EGR326 F'09

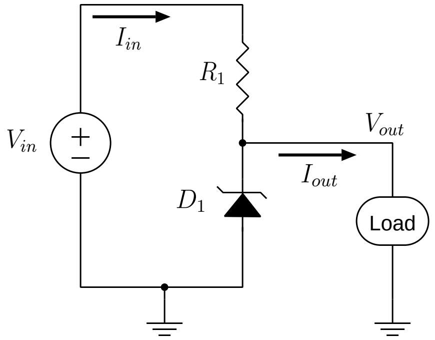
Exam #1

Solutions

1. **[15]** For the following power supply design requirements, **show your derivation** for the appropriate design and draw a schematic of the final circuit with all components labelled. You may use exact resistor values and not worry about rounding to commercially-available values.

   (a) A shunt regulator is to be designed to provide a 5.1V output at load currents of between 50mA-100mA from an input voltage of between 15V-18V. Assume at least 10mA of bias current is required for the zener diode.

   Copying the schematic from Problem 2:



   Choosing a 5.1V zener diode, it remains to design the resistance R_1. We must design for minimum input voltage and maximum load current:

$$\begin{aligned} R_1 &= \frac{15-5.1}{0.1+0.01} \\ &= 90\Omega \end{aligned}$$

   (b) A linear voltage regulator using an LM317 is to be designed to provide a 5.5V output voltage from a 7V-10V input at a load current of between 0.1A to 0.3A.

   The circuit of Figure 20 (page 19) in your lecture notes is appropriate. Using the design equation (which you have either memorized or easily derived):

$$V_{out} = 1.25 \cdot \left(1 + \frac{R_2}{R_1}\right)$$

   we can solve:

$$\begin{aligned} 5.5 &= 1.25\left(1 + \frac{R_2}{R_1}\right) \\ \frac{R_2}{R_1} &= 3.4 \end{aligned}$$

   Remember we can't make R_1 too low else there will be excessive power consumption. Since there will always be a load current of at least 0.1A, it doesn't matter (within reasonable limits) how large R_1 is as it doesn't need to provide a minimum current path for the regulator.

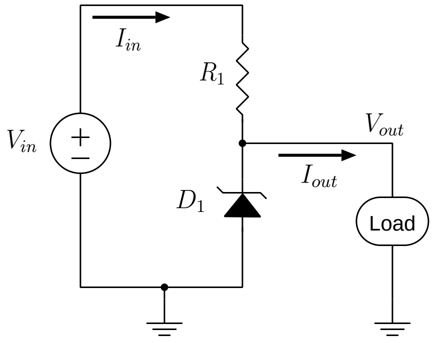
   So pick any values you want, as long as $R_2/R_1 = 3.4$.

   You may have noticed that 5.5V is not at least 2V below the minimum input voltage of 7V, i.e., we may have dropout problems.

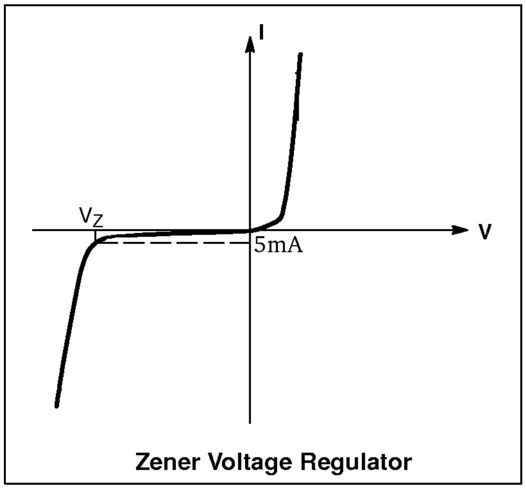
(c) A non-isolated flyback switching regulator is to be designed using only discrete components and a microcontroller for load and line regulation. The input voltage will be 3.3V and the output voltage is to be 5V.

Figure 53 (page 48) of your lecture notes is the appropriate topology, with a connection between the two ground references. This connection makes the regulator non-isolated, and it also simplifies the "observer" aspect of the design as you can now simply connect the output V_{out} directly to the controller block.

2. **[6]** A 5.1V shunt regulator is constructed as shown in the figure below.



The voltage source is a constant $V_{in} = 7$V and the resistor R_1 has been selected to have a value of 120Ω. The datasheet for the $V_z = 5.1$V zener diode D_1 has the I-V characteristic shown below.



Sketch a graph of V_{out} as a function of I_{out} for the voltage regulator for I_{out} in the range of 0mA to 30mA. The X-axis and Y-axis of your sketch must be marked with actual values and your sketch must properly correlate with values on both axes.

