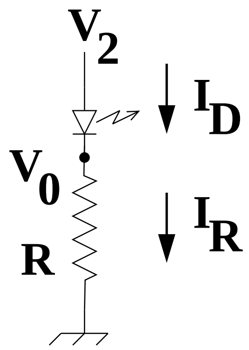
Embedded Systems (AME 3623)
Homework 2 Solutions

March 8, 2011

Question 1

Consider the following circuit:



Assume that $V_f = 1.5V$ (the forward voltage of the diode).

1. (10pts) What equations are always true, no matter the state of the diode? (i.e., what are the fundamental equations?)

$$\begin{aligned} V_0 - 0 &= RI_R \\ I_D &= I_R \end{aligned}$$

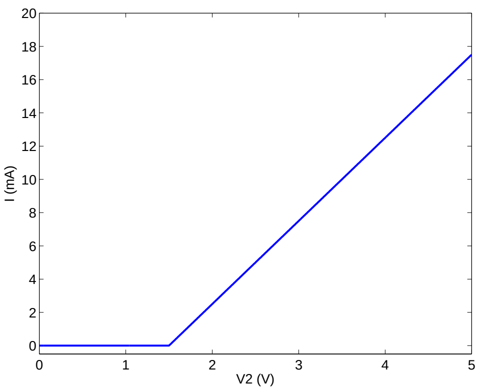
2. (15pts) At what V_2 does the diode begin to conduct current?

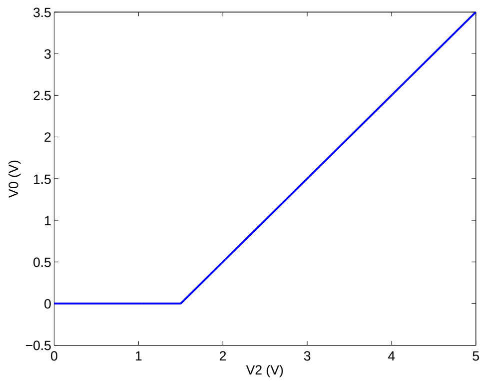
   The diode conducting current implies that: $V_2 - V_0 = V_f$.

   "Beginning to conduct current" implies that I_D is very small. This means that the voltage drop across the resistor is very small, i.e. $V_0 \approx 0$.

   Therefore: $V_2 \approx V_f$

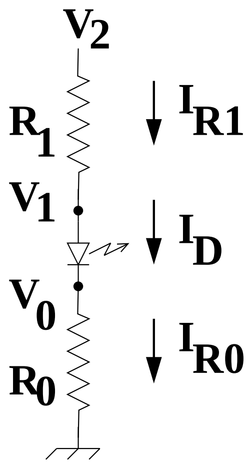
3. (10pts) Assume that $R = 200\Omega$. Draw V_0 and I_D as a function of V_2. (use separate figures)





Question 2

Consider the following circuit:



1. (10pts) What equations are always true, no matter the state of the diode? (i.e., what are the fundamental equations?)

$$\begin{aligned} V_2 - V_1 &= R_1 I_{R1} \\ V_0 - 0 &= R_0 I_{R0} \\ I_{R1} &= I_D \\ I_{R0} &= I_D \end{aligned}$$

2. (15pts) At what V_2 does the diode begin to conduct current?

   The diode conducting current implies that: $V_1 - V_0 = V_f$.

   "Beginning to conduct current" implies that I_D is very small. This means that the voltage drop across the resistors is very small, i.e. $V_0 \approx 0$ and $V_1 \approx V_2$.

   Therefore: $V_2 \approx V_f$

3. (10pts) Assume that $R_0 = 500\Omega$ and $R_1 = 200\Omega$. Draw V_0 and V_1 (one figure) and I_D (second figure) as a function of V_2.

