SI100B – Electrical Engineering, 2023 Spring

Homework #1

Notes:

1. The submission deadline is 2023-04-16 23:59:59. Late assignments will incur a 10-point deduction per day.
2. You must work on this homework individually. Any plagiarism will result in a zero grade for this assignment.
3. You can either type your answers in a word document or handwrite them and scan them as a pdf file.
4. The simulation files that support your analysis should be named according to the problems. You can zip them together with your solutions into a single file.

Problem 1. Circuit analysis (45 points)

For this problem, you need to apply the circuit principles you have learned to analyze the voltage and current in the circuit.

1) Based on the circuit shown in Fig. 1-1, write down the KVL and KCL equations. **(15 points)**

2) Using the equations you wrote, find the resistor currents i_1, i_2, i_3, i_4, and the voltage drops across the resistors v_1, v_2, v_3, v_4. Given: $V_s = 20V$, $I_s = 1A$, $R_1 = R_2 = 2\Omega$, $R_3 = R_4 = 4\Omega$. **(15 points)**

3) Use a simulation software (MATLAB, Multisim, or any other software you prefer) to verify your results. **(15 points)**

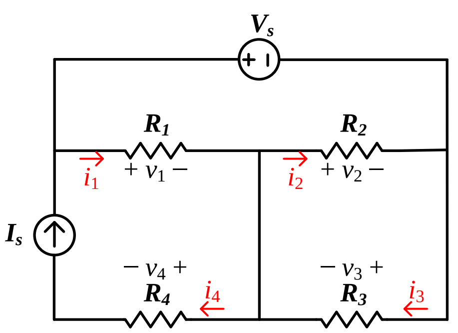


Fig. 1-1

(Hint: You should show all the equations you used to solve the circuit. Zip the simulation file and the answer into a single file.)

Solution:

1):

$$\begin{cases} i_4 = I_s \\ i_1 + i_3 = i_2 + i_4 \\ i_1 R_1 + i_2 R_2 = V_s \\ i_2 R_2 + i_3 R_3 = 0 \end{cases} \tag{1.1}$$

2):

By substituting the given conditions into equation set (1.1), we obtain

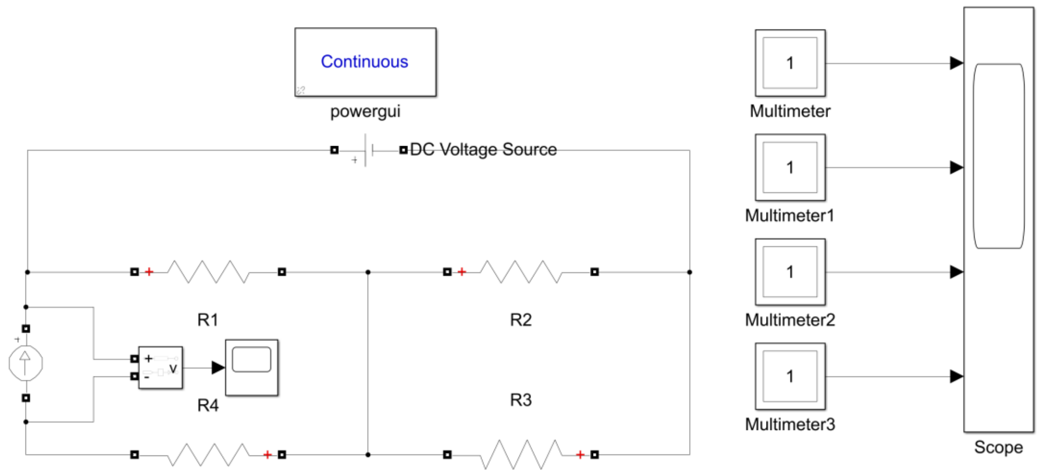
$$\begin{cases} i_1 = 6.4\text{A} \\ i_2 = 3.6\text{A} \\ i_3 = -1.8\text{A} \\ i_4 = 1\text{A} \end{cases} \tag{1.2}$$