The key here is to find where the "knee" of the I-V curve of the diode maps onto the load regulation graph. As with all shunt regulators with constant voltage input, the current sourced by the input is constant:

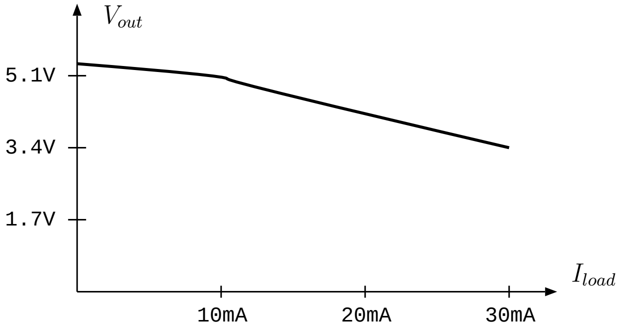
$$I_{in} = \frac{V_{in} - V_Z}{R_1} = \frac{7 - 5.1}{120} = 15.83\text{mA}$$

When the zener diode is conducting exactly 5mA, this means the load current is 10.8mA. Thus, the "knee" of the I-V curve appears at a load point of 10.8mA on our plot.

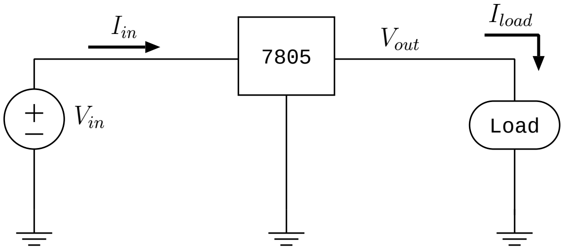
What happens beyond the knee? The zener diode is essentially off (i.e., conducts negligible current) and voltage follows the load line:

$$V_{out} = V_{in} - I_{load}R_1 = 7 - 120I_{load}$$

This voltage reaches 0 when I_{load} is 58mA. At 30mA (the highest current you were asked to plot) the voltage is 3.4V. This graph is a good approximation:



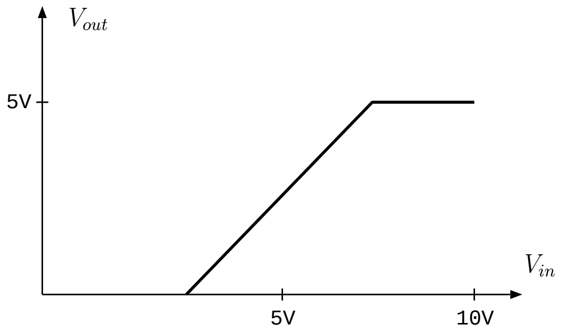
3. **[10]** Consider the following circuit.



Reproduce and complete the following graphs in your blue book.

(a) V_{in} is fixed at 10V. The 7805 has very good load regulation, thus we would expect its voltage to remain at 5V or very close to it throughout this load range, maybe sinking just a little bit.

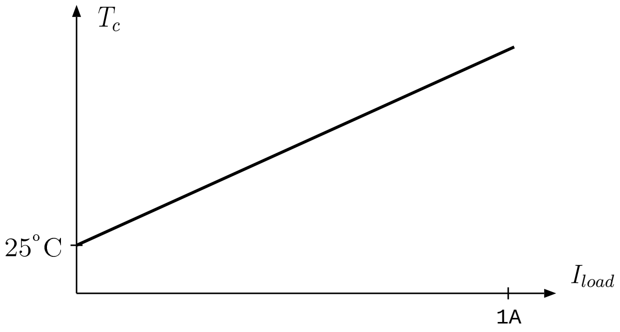
(b) I_{load} is 10mA. Here we observe the dropout voltage behavior of the 7805. You have to put in 7V (worst case) to get 5V out.



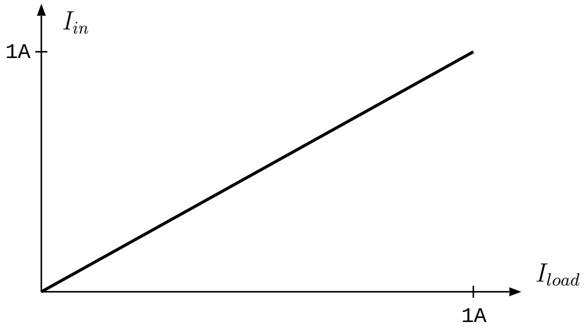
(c) V_{in} is fixed at 10V, T_c is case temperature. The power dissipation is:

$$P_d = (V_{in} - V_{out}) \cdot I_{load} = 5I_{load}$$

and you have seen in the lab that case temperature increases linearly with power dissipation at about 60^{O}C/W. At a load current of 1A, the power dissipation is 5W and we expect a temperature increase of about 300^{O}C. Perhaps not a very realistic problem (the 7805 will be destroyed or go into thermal shutdown before it gets to 1A), but the important part of your graph is the linear increase in temperature with power dissipation, hence linear increase in temperature with load current.