   Combining all of the fundamental equations:

$$\begin{aligned} V_2 - V_1 + V_0 &= R_1 I_{R1} + R_0 I_{R0} \\ &= (R_1 + R_0) I_D \end{aligned}$$

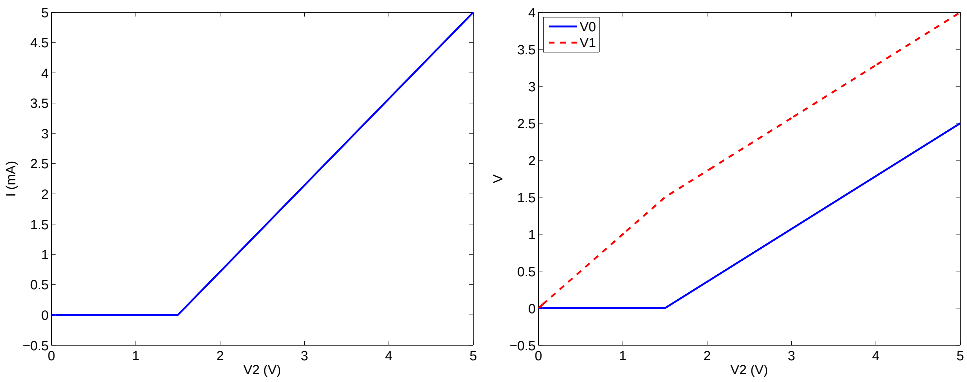
   When the diode conducts current:

$$\begin{aligned} V_2 - V_f &= (R_1 + R_0) I_D \\ I_D &= \frac{V_2 - V_f}{R_1 + R_0} \end{aligned}$$

   When the diode is not conducting current:

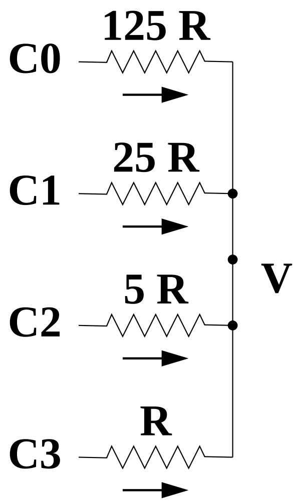
$$\begin{aligned} V_1 &= V_2 \\ V_0 &= 0 \end{aligned}$$

   Therefore:



Question 3

Consider the following circuit:



1. (10 pts) What are the fundamental equations that determine V and other associated unknown variables? (i.e., give the equations that are derived directly from fundamental electronic principles).

   For each resistor:

   $5C_i - V = 5^{3-i} R I_i$

   Kirchhoff's current law:

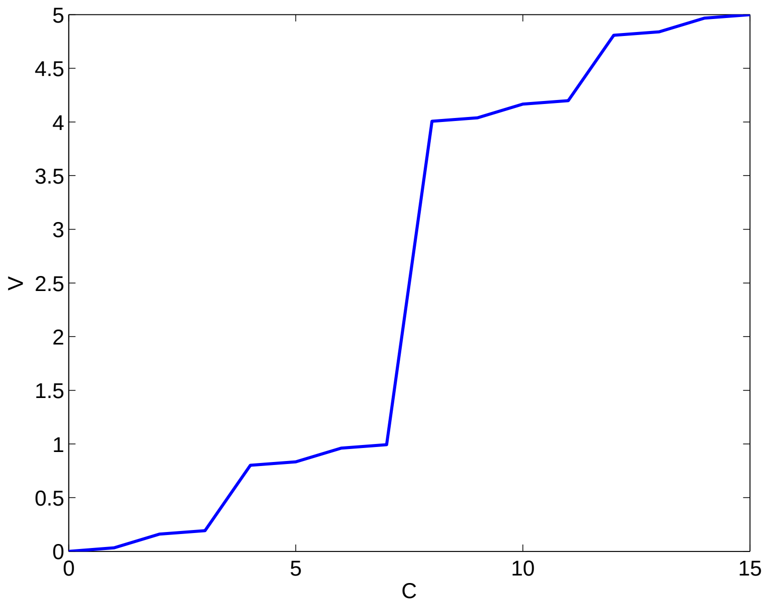
   $\sum_{i=0}^{3} I_i = 0$

2. (10 pts) Derive an equation for V in terms of the known variables.

$$\begin{aligned}
\sum_{i=0}^{3} \frac{5C_i - V}{5^{3-i} R} &= 0 \\
\sum_{i=0}^{3} \frac{5C_i}{5^{3-i}} &= \sum_{i=0}^{3} \frac{V}{5^{3-i}} \\
5 \sum_{i=0}^{3} \frac{C_i}{5^{3-i}} &= V \sum_{i=0}^{3} \frac{1}{5^{3-i}}
\end{aligned}$$

$$
\begin{aligned}
5\sum_{i=0}^{3} C_i\, 5^i &= V \sum_{i=0}^{3} 5^i \\
V &= 5\left(\sum_{i=0}^{3} C_i\, 5^i\right) / \sum_{i=0}^{3} 5^i \\
&= \frac{5}{156}(C_0 + 5C_1 + 25C_2 + 125C_3)
\end{aligned}
$$

