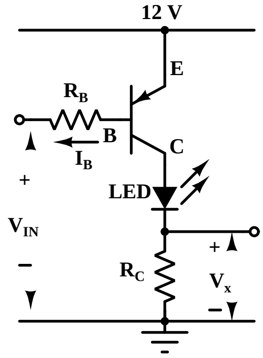
Solution to EE Quiz-2,
MS-101 Makerspace: Autumn Semester 2023

Q–1 Consider an LED being driven by a pnp transistor as shown in the circuit below.



a) Assume that values of V_{IN} and R_B are chosen such that the transistor is in saturation and $|V_{CEsat}|$ for the transistor is 0.2 V.

Find the value of R_C such that a current of 30 mA passes through the LED. Assume that the drop across the LED when 30 mA of current passes through it is 2.8 V.

What is the value of the voltage V_x in this case?

Calculation Steps:

$$V_x = 12 - V_{EC} - V_{LED} = 12 - 0.2 - 2.8 = 9 \text{ V}$$

For $I_C = 30$ mA, $R_C = 9$ V/30 mA $= 300\ \Omega$.

Answer:

$\boxed{\mathbf{R_C} = 300\ \Omega}$

$\boxed{\mathbf{V_X} = 9 \text{ V}}$ – [4]

b) Assume that the current gain β of the transistor is 30 and $|V_{BE}|$ is 0.8 V. If $V_{IN} = 6$ V, What is the maximum value of R_B for which the pnp transistor will remain saturated?

Calculation Steps: by KVL: voltage across R_B is $V_{CC} - V_{EB} - V_{IN} = 12 - 0.8 - 6 = 5.2$ V.
For the transistor to be saturated,
$I_B \geq 30 \text{ mA}/\beta = 30 \text{ mA}/30 = 1$ mA.
Therefore $R_B \leq 5.2 \text{ V}/1 \text{ mA} = 5200\Omega$

Answer:

$\boxed{\text{Max. } \mathbf{R_B} = 5200\ \Omega}$

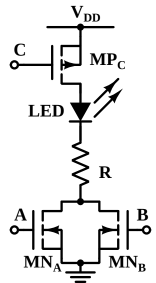
– [2]

– **[Q1: 4 + 2 = 6 marks]**

Q–2 Current through an LED is controlled using two enhancement mode nMOS transistors and an enhancement mode pMOS transistor as shown in the circuit below.

Voltages at A, B and C represent logic values and are at 0 V or at V_{DD} depending on the logic value being '0' or '1' respectively.

MOS transistors MN_A, MN_B and MP_C are either OFF or fully ON for digital input values, depending on the voltage and the type of the transistor (nMOS or pMOS).



a) Fill in the state of the LED in the table below corresponding to combinations of ON and OFF states for MN_A, MN_B and MP_C. Use 1 for LED being lit and 0 for LED unlit.

Answer: For the LED to light up, either or both of MN_A and MN_B must be ON, AND MP_C must also be ON.

MN_A	MN_B	MP_C	LED	MN_A	MN_B	MP_C	LED
OFF	OFF	OFF	0	OFF	OFF	ON	0
OFF	ON	OFF	0	OFF	ON	ON	1
ON	OFF	OFF	0	ON	OFF	ON	1
ON	ON	OFF	0	ON	ON	ON	1

– **[2]**

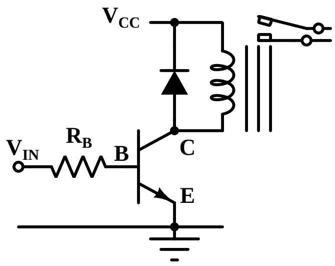
b) Find the logic expression which is TRUE whenever the LED is lit, as a function of **digital input values** of A, B and C.
(n channel MOS transistors MN_A/MN_B are ON when A/B = 1 while the p channel MOS transistor MP_C is ON when C = 0).

Answer: Logic expression is: $\boxed{(A+B)\cdot\overline{C}}$ – **[2]**

– **[Q2: 2 + 2 = 4 marks]**

Q–3 A relay is driven using an npn transistor.

The supply voltage V_{CC} is 12 V and the coil resistance is 600 Ω. A flywheel diode is used in the circuit as shown. To activate the relay, the transistor is turned ON by taking the input voltage V_{IN} to V_{CC} = 12 V. The value of R_B is so chosen that the transistor is saturated when 12 V is applied to the input and V_{CE} = 0.2 V in this case.



a) What is the current in the relay coil when the transistor is ON?

$$I = \frac{V_{CC} - V_{CEsat}}{R_{coil}} = \frac{(12-0.2)}{600} = 19.67 \text{ mA}$$

Answer: 19.67 mA

– **[2]**

b) What should be the current rating for the flywheel diode?
(Since current through an inductor cannot change instantaneously, max. current through the diode is equal to the current flowing through the transistor when it is cut off. Diode current rating should be ≥ this value.)

Answer: ≥ 19.67 mA

– **[1]**

– **[Q3: 2 + 1 = 3 marks]**

Q–4 A DC motor is driven using a +10 V supply and rotates at some speed under no load. When it is coupled to a load, its speed reduces. For this loaded condition, what will be the changes to the armature current I_a and the back emf E_b? Choose the most appropriate option from the following:

When the motor is loaded:
A) Both I_a and E_b increase.
B) Both I_a and E_b decrease.
C) I_a increases but E_b decreases.
D) I_a decreases but E_b increases.