According to Ohm’s law,

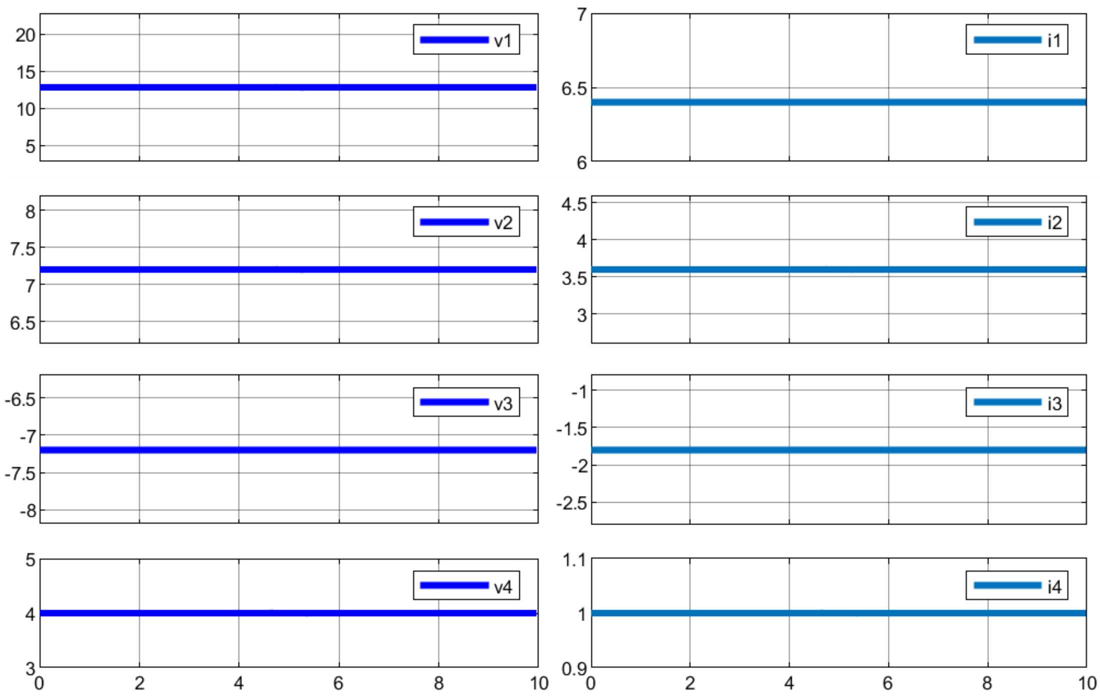
$$\begin{cases} v_1 = i_1 R_1 = 12.8\text{V} \\ v_2 = i_2 R_2 = 7.2\text{V} \\ v_3 = i_3 R_3 = -7.2\text{V} \\ v_4 = i_4 R_4 = 4\text{V} \end{cases} \tag{1.3}$$

3):

The simulation model built in Simulink:



Simulation results:



Problem 2. Diode Circuits (30 points)

You need to design an LED lamp circuit using a LED, a voltage source ($V_s = 6V$) and some resistors. The LED has a maximum current rating of $I_{max} = 20mA$. To prevent the LED from burning out, you need to add a current limiting resistor R_s. See Fig. 2-1 for the circuit diagram. Fig. 2-2 and Fig. 2-3 show the **RELATIVE LUMINOUS INTENSITY-FORWARD CURRENT** and **FORWARD CURRENT-FORWARD VOLTAGE** characteristics of the LED, respectively.