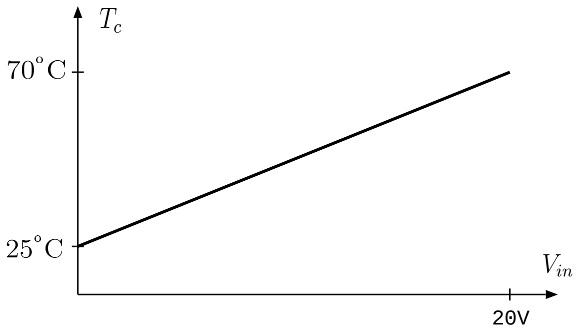
(d) V_{in} is fixed at 10V. The basic idea is that $I_{in} \approx I_{load}$, except for the small bias current that flows out the ground pin (a few mA).



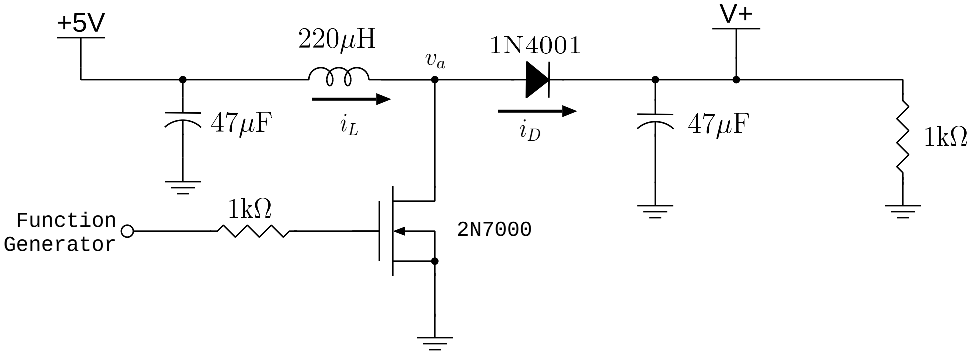
(e) I_{load} is fixed at 50mA, T_c is case temperature. Same equation as above, $P_D = (V_{in} - V_{out})\,I_{load}$ but in this case V_{in} is variable and I_{load} is fixed. Simplifying:

$$P_D = 0.05V_{in} - 0.25$$

When $V_{in} = 20$V then $P_D = 0.75$W and we expect a temperature increase of $\Delta T_c = 0.75 \cdot 60^{\text{O}}\text{C/W} = 45^{\text{O}}$C above ambient. Thus the temperature should rise to about 70^{O}C. The important part, however, was that once again you realize that temperature increases linearly with applied voltage.



4. **[9]** Consider the switching regulator shown below which is configured to boost the $+5$V input source to $V_+ = 12$V. The function generator has been configured for a 400 kHz square wave and it appears that a 50% duty cycle drives the output to exactly 12V under the given load condition (1kΩ load resistor).



(a) Sketch a graph of three periods of i_L as a function of time, labelling both X and Y axes with specific numbers (and proper units of course).

A frequency of 400 kHz means a period of 2.5μs, and a 50% duty cycle means the transistor will be on for 1.25μs and off for the same amount of time. When the transistor is on, $v_a \approx 0$ and the current in the inductor will be increasing according to:

$$\begin{aligned}\frac{di_L(t)}{dt} &= \frac{5}{220\mu\text{H}} \\ &= 22727\frac{A}{\text{s}}\end{aligned}$$

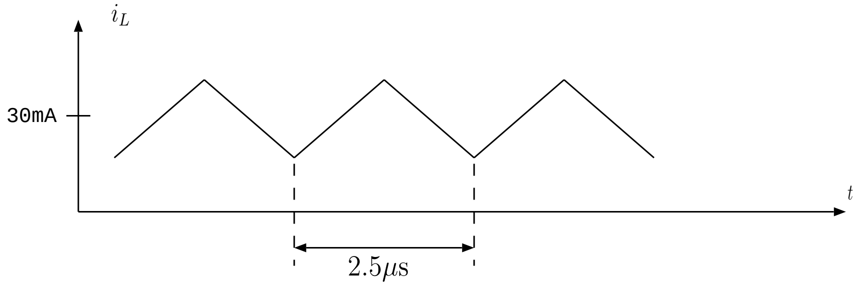
In 1.25μs we expect a current rise of about 28.4mA. Since the circuit is being kept in steady state by the controller, we expect the same amount of current decrease over the off-interval of the transistor.

