Instructions, notes, and hints:

You may make reasonable assumptions and approximations in order to compensate for missing information, if any. Provide the details of all solutions, including important intermediate steps. You will not receive credit if you do not show your work.

For all BJT problems, assume that $\beta = 150$, $V_{CE_{sat}} = 0.2 \text{ V}$, and $V_{BE} = 0.7 \text{ V}$ (if the BE junction is forward biased) when necessary unless otherwise specified. Also assume that the BJT is at room temperature. Note that some of the BJTs are $npn$ types and some are $pnp$ types. In many of the problems you will need to confirm the region of operation of the BJT.

Assignment:

1. Find each of the indicated node voltages in the circuit shown below, and determine the region of operation of the BJT.

   ![Circuit Diagram](image_url)

   - $V_{CC} = +3 \text{ V}$
   - $V_{EE} = -3 \text{ V}$
   - $R_1 = 91 \text{ k}\Omega$
   - $R_2 = 150 \text{ k}\Omega$
   - $R_E = 3.3 \text{ k}\Omega$
   - $R_C = 5.1 \text{ k}\Omega$

2. Design a bias network like the one shown in Fig. 6.61 of the textbook to meet the following specifications:

   - $V_{CC} \text{ and } -V_{EE} = \pm 6 \text{ V}$ (power supply voltages)
   - $V_C = 2 \text{ V}$ (quiescent voltage at the collector node)
   - $V_E = -2 \text{ V}$ (quiescent voltage at the emitter node)
   - $I_C = 100 \mu\text{A}$ (quiescent collector current)

   Assume that the nominal value of $\beta$ is 150. Use the closest standard 5% resistor values for all three resistors in the network.

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3. The resistor values in the circuit below have been chosen so that the BJT operates in the active region when $\beta = 100$. What is the value of $V_C$ when $\beta = 100$? Suppose the temperature changes and causes a corresponding change in the value of $\beta$. At what value of $\beta$ would the BJT just begin to operate in the saturation region? Assume that the resistor values are exactly equal to the values indicated in the figure.

4. Suppose in the previous problem that the resistors have 5% tolerances and that the value of $R_1$ is 5% higher than its nominal value and the value of $R_2$ is 5% lower. Try to find the value of $V_C$ when $\beta = 100$. What’s wrong? (In a real circuit, the value of $V_F$ would end up being something other than 0.7 V so that the circuit would work.)

5. Design a four-resistor BJT bias network (shown below) to meet the following specifications:

- $V_{CC} = 15$ V (power supply voltage)
- $V_C = 10$ V (quiescent voltage at the collector node)
- $I_C = 2$ mA (quiescent collector current)

Assume that the nominal value of $\beta$ is 200. Use the method described on p. 448 of the textbook and illustrated in Example 6.20 on p. 449 with a “voltage divider” current of $0.1I_E$. (The network formed by resistors $R_1$ and $R_2$ is not a true voltage divider because significant current flows into the base.) Adjust the value of $R_E$ as described in Example 6.30 so that the proper value of $I_E$ (or $I_C$) is obtained. Use the closest standard 5% resistor values for all four resistors in the network.
6. Repeat the previous problem using the biasing method described in class. That is, set $I_C R_C = V_{CE} = I_E R_E = V_{CC}/3$, assume $I_C \approx I_E$, and make the current through $R_2$ (call it $I_2$) equal to 10 times the base current. Assume a nominal value of 200 for $\beta$. Use the closest standard 5% resistor values for all of the resistors in the network.

7. Design a bias network like the one shown below for the same specifications as given in the two previous problems. Assume that $I_C \approx I_E$, and use a nominal value of 200 for $\beta$. Use the closest standard 5% resistor values for the resistors in the network.

8. Calculate the values of $I_C$ for the circuits designed in three previous problems for the cases when $\beta$ changes in value to 100 and 300 but the resistor values remain unchanged. Compare the new values of $I_C$ to the target values. (List them in a table.) Is one of the three biasing methods clearly superior to the others? Explain why or why not.

9. As shown in the diagram on the next page, a water level monitoring circuit used to control a basement sump pump is built using 4000-series CMOS logic gates. The monitoring circuit operates at 10 V and produces a logic 0 ($V_{alarm} = 0$ V) at its output when the water level is below a safe threshold and a logic level 1 ($V_{alarm} = 10$ V) if the water rises above the threshold. A relay is to be used to switch power to the sump pump (which operates at 120 Vrms AC and draws many amperes of current). However, the relay coil draws roughly 15 mA when 10 V is applied to it, and the output current of the CMOS monitoring circuit is limited to only 1 mA or less. Therefore, an npn BJT rated to handle the relay coil current will be used to switch the relay on and off. The BJT must operate in the cut-off region when the monitor’s output signal is low (0 V) since the pump must be off in that case. It must operate in the saturation region when the monitor’s output is high (10 V) and the pump is to be switched on.

The double lines next to the relay coil indicate that it is wound on an iron core and therefore operates as an electromagnet. When the coil is energized, it pulls down the movable conductor connected to the relay’s COM (for “common” terminal) so that it connects to the NO (for “normally open”) contact. A small spring holds the center conductor against the NC (for “normally closed”) contact when the relay is not energized. That is, the movable conductor is in the NC position when the relay is not energized and in the NO position when it is energized.

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The diode connected across the relay coil provides a safe path to dissipate the current surge that results when the coil is de-energized. It limits the voltage spike that would otherwise appear across the coil (and the BJT). The diode is included here to illustrate standard practice and has no impact on the solution to the problem. Note that the diode does not pass any current after the relay has been on or off for a while (i.e., when the coil’s magnetic field is not building or dissipating).

Your task is to find an appropriate value for resistor $R_B$ so that the circuit operates properly. The output current of the monitor must be kept below 1 mA, and the $\beta$ value of the BJT can range from 40 to 400. Before you select the final value for $R_B$, apply a ×2 safety factor; that is, ensure that the base current will be at least two times the maximum required value and less than one-half the minimum required value to ensure proper operation. The relay operates normally with any voltage from 8 V to 12 V across its coil.

10. Find the total power dissipated by the BJT in the previous problem when it is switched on (i.e., operating in the saturation region). Remember that power dissipation occurs whenever a current flows through a voltage drop.

Compare the power dissipated by the BE junction to that dissipated between the collector and emitter. A type 2N2222 npn transistor is rated to dissipate up to 800 mW of power. Could that type of BJT be used in this application, even if a ×2 power dissipation safety factor were applied?