ME 333 Introduction to Mechatronics
Winter 2011
Circuits Quiz

No books, calculators, computers, notes, etc. Just a pen or pencil. Show your work to receive full credit. If you can’t do a particular calculation without a calculator, such as $\sqrt{12.2}$, feel free to leave the mathematical expression without simplifying. Similarly, feel free to leave fractions.

1. Consider the circuit below. The switch has been closed (conducting) for a long time. The forward bias voltage of the diode, when it is conducting, is 0.7 V. According to the arrows shown (current is positive if it flows in the direction of the arrow), what are the currents $I_1$, $I_2$, and $I_3$ with the switch closed? Be sure to give the proper signs and units.

Now the switch is opened. Immediately after the switch is opened, what are the currents $I_1$, $I_2$, and $I_3$? According to the sign convention shown for the inductor voltage $V_L$, what is the voltage across the inductor right after the switch is opened? What is the rate of change of the current through the inductor, $dI_2/dt$? For all answers, give signs and units.

$I_1$: 0 A

$I_2$: 0.5 A

$I_3$: -0.5 A

$V_L$: -5.7 V

$dI_2/dt$: $-\frac{5.7}{5}$ A/s

Current through the inductor does not change discontinuously. Circuit becomes

$KVL: 0 = (0.5 A)(10\Omega) + V_L + 0.7 V$

$V_L = -5.7 V = L \frac{dI_2}{dt}$

$\frac{dI_2}{dt} = \frac{-5.7 V}{5 \Omega} = -\frac{5.7}{5}$ A/s
2. For the circuit shown below, give the voltage $V_A$, the current provided by the 10 V battery, and the power provided by the battery. Give units.

\[ V_A: \quad \frac{25}{6} \text{ V} \]

\[ \text{current:} \quad I_1 = \frac{35}{12} \text{ A} \]

\[ \text{power:} \quad (10 \text{ V}) I_1 = \frac{175}{6} \text{ W} \]

KCL: \quad I_1 = I_2 + I_3

KVL: \quad 10 - 2I_1 - 2I_2 = 0 \quad \quad \text{and} \quad 10 - 2I_1 - 5I_3 = 0

Solve these 3 linear equations in 3 variables to get:

\[ I_1 = \frac{35}{12} \text{ A}, \quad I_2 = \frac{25}{12} \text{ A}, \quad I_3 = \frac{5}{6} \text{ A} \]

\[ V_A = 2I_2 = 5I_3 = \frac{25}{6} \text{ V} \]

3. In the circuit below, plot the voltage $V_{out}$ as a function of the input voltage $V_{in}$, where $V_{in}$ takes values between -2 V and 2 V. The diode drop is 0.7 V when it is conducting current.

\[ V_{out} \quad \text{(Volts)} \]

\[ V_{in} \quad \text{(Volts)} \]

\[ \text{diode does nothing; voltage divider} \]

\[ \text{diode turns on, keeps} \]

\[ V_{out} = V_{in} - 0.7 \text{ V} \]
4. In the circuit below, the gain of the npn bipolar junction transistor is \( \beta \) when it is in the linear regime. When the transistor is on, the voltage drop from the base B to the emitter E is \( V_{BE} \). When the transistor is saturated, the voltage drop from the collector C to the emitter E is \( V_{CE} \). Using this information, find the range of voltages \( V_{in} \) where the transistor is off; the range of voltages \( V_{in} \) where the transistor is in its linear regime; and the range of voltages \( V_{in} \) where the transistor is saturated. Your answers should be in terms of (some subset of) \( V_s \), \( \beta \), \( R \), \( V_{BE} \), and \( V_{CE} \).

![Circuit Diagram]

\( V_{in} \) range where transistor is off:

\[ V_{BE} \leq V_{in} < \frac{2}{\beta} \left( V_s - V_{CE} \right) + V_{BE} \]

\( V_{in} \) range where transistor is in linear regime:

\[ V_{in} \geq \frac{2}{\beta} \left( V_s - V_{CE} \right) + V_{BE} \]

\( V_{in} \) range where transistor is saturated:

\[ V_{in} \leq V_{BE} \]

Transition point between linear and saturated:

\[ R \beta I_2 + V_{CE} = V_s \]

\[ I_2 = \beta I_1 \]

\[ I_1 = \frac{V_{in} - V_{BE}}{2R} \Rightarrow R \beta \left( \frac{V_{in} - V_{BE}}{2R} \right) + V_{CE} = V_s \]

\[ V_{in} - V_{BE} = \frac{2}{\beta} \left( V_s - V_{CE} \right) \]

\[ V_{in} = \frac{2}{\beta} \left( V_s - V_{CE} \right) + V_{BE} \]

Larger values: saturated

Smaller values: linear
5. (In this problem, the forward bias voltage of the diode is 0 V when it is conducting.) Consider the circuit below. In one case, $V_{in}$ has been held at a positive value for a long time, and then it drops to 0 V. In the other case, $V_{in}$ has been held at 0 V for a long time, and then switches to a positive value. Approximately plot $V_{out}$ for each case. Put a numerical time scale on your plots.

\[ \Delta t = R \cdot C = (5 \times 10^{-3})(1 \times 10^{-6}) = 5 \times 10^{-9} \text{s} \]

6. In the circuit below, find $I_1, I_2, I_3$, and $V_{out}$ as a function of $V_{in}, R_1, R_2, R_3$, and $R_4$.

\[ I_2 = I_3 = 0 \text{ by property of op amp} \]

\[ V^+ = V_{in} \frac{R_2}{R_1 + R_2} \text{ solve voltage divider because of negative feedback} \]

\[ V^- = V^+ = V_{in} \frac{R_2}{R_1 + R_2} \]

\[ V_{out} = -I_1(R_3 + R_4) \]

\[ V^- = -I_1R_3 = \frac{V_{in}R_2}{R_1 + R_2} \]

So \[ I_1 = -\frac{V_{in}R_2}{R_3(R_1 + R_2)} \]

\[ V_{out} = \frac{V_{in}R_2(R_3 + R_4)}{R_3(R_1 + R_2)} \]