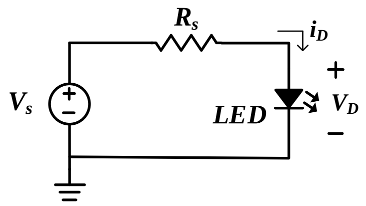


Fig. 2-1

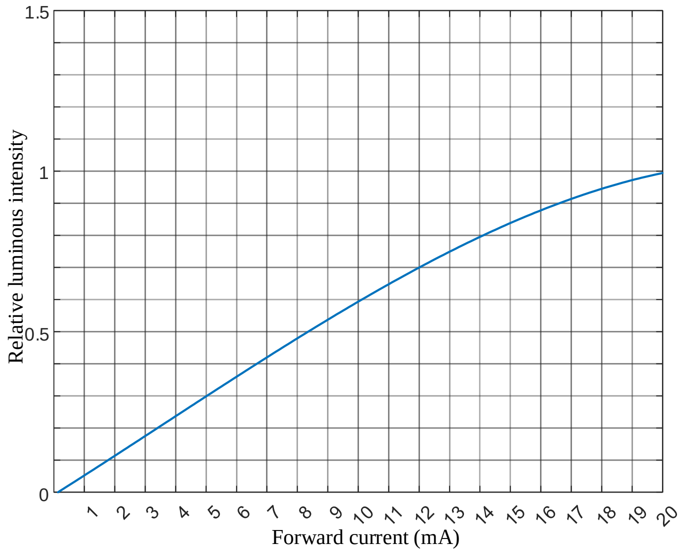


Fig. 2-2 Relative luminous intensity-current

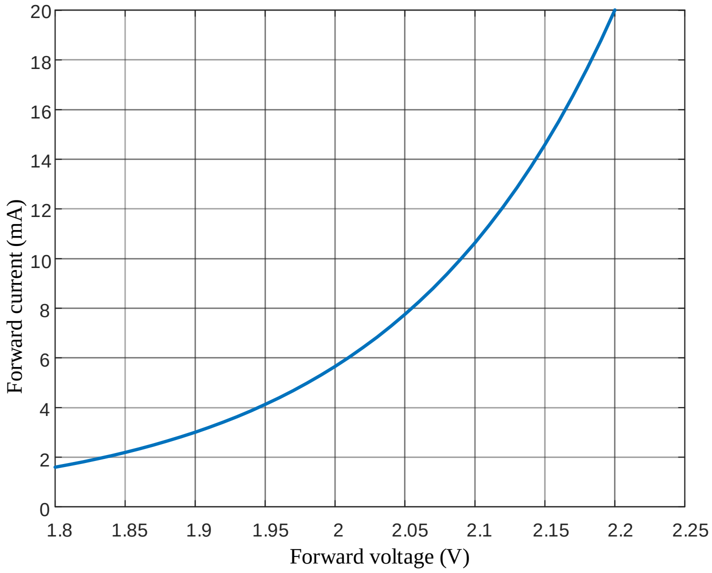


Fig. 2-3 I-V characteristic

1) To make the LED operate at a relative luminous intensity of 0.6, find the forward voltage and the value of R_S. **(15 points)**

(Hint: You only need to calculate the approximate value.)

2) If $R_S = 400\Omega$, what are the voltage drop, forward current, and relative luminous intensity of the LED in this case? **(15 points)**

(Hint: You can use the load-line analysis method from the reference book EEPA Chapter 9.2 to help you determine the diode operating point.)

Solution:

1):

From Fig. 2-2, we can see that the LED needs a forward current of 10 mA to work at a relative luminous intensity of 0.6. From Fig. 2-3, we can find that the corresponding forward voltage is about 2.06V. Thus, the value of R_S can be calculated as

$$R_s = \frac{V_s - V_D}{i_D} = \frac{6\text{V} - 2.06\text{V}}{10\text{mA}} = 394\Omega \tag{2.1}$$

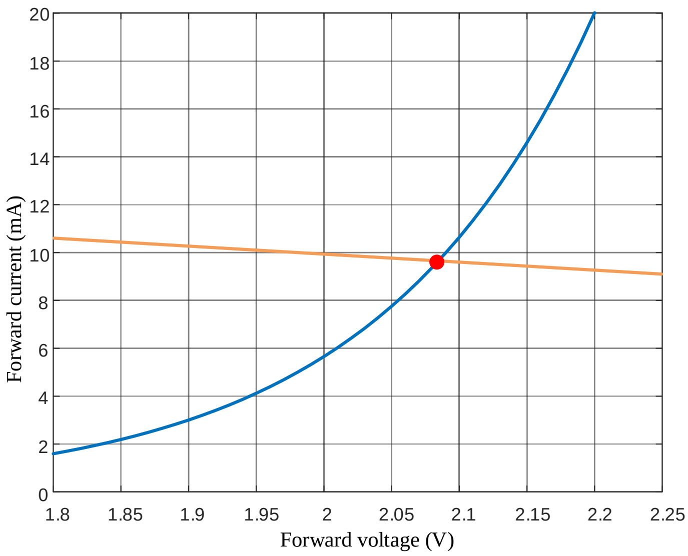
2):

According to KVL,

$$V_D + i_D R_s = V_s \tag{2.2}$$

Consider that current is measured in milliamperes, voltage is measured in volts, (2.2) can be rewritten as

$$i_D = -\frac{V_D}{R_s} + \frac{V_s}{R_s} = -\frac{V_D}{400} + \frac{6}{400}(\text{A}) = -2.5V_D + 15(\text{mA}) \tag{2.3}$$



Results:

$$2.05\text{V} < V_D < 2.1\text{V}, \quad 9\text{mA} < i_D < 10\text{mA} \tag{2.4}$$

Based on the forward current i_D and Fig. 2.2,

$$0.5 < \text{Relative luminous intensity} < 0.6 \tag{2.5}$$

Problem 3. CMOS (25 points)

You have learned how to make two-input CMOS NAND and NOR gates in class. In this problem, you need to design a two-input CMOS AND gate.

