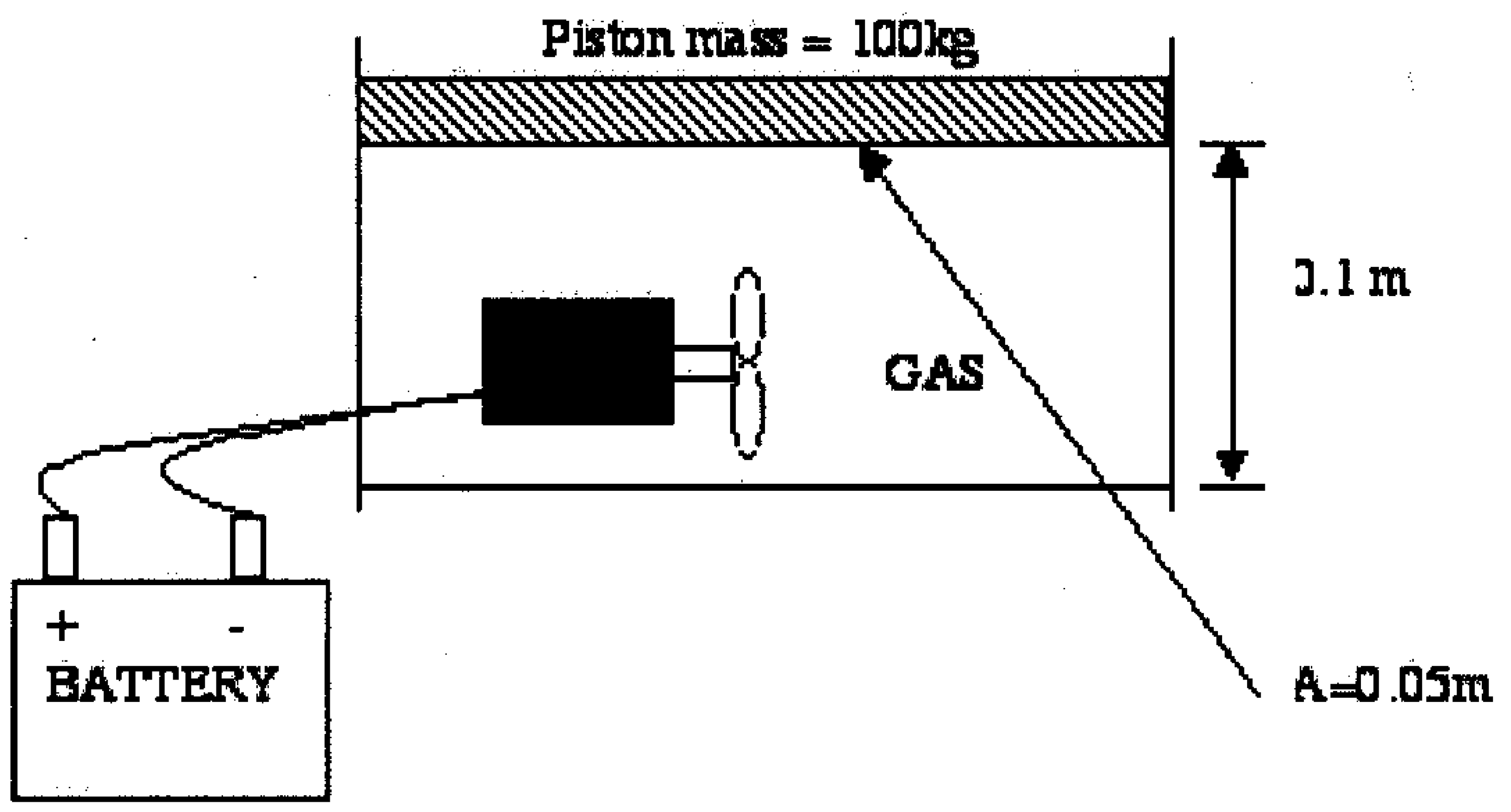
b) What is the work to raise the piston?

c) What is the work done against the pressure of the atmosphere?

d) What is the net work done by the gas in the chamber during the 50 s period?

e) If the final value of internal energy were the same as the initial value, what is the heat transfer to or from the surroundings during this period?

