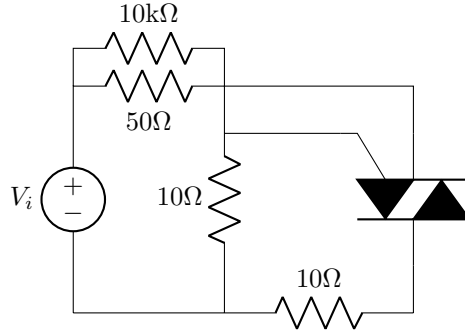


Physics 2250: Problem Set VII

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Problem 1. Consider the circuit below containing an ac voltage source, $V_i = \cos\left(\frac{2\pi}{T}t\right)$ V, and a triac device with a trigger voltage of $V_t = \pm 1$ V and holding current threshold of $I_H \approx 100\mu\text{A}$. $R_1 = 50\Omega$, $R_2 = 10\text{k}\Omega$, $R_3 = 10\Omega$, $R_L = 10\Omega$.



Solution 1.

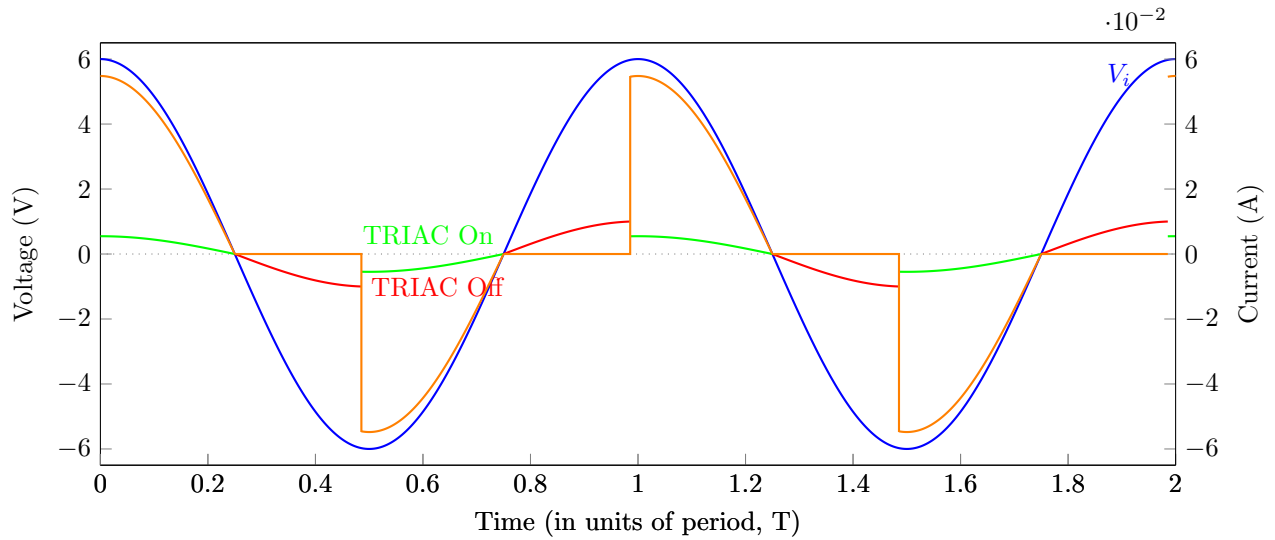
$$V_T = V_i - I_i (R_1^{-1} + R_2^{-1})^{-1}$$

$$I_L = I_i \left(\frac{R_3}{R_3 + R_L} \right)$$

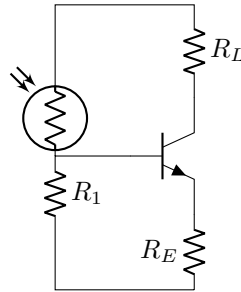
$$I_{ion} = \frac{V_i}{(R_1^{-1} + R_2^{-1})^{-1} + (R_L^{-1} + R_3^{-1})^{-1}} = \frac{V_i}{(R_1^{-1} + R_2^{-1})^{-1} + 5\Omega}$$

$$I_{ioff} = \frac{V_i}{(R_1^{-1} + R_2^{-1})^{-1} + R_3} = \frac{V_i}{(R_1^{-1} + R_2^{-1})^{-1} + 10\Omega}$$

$\cos(2\pi t)$ will start high, eg at 6V which logically means the device will turn on immediately which means a current of $\frac{V_i}{(R_1^{-1} + R_2^{-1})^{-1} + 5\Omega} \left(\frac{R_3}{R_3 + R_L} \right) = \frac{6\text{V}}{2 \cdot (49.75\Omega + 5\Omega)} = \frac{4}{73}\text{A}$. This (time-variant) current will continue to flow until $\cos(2\pi t) \approx 0$ at which point the triac will shut off as both current and gate voltage have dropped below their thresholds. The triac will next reactivate when $6 \cos(2\pi t) \left(1 - \frac{(R_1^{-1} + R_2^{-1})^{-1}}{(R_1^{-1} + R_2^{-1})^{-1} + 10\Omega} \right) = -1\text{V}$ and will remain active until the current again reaches $\approx 0\text{A}$. Then, the triac will reactivate at $V_t = 1\text{V}$ and the cycle repeats from there.