1) Draw the circuit diagram of a two-input CMOS AND gate. **(5 points)**

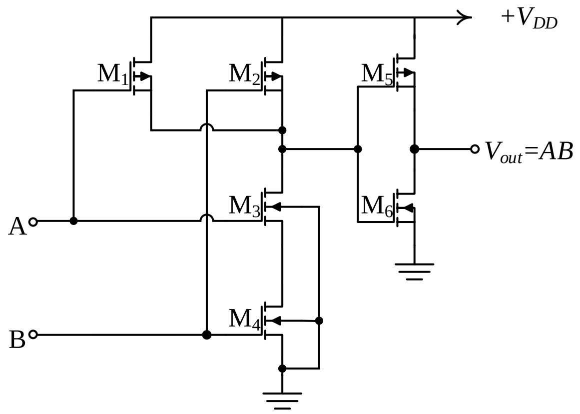
2) Show a truth table for the AND gate. **(5 points)**

3) Draw the equivalent circuits of the AND gate for: **a.** A high and B high; **b.** A high and B low; **c.** A low and B low. **(15 points)**

(Hint: You can refer to Figure 11.34 from the reference book EEPA Chapter 11.7.)

Solution:

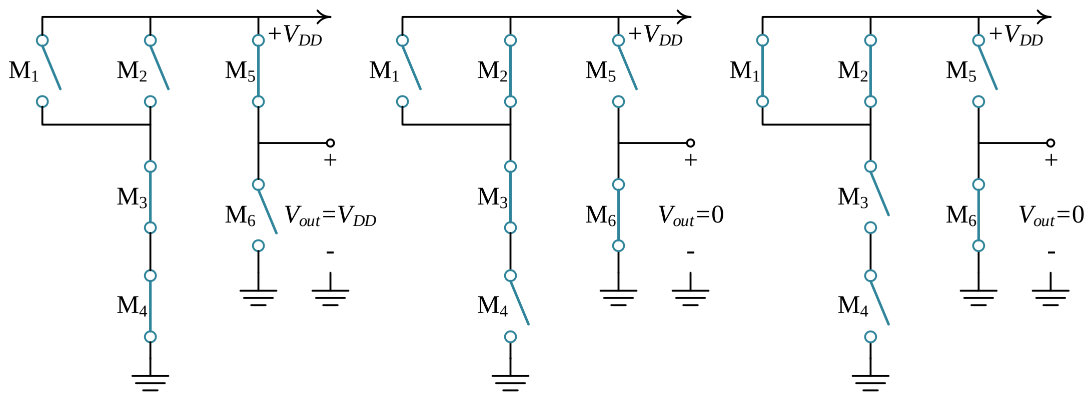
1): AND gate can be obtained by connecting NAND gate and NOT gate in series.



2):

A	B	V_{out}
High	High	High
High	Low	Low
Low	High	Low
Low	Low	Low

3):



(a) A and B both high (b) A high and B low (c) A low and B both low

Bonus question (10 points)

You can earn some bonus points for this homework (up to a total score of 100) if you answer the following questions reasonably. You can search the Internet for more information if you are interested in these topics.

1) Actually, we can use the Shockley diode equation to describe the relationship between current and voltage for diodes

$$i = I_s(e^{qv/nkT} - 1)$$

Where i is the current through the diode, I_s is the reverse saturation current ($I_s = 1.5 \times 10^{-9}$ A), e is the natural logarithm base, q is the charge on an electron ($q = 1.602 \times 10^{-19}$ C), v is diode voltage, n is the ideality factor (n=4 for this case), k is Boltzmann's constant ($k = 1.380 \times 10^{-23}$ J/K), T is the temperature in kelvin (T=300K).

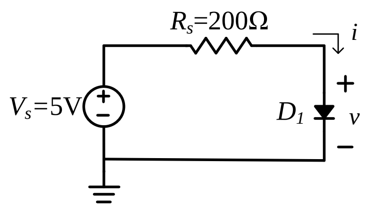


Fig. 4-1

Use this equation to find the diode current and voltage in Fig. 4-1. **(10 points)**

(Hint: You should use mathematical tools like MATLAB to solve the equations. If you do so, please include your codes in your submission.)

Solution:

$$\begin{cases} i = I_s(e^{qv/nkT} - 1) \\ iR_s + v = V_s \end{cases} \quad (4.1)$$

$$\begin{cases} i = 0.0166\text{A} \\ v = 1.6767\text{V} \end{cases} \quad (4.2)$$

***MATLAB CODE*:**

```
syms v

Is = 1.5e-9;
q = 1.602e-19;
n = 4;
k = 1.38e-23;
T = 300; % constant

f = 200*Is*(exp(q*v/n/k/T)-1) + v -5 == 0; % circuit equation
v = solve(f,v); % solve the equation
v =vpa(v,6) % Set the solving precision, with 6 significant digits
```