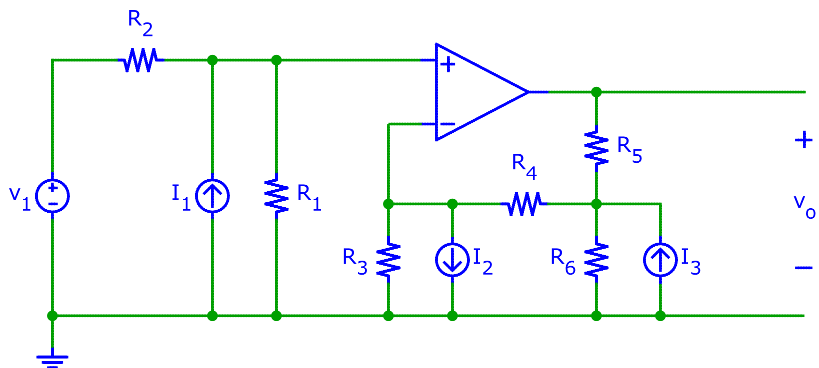
This assignement is due Tuesday to give you time to look at the solution before the exam!

1. Redo practice problem 7.1 in Alexander and Sadiku, 5h Edition. Replace the $6\,\Omega$ resistor with $7\,\Omega$.
2. (optional) Redo practice problem 7.4 in Alexander and Sadiku, 5h Edition. Replace the 2 H inductor with 3 H.
3. Redo practice problem 7.10 in Alexander and Sadiku, 5h Edition. Replace the 10 V source with 15 V.
4. (5-8) Find the value of v_o for $V_1 = 6.9\,\text{V}$, $I_1 = 2.7\,\text{mA}$, $I_2 = 6.3\,\text{mA}$, $I_3 = 4.9\,\text{mA}$ and $R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = 1\,\text{k}\Omega$.
   Suggestion: use superposition.

   $v_o =$ ☐



5. (D-60) In this problem we design a "step down converter" (Buck converter) to efficiently convert the input voltage V_s =110 V to a lower value $v_o = 18\,\text{V}$. Such circuits are employed in the familiar "power bricks" used to power laptops and gadgets from the grid. In the diagram below the switch is controlled by a periodic waveform. It is closed for a period T_1, followed by a period $T_2 = T - T_1$ during which it is open. The diode D_1 acts like a "valve": current passes for $v_d \geq 0\,\text{V}$; for $v_d < 0\,\text{V}$ the diode behaves like an open circuit.

   To simplify the analysis, assume that the output voltage v_o is constant and equal to the design value. This leads to minimal errors when the ripple is small. In practice we would verify the ciruit with SPICE to check if all assumptions are valid and we have not made design errors.

   a) Assuming that the circuit behaves as intended, i.e. v_o has the desired value, draw a simplified circuit when the switch is closed.
   b) Repeat (a) when the switch is open.
   c) Derive expressions for the change of the current Δi_L through the inductor when the switch is opened and closed. These expressions are functions of V_s, v_o, L_1, T_1, and T_2.
   d) In steady state, the change of the inductor current Δi_L when the switch is closed and the change when the switch is opened must be equal. Use this condition to derive an expression for $\frac{v_o}{V_s}$ as a function of T_1 and T_2.
   e) Find T_1 and T_2 for $T = T_1 + T_2 = 2.8\,\mu\text{s}$.

      $T_1 =$ ☐

      $T_2 =$ ☐
   f) Find the value of L_1 that results in $\Delta i_L = 51\,\text{mA}$. In practice these supplies are designed for the maximum acceptable ripple Δi_L to minimize the size of the inductor required, thus minimizing cost.

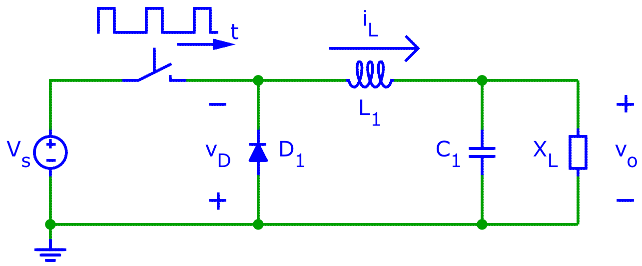
      $L_1 =$ ☐

g) What is the efficiency η of this circuit, defined as the ratio of power dissipated by the load X_L divided by the power delivered by the source V_s? Hint: determine which elements dissipate power.

$\eta =$ [ ]

h) The efficiency of actual realizations of this circuit is 80 . . . 95 %. What nonidealities in the circuit are responsible for dissipation?

Practical realizations contain additional circuitry to dynamically adjust the duty cycle T_1/T_2 to keep v_o constant despite of variations of V_s or the current drawn by the load.



6. Your electricity bill for last month shows a charge for \$3.40. The cost of energy is \$ 0.35/kWh.
   a) What is the amount of energy you consumed in SI-units (Joules)?
   b) Assuming all you used this energy was a light with a 60 Watt bulb (to study at night for EE49). How many hours was the light turned on?
   c) Now you replace the (incandescent) 60 Watt bulb with a low energy 4 Watt bulb. If you use the light for the same number of hours, what is the charge on your new electricity bill?