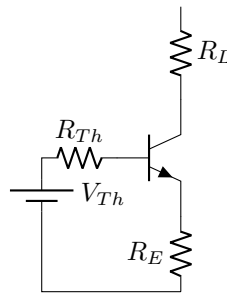


Problem 2. The circuit shown below controls the brightness of a smartphone screen (via R_L). It works such that when the photoconductive cell detects a high level of ambient light (e.g., when you are out in the sun) the base-emitter junction of the transistor becomes forward biased and automatically increases the brightness of the screen via power expended in R_L . The turning on/off only depends on how the resistance of the photoconductive cell (R_C) varies with the amount of light striking it. Notes: The voltage supply is $V_{CC} = 20V$; The resistors are: $R = 10k\Omega$, $R_L = 1k\Omega$, $R_E = 2k\Omega$; and the transistor has a forward-active working point voltage of $V_{CE} = 6V$ and gain $\beta = 50$.



Solution 2.

a) We can find the Thévenin equivalent of the right circuit with $R_{Th} = R_b = \frac{R_x R_1}{R_x + R_1}$ (I used R_x because I kept confusing C and L when writing this on paper) and $V_{Th} = V_b = \frac{V_{CC} R_1}{R_1 + R_x}$.



From there we can use KVL on the bottom loop $V_{CC} \frac{R_1}{R_1 + R_x} - I_b \frac{R_x R_1}{R_x + R_1} - 0.7 - (1 + \beta) I_b R_E \implies I_b = \frac{0.7 - \frac{V_{CC} R_1}{R_1 + R_x}}{-\frac{R_x R_1}{R_x + R_1} - (1 + \beta) R_E}$. Now, we are looking for when the transistor activates and allows current flow through R_L . This will occur when $V_b + 0.7V = V_e$ when the transistor is just barely active. I think (my understanding of

transistors is still very poor) that $V_e = V_{CC} - I_C R_L - V_{CE}$ so under that slightly educated assumption

$$\begin{aligned}\frac{V_{CC}R_1}{R_1 + R_x} + 0.7V &= V_{CC} - I_C R_L - V_{CE} \\ \frac{20R_1}{R_1 + R_x} + 0.7V &= 20 - \beta I_b R_L - 6 \\ \frac{20R_1}{R_1 + R_x} + 0.7V &= 20 - \beta \frac{0.7 - \frac{V_{CC}R_1}{R_1 + R_x}}{-\frac{R_x R_1}{R_x + R_1} - (1 + \beta) R_E} R_L - 6 \\ \frac{20R_1}{R_1 + R_x} + 0.7V &= 20 - \beta \frac{0.7 - \frac{V_{CC}R_1}{R_1 + R_x}}{-\frac{R_x R_1}{R_x + R_1} - (1 + \beta) R_E} R_L - 6 \\ R_x &\approx 11514\Omega\end{aligned}$$

b) It's difficult to be accurate as all the indicator lines are faded but it looks like the line fits well about a third of the way between 30 and 100 lx and at exactly 3kΩ so $\frac{3k\Omega - 100k\Omega}{53lx - 1lx} \approx -1865\Omega lx^{-1} \implies \Omega(l) = -1865\Omega lx^{-1}l + 101865\Omega$

Problem 3. Consider the circuit (not) below that uses a K-type thermocouple to measure and control the temperature of a reaction in a beaker. Power expended in the 50Ω load resistor RL is used to heat the reaction beaker. [$V_{cc} = 24V$, $R = 10\Omega$, $R_f = 5k\Omega$, and the BJT is made is of silicon, with an operating point of $V_{CE} = 6V$, $V_F = 0.7V$, and $\beta = 50$. A K-type thermocouple look-up voltage table is included in the lecture notes]

Solution 3.

a) $P = \frac{V^2}{R} = \frac{(V_{cc} - V_{ce})^2}{R_L} = 3.92W$

b) Using the lookup table a 22°C temperature corresponds to $V_{ref} = 0.879mV$. The load resistor drops $V_e = (1 + \beta) I_b R_L$ and we are looking to have an output from the subtractor op amp configuration that satisfies $V_e = V_b \implies (1 + \beta) I_b R_L = \frac{R_f}{R} (V_{TC} - V_{set})$. To find I_b we go from V_{cc} to ground $V_{cc} - V_{ce} - (1 + \beta) I_b R_L = 0 \implies I_b = 7.06mA$

$$\begin{aligned}(1 + \beta) I_b R_L &= \frac{R_f}{R} (V_{TC} - V_{set}) \\ 51 \cdot 7.0588mA \cdot 50\Omega &= \frac{5k\Omega}{10\Omega} (V_{TC} + 36mV) \\ V_{TC} &= 0\end{aligned}$$

c) $V_{lookup} = V_{TC} - V_{ref} = -0.879mV$ which doesn't really make any sense at all as when I looked up a bigger table that value corresponds to an output temperature of $-22.6687^\circ C$ which to my understanding of resistance is physically impossible. I've attached my work for this question and the others in case that helps my case here but I cannot seem to figure out getting an answer that makes sense.

d)