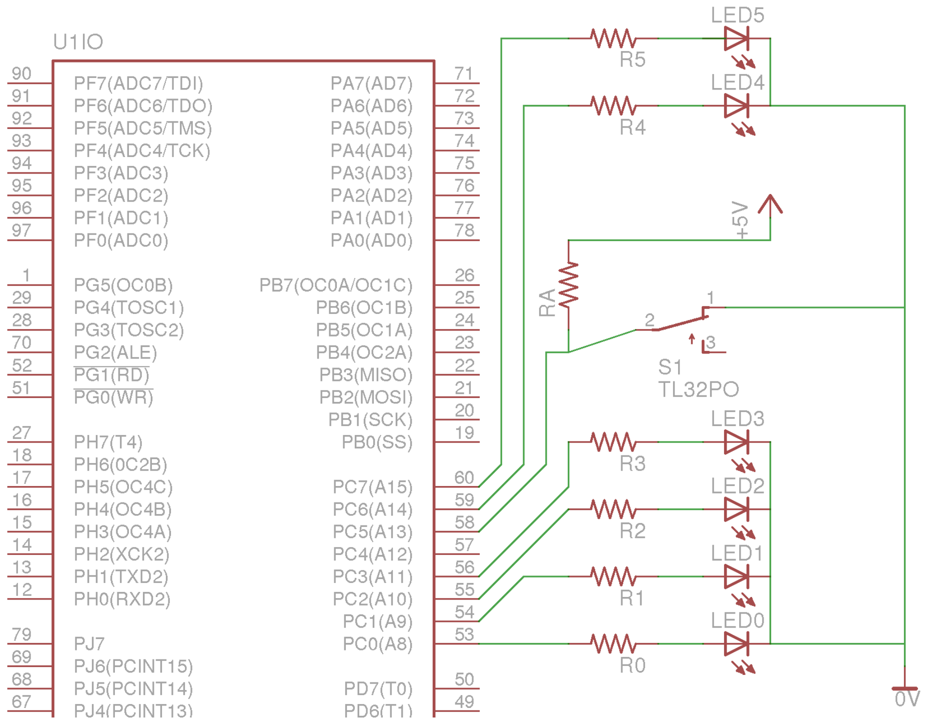
3. (10 pts) Show in graph form V as a function of the binary number C.



Lesson: the factors of two in our original design are critical.

Question 4

Consider the following circuit:



and consider the associated program:

```
int main (void)
{
  DDRC = 0xCF;
  PORTC = 0;
  uint8_t count = 0;

  while(1) {
    while(PINC & 0x20) {};                          // Inner loop
    PORTC = (PORTC & 0xF0) | (count & 0xF);         // Set LEDs
    delay_ms(50);
    ++count;
  };
}
```

1. (10 pts) Briefly explain the behavior of the inner while loop.

   The code will stop and wait for the switch to be "closed" (i.e. it waits for the pin to be connected to ground).

2. (10 pts) At what frequency and duty cycle does LED0 flash?

   When the switch is closed: Duty cycle = 50%; Frequency = $10Hz$

   When the switch is open: the LED does not flash

3. (10 pts) At what frequency and duty cycle does LED2 flash?

   When the switch is closed: Duty cycle = 50%, Frequency = $2.5Hz$

   When the switch is open: the LED does not flash

4. (10 pts) At what frequency and duty cycle does LED5 flash?

   LED5 does not flash (it is off all of the time).

5. (20 pts) Suppose we wanted to use the first 6 bits of the counter to drive the LEDs (as opposed to just the first 4 bits). Modify the *set LEDs* line so that we accomplish this.

   Now: we need to also set LED4 and LED5. This requires 2 change, first we need to also mask these two pins out (C6 and C7). Then, we need to shift bits 4 and 5 of the counter so that they align with C6 and C7.

   ```
   PORTC = (PORTC & 0x30) | (count & 0xF)
                          | ((count & 0x30)<<2) ;
   ```