So the inductor current bounces up and down by 28.4mA, but around what center value? As an estimate, consider the regulator to be 100% efficient so that $P_{out} = P_{in}$. Under this assumption:

$$\frac{12^2}{1\text{k}} = 5 \cdot I_{avg}$$

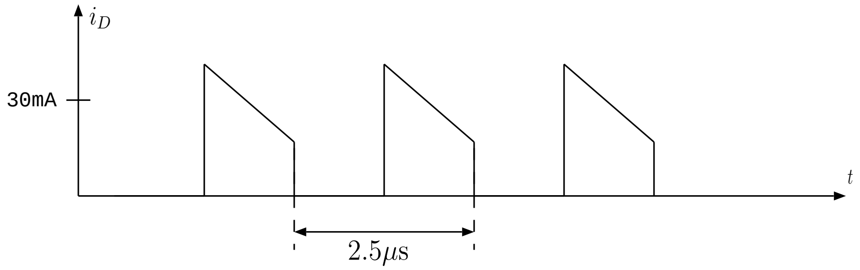
where I_{avg} is the average current delivered by the source. Solving, $I_{avg} = 28.8$mA. So to a first approximation, the inductor current varies between $(28.8 + 28.4/2)$ mA and $(28.8 - 28.4/2)$ mA. Very roughly. Important concepts are:

- Inductor current increases during on-time, decreases during off-time
- Inductor current oscillates around some non-zero average value
- Average value is in the ballpark of 30mA



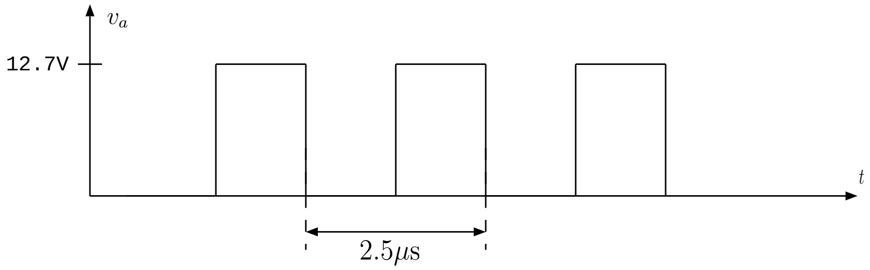
(b) Sketch a graph of i_D as a function of time, labelling both X and Y axes with specific numbers, and taking care to use the same scale as the graph of part (a) so that they span the same time range and are time-aligned.

The diode current is simply the inductor current during transistor off-times, as the inductor current has nowhere else to go. During transistor on-times, the diode is reverse biased and conducts no current.

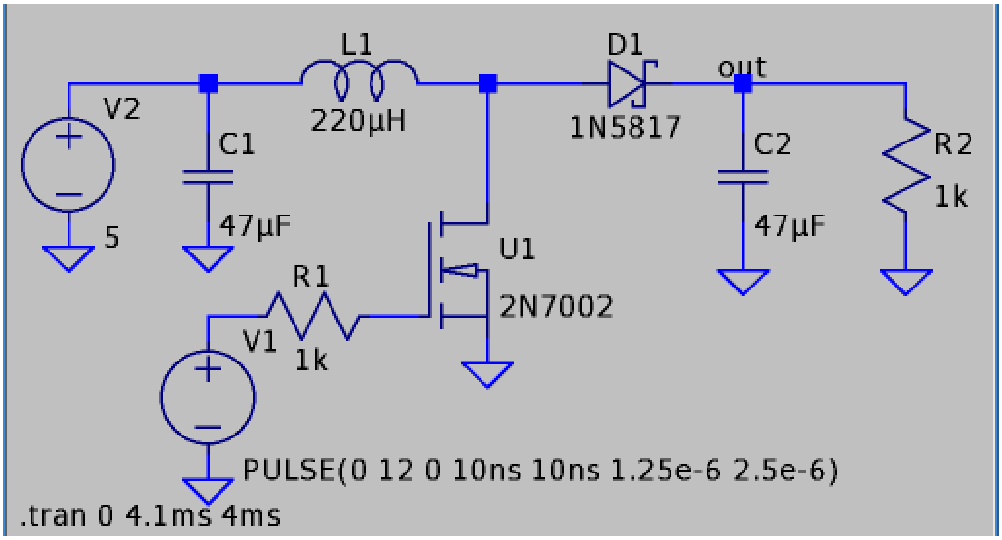


(c) Sketch a graph of v_a as a function of time, labelling both X and Y axes with specific numbers, and taking care to use the same scale as the graph of part (a) so that they span the same time range and are time-aligned.

During transistor on-times, $v_a \approx 0$. During on-times, v_a is about one diode drop above $V_{out} = 12$V so we could reasonably estimate $v_a = 12.7$V.



For some confirmation, here's an LTSpice simulation of the circuit:



(I cheated a bit and used a 1N5817 instead of a 1N4001). And here are the simulation waveforms. I underestimated the average current a bit but the waveform shapes are right.