7. Your lab kit includes the 500 mAh Lithium Polymer battery described at https://www.adafruit.com/product/1578. In all questions below you may assume that the full "rated" energy of the battery is available (in practice, the battery voltage drops as it gets discharged; once it falls below the level required by the application–e.g. 3.3 Volt for an ESP32–the remaining charge can no longer be used).
   For this problem, assume that a linear dropout regulator is used to generate 3.3 Volt from the (higher) battery voltage.
   a) What is the minimum total amount of energy stored in a fully charged cell?
      Note: because of manufacturing variations and other factors, capacity varies from one battery to another. Because of this, manufacturers frequently specify a range for parameters such as voltage. When designing with these parts (e.g. batteries) it is important to use the minimum (or worst case) specified values to ensure correct operation under all conditions.
   b) For how many hours can you operate an ESP32 drawing 120 mA?
   c) You use the ESP32 to monitor the snow level in a remote location (somewhere it actually snows). Every measurement takes 30 seconds, and you take one measurement every 6 hours. Between measurements you put the ESP32 into "deepsleep", a mode in which it consumes only 100 μA (120 mA when doing a measurement). For how many days can you monitor the snow pack before the battery runs out?
   d) Provided you wanted this experiment to run for 10 years without intervention (e.g. without recharging or replacing the battery), what is the required battery capacity in Amp-hours?

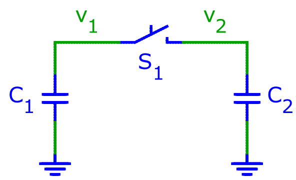
The remaining problems in this assignment are optional (practice for the midterm?).

8. (D-46) In the circuit below capacitors $C_1 = 3.4\,\text{pF}$ and $C_2 = 19\,\text{pF}$ are initially charged to $v_1 = 1.2\,\text{V}$ and $v_2 = 8.8\,\text{V}$ and switch S_1 is open. At time $t = 0$ the switch closes. Calculate the total energy stored on C_1 and C_2 before and after the switch closes, and the voltage $v_{12} = v_1 = v_2$ after the switch closes.

Total energy, S_1 open

Total energy, S_1 closed

v_{12}



9. (D-49) Electronic levels not only indicate horizontal and vertical features, but also display inclination in degrees. In this problem we design a capacitive transducer for angle measurement. Figure 1 shows the principle. The gap between two parallel plate capacitors is filled with a fluid. Tilting the level results in an imbalance between C_1 and C_2.

   Constrained by the application, we use $W = 21\,\text{mm}$, $H = 82\,\text{mm}$, and the nominal level of fluid when the device is horizontal ($\alpha = 0$) $x = 42\,\text{mm}$. The permittivity of the fluid is $\epsilon_{rf} = 24$.

   Determine the depth D of the reservoir such that $C_1 = C_2 = 36\,\text{pF}$.

   $D =$

   Now derive an expression for C_1 and C_2 and evaluate for $\alpha = 18$ degrees.

   $C_1 =$

   $C_2 =$

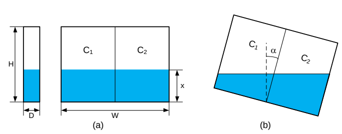


Figure 1 A capacitive angle measurement for an electronic level consists of a reservoir with dimensions W, D, and H as indicated and filled partially with a fluid with permittivity $\epsilon_{rf} \gg 1$. Two sets of electrodes on the front and back side form two capacitors C_1 and C_2. (a) When the device is level both capacitors have equal value. (b) Tilting by angle α results in an imbalance between C_1 and C_2 due to the permittivity of the fluid which is higher than that of the air above ($\epsilon_r = 1$).

10. The following article https://en.wikipedia.org/wiki/Battery_(electricity) describes many different battery technologies, including single use and rechargeable, and different chemistries such as Lithium and Nickel-metal-hydride (NiMH). These batteries have diverse characteristics, including voltage and capacity, energy density (relative to volume or weight), operating temperature range, shelf life (self discharge rate), maximum discharge current and cost. This website shows a comparison of some of these characteristics. The optimal choice of battery depends on specific application requirements.

    The ESP32 consumes 200 mA in its fully active state (WiFi radio transmitting and processor operating at maximum speed) and just 10 μA in its lowest power mode (deepsleep, when most functions are off except a wakeup timer and some peripherals). In both states, the ESP32 draws current from a 3.3 V supply.

Most batteries do not deliver 3.3 V, but some other voltage like 1.2 V or 12 V. Special circuits called power converters are used to change the battery voltage to the voltage needed by the application. For the questions below you may assume that such a device is used to produce the correct operating voltage and that the converter is 100% efficiency. This means that the converter has no power losses and the entire energy delivered by the battery is available for use by the ESP32. Use the table at https://en.wikipedia.org/wiki/Comparison_of_commercial_battery_types to answer parts (b) and (c) below.

a) Calculate the power dissipation of the ESP32 in its on state and in deepsleep. What are the units of your results?
b) What is the maximum operating time (in hours or days) of the ESP32 using
   i. a battery weighing 100 grams,
   ii. a battery with 0.1 Liter volume?
c) Now suppose you must use a 100 gram battery. Calculate the operating time for the following situations:
   i. ESP32 fully on continuously (i.e. 200 mA current draw),
   ii. ESP32 in deepsleep,
   iii. ESP32 on 10 % and in deepsleep 90 % of the time, and
   iv. ESP32 on 1 % and in deepsleep 99 % of the time.

   Do the calculations for the following battery types
   i. Nickel-metal hydride
   ii. Lithium iron phosphate
   iii. "best" battery for the purpose you can find in the table.

   If a range of parameter values is given in the table, use the worst case (i.e. least favorable) value. This ensures that a design will work even under worst conditions and your customers are happy. Summarize your results in the table below.

Operating condition	NiMH	LiPhosphate	Best
200 mA			
10 μA			
10-90 %			
1-99 %			