(LO#1, LO#4)



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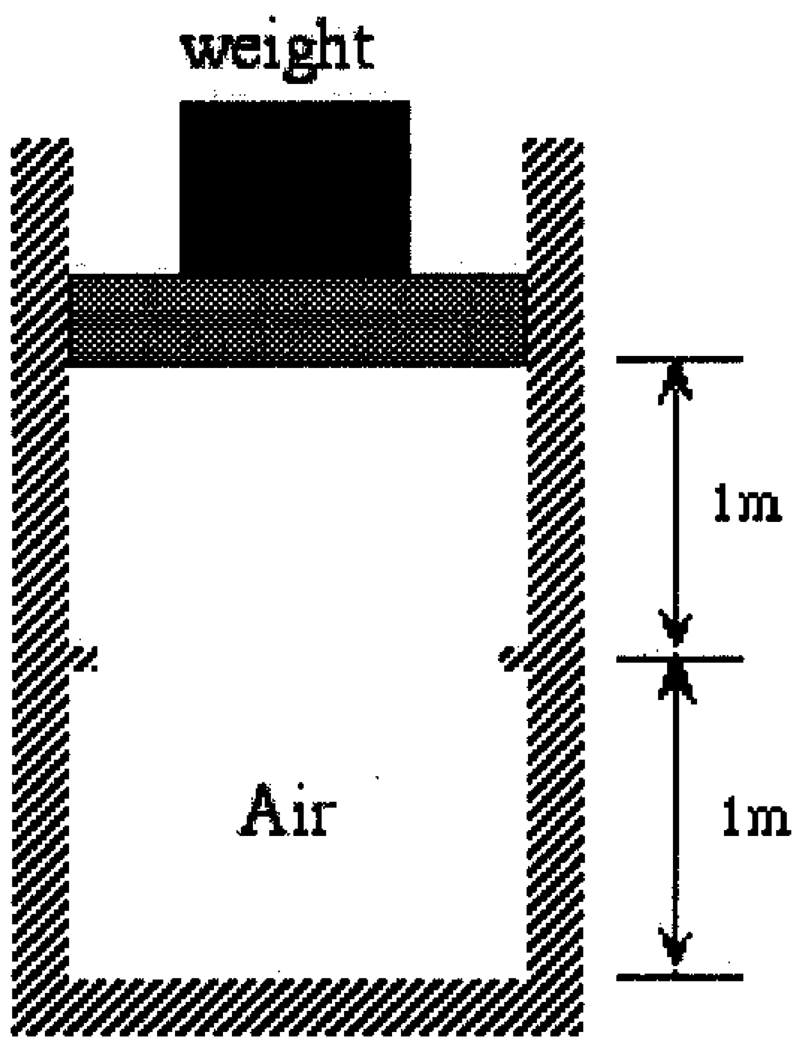
Problem T3 (Unified Thermodynamics)

Air (assume it behaves as a thermally perfect gas) is contained in a vertical cylinder that is fitted with a frictionless piston and a set of stops, as shown below. The piston cross-sectional area is $0.5m^2$ and the air inside is initially at 200kPa and 800K. The air is then slowly cooled as a result of heat transfer to the surroundings. (LO#4, LO#5)



a) Sketch these two processes on p-V and T-v diagrams

b) What is the temperature of the air inside the cylinder when the piston reaches the stops?

c) After the piston hits the stops, the cooling is continued until the temperature reaches 300K. What is the pressure at this state?

d) How much work is done by the system in the first cooling process?

e) How much work is done by the system in the second cooling process?

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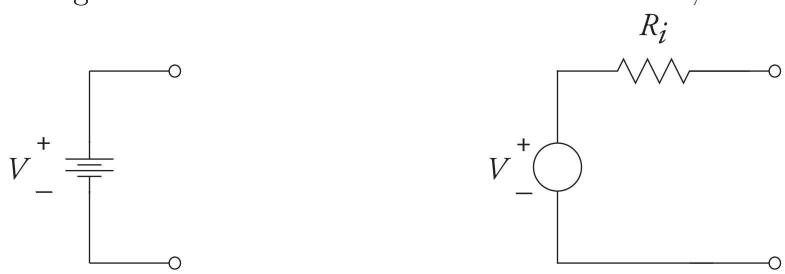
Problem S7 (Signals and Systems)

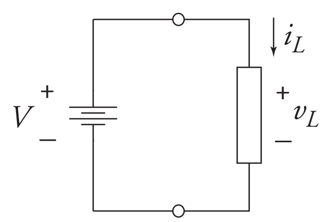
As discussed in the notes and in class, one useful model for a battery is an ideal voltage source in series with an internal resistance, as shown below:



battery circuit element model for battery including internal resistance

For a typical car battery, $V = 12$ volts, and $R_i = 0.01\ \Omega$.