Answer:

~~A~~ / ~~B~~ / C / ~~D~~

(strike out the wrong options)

– **[Q4: 1 mark]**

Q–5 Using the built-in 10 bit A to D converter in the micro-controller used in Arduino cards, a set of analog voltages have been measured using the default reference voltage of 5.0 V. The output of the ADC is found to lie in the range 95 to 240.

a) We want to represent each reading in terms of percentage of the range by which it lies above the minimum reading, with 0% representing 95 and 100% representing 240. Show how we can use the library function **"map"** for this. Give the **full statement** we should use in a sketch to convert a given reading stored in variable x (of type int) to the corresponding *percentage* value to be stored as y?
Answer:

y = map(x, 95, 240, 0, 100);

– [**2**]

b) To improve the resolution of these measurements, we can use the internal voltage reference of 1.2 V. What is the range of ADC values in which we expect the same set of measurements to lie when the internal reference of 1.2 V is used?
Answer:

New Min. value $= 95 \times 5/1.2 = 396$, New Max. value $= 240 \times 5/1.2 = 1000$

(ADC values are integers) – [**4**]

c) Give the **full statement** we should include in the sketch to make the function call in order to switch the reference voltage from the default 5.0 V to the internal reference of 1.2 V.
Answer:

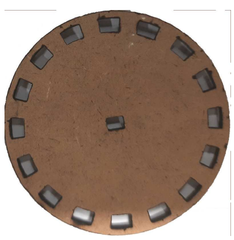
analogReference(INTERNAL);

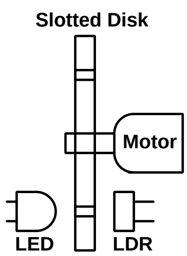
– [**1**]

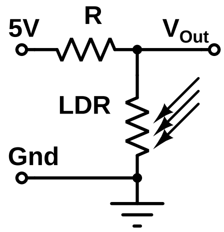
– **[Q5: 2 + 4 + 1 = 7 marks]**

Q–6

We use a rotating wheel with 16 slots, mounted on a motor, to periodically interrupt a beam of light as shown on the right. Assume that the light beam is collimated and has a crossection exactly matching the slots and the space between the slots is the same as the slot width.



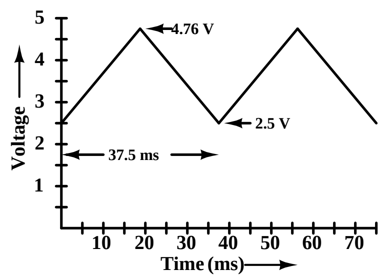




We use the circuit shown on the right to detect the chopped light. The resistance of LDR in dark is 100 kΩ, while its resistance when exposed to the beam of light is 5 kΩ. The waveform appearing at V_{out} is viewed using an oscilloscope.

a) Sketch the waveform that will be seen at V_{out} if the motor is rotating at 100 RPM and $R = 5$ kΩ. Time and voltage scales should be shown.

Waveform:



Peak value $= 5 * 100/(100 + 5) = 4.76$ V,
bottom value $= 5 \times 5/(5 + 5) = 2.5$ V,
100 RPM $= 100/60$ rev. per second,
$16 \times 100/60$ slots pass per second.
So period $= 60/(100 \times 16) = 37.5$ ms.

Give a one line justification for the shape of the waveform.
As the wheel rotates, light beam will be progressively blocked by the space between slots and then will be progressively uncovered by the next slot – so a triangular wave is expected. – [**3**]

b) The time period of the waveform at V_{out} as measured using an oscilloscope is 30.5 ms. What is the rotation speed of the motor in revolutions per minute (RPM)?

Steps: Time per slot = 30.5 ms,
Time for 1 revolution $= 16 \times 30.5 = 488$ ms.
Rev. per second $= 1000/488 = 2.0492$,
RPM $= 2.0492 \times 60 = 122.95$

Answer:

RPM = 122.95

– [**2**]

c) What should be the value of the series resistor R such that the peak to peak amplitude of the waveform at V_{out} is 2.5 V?
Answer: Take all resistance values in kΩ.

$$V_{p-p} = 2.5 = 5 \times \left(\frac{R_{dark}}{R + R_{dark}} - \frac{R_{lit}}{R + R_{lit}}\right) = 5\frac{R(R_{dark} - R_{lit})}{(R + R_{dark})(R + R_{lit})}$$

$$\frac{1}{2} = \frac{95R}{(R + 100)(R + 5)} \qquad \text{So } 190R = R^2 + 105R + 500$$

Solving the quadratic equation $R^2 - 85R + 500 = 0$ gives

$R = (85 \pm 72.2842)/2$ or 78.64 kΩ and 6.36 kΩ.

Answer: $R = 78.64$ **kΩ or** 6.36 **kΩ**

(Full credit for either answer).
Confirmation: $R = 78.64$ kΩ, $V_H = 5 \times 100/(100 + 78.64) = 2.7989$ V,
$V_L = 5 \times 5/(5 + 78.64) = 0.2989$ V, So $V_{p-p} = 2.7989 - 0.2989 = 2.5$ V.
When $R = 6.36$ kΩ, $V_H = 5 \times 100/(100 + 6.36) = 4.7011$ V,
$V_L = 5 \times 5/(5 + 6.36) = 2.2011$ V, So $V_{p-p} = 4.7011 - 2.2011 = 2.5$ V. – [**4**]

– [**Q6: 3 + 2 + 4 = 9 marks**]