Now, suppose we attach the car battery to a load, such as the starter motor, as in the figure below:



The load will draw current from the battery, which will reduce the voltage of the battery somewhat. The goal is to design the load (the starter) to get as much power from the battery as possible.

1. Find the voltage across the load, v_L, as a function of the current through the load, i_L.
2. Find the power dissipated by the load, P_L, in terms of the current through the load.
3. Find the value of i_L that maximizes the power dissipated by the load. Also find the corresponding voltage across the load.
4. How much power can a typical 12 volt car battery supply to a starter? Does this answer seem reasonable to you? Note: 1 horsepower is equal to 746 Watts.
5. If the load were a resistor instead of a starter motor, what value of resistance would maximize the power dissipated across the load?

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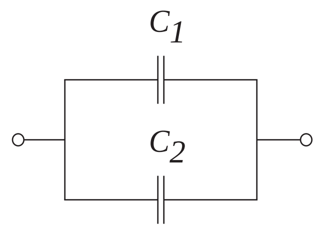
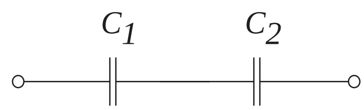
Problem S8 (Signals and Systems)

1. Using the constitutive law for capacitors and inductors, derive the equivalent capacitance and inductance for the following series and parallel configurations:

   a)

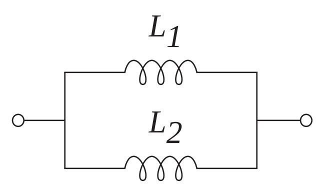


   b)

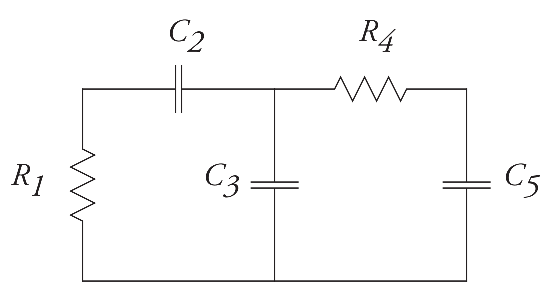


   c)

   d)



2. Find a set of differential equations that describe the dynamics of the circuit below, using the node method



   where

$$R_1 = 1\ \Omega, \quad C_2 = 0.2\ \text{F}, \quad C_3 = 0.2\ \text{F}, \quad R_4 = 4\ \Omega, \quad C_5 = 0.5\ \text{F}$$

   Note: You do not have to solve the differential equations.

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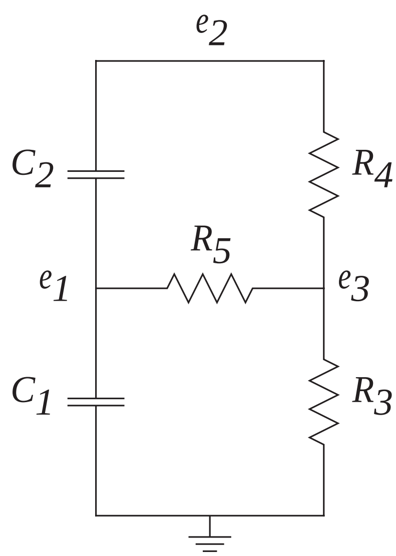
Problem S9 (Signals and Systems)



Consider the network above, with

$$C_1 = 1 \text{ F}, \quad C_2 = 2 \text{ F}, \quad R_3 = 2\ \Omega, \quad R_4 = 1\ \Omega, \quad R_5 = 1\ \Omega$$

The capacitor voltages at time $t = 0$ are such that

$$e_1(0) = 3 \text{ V}, \quad e_2(0) = 6 \text{ V}$$

Find the node voltages $(e_1(t), e_2(t), e_3(t))$ as a function of time.