23 October 2019 Exercise session

The following figure shows a generic block diagram of a pulse oximeter :

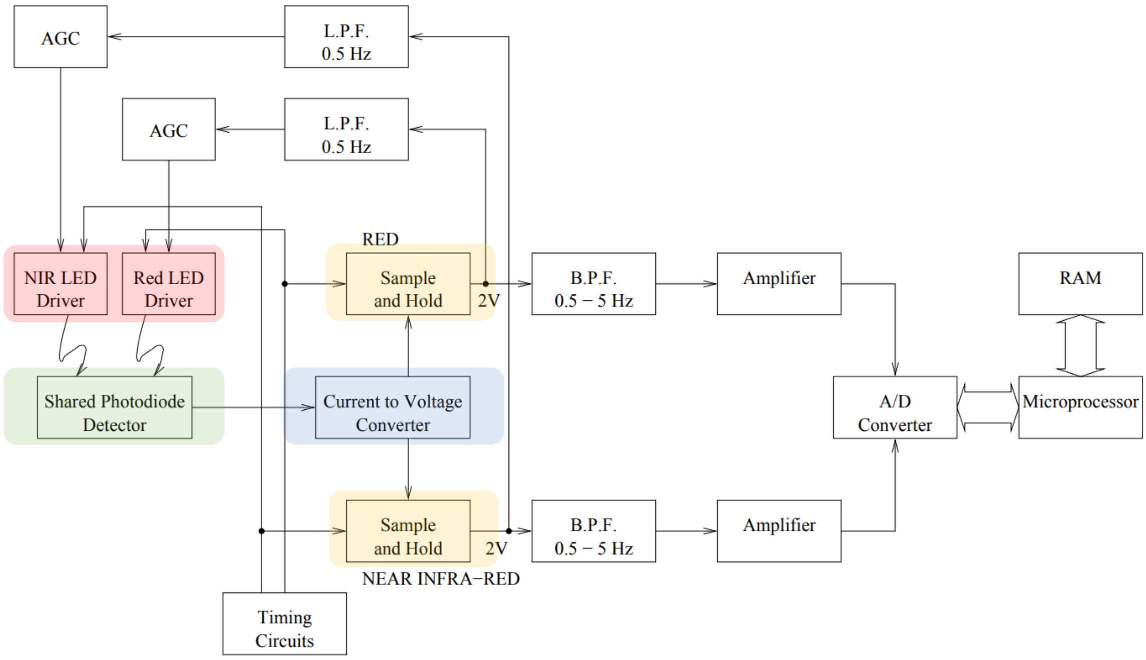


Figure 1 - Pulse Oximeter Block Diagram

- Design a simple constant current source to drive each LED under a constant current of 1A. You have access to a single 12V supply voltage. Aim for maximum accuracy (this will impact your component choices).
- You wish to drive the LEDs in pulsed mode for lower power dissipation, so you choose to use the classic 555 timer IC in astable mode for this application. Using the 555 Datasheet, calculate the auxiliary component values required to obtain:
  - cycle frequency of 1kHz
  - average current consumption of ONE driver circuit of 50mA/cycle.
- You are using a photodetector that under full illumination has an equivalent resistance of 120MOhm, and you are using the following circuit for its readout:

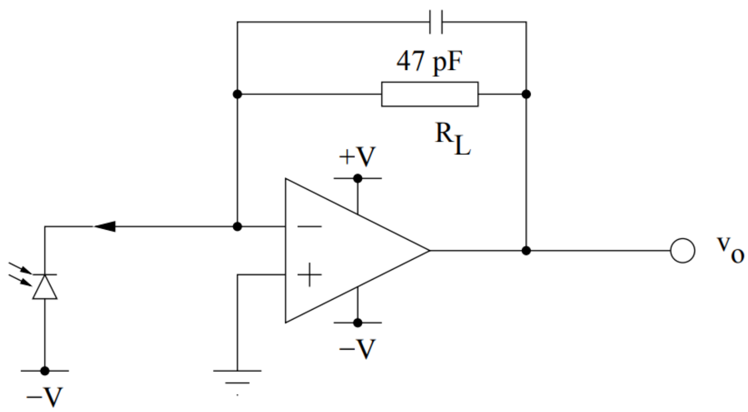


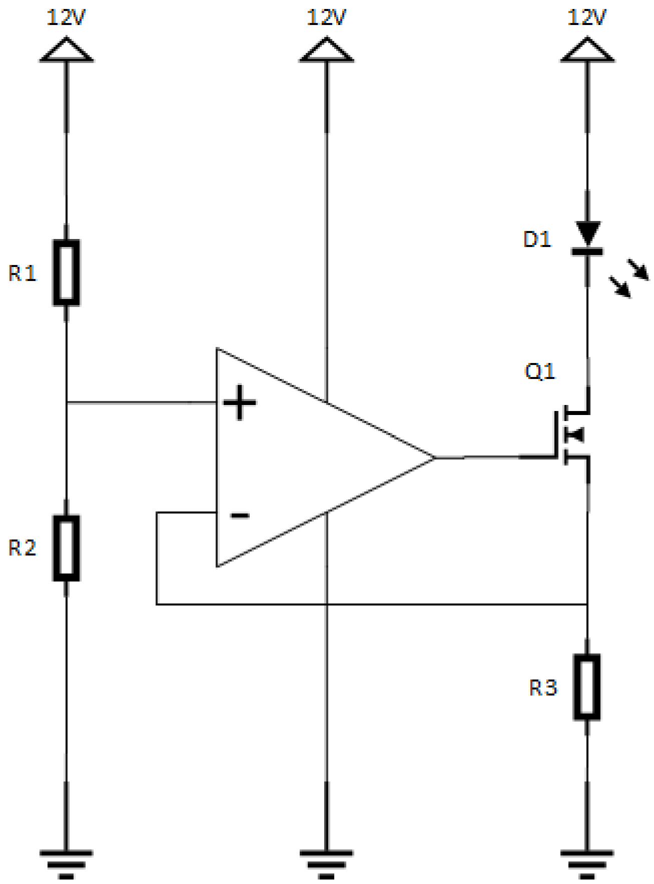
Figure 2 - Photodetector readout

Assuming that the negative voltage rail is at -12V, calculate the value of R_L such that under full illumination the output voltage v_o is equal to 2V.

- Bonus Question: Discuss on the role of the 47 pF capacitor in the feedback loop and if/how it affects the functionality of the circuit.

Solution

Point 1:



We can use this generic schematic of a constant current source to drive the LED. Notice we are using a MOSFET as a pass transistor, instead of a BJT. The reason is when using a BJT the circuit controls the emitter current while the LED is being driven with collector current. The fact that the beta of a BJT is a finite number and not always constant can introduce errors between the regulated current and the actual current through the LED. A MOSFET is a more elegant and error-proof solution, as its Drain current matches Source current much more closely.

First, we use the voltage divider to set the reference voltage of the OpAmp at 5V.

$$\frac{5V}{12V} = \frac{R_2}{R_1 + R_2}$$

A convenient set of values is $R_1 = 70k\Omega$ and $R_2 = 50k\Omega$

Next, we choose R_3 such that the current through the rightmost branch is 1A.

Since the OpAmp will use the negative feedback to keep its differential input voltage close to 0, we can assume a voltage frop of 5V across R_3. Using Ohm's law we find $R_3 = \frac{5V}{1A} = 5\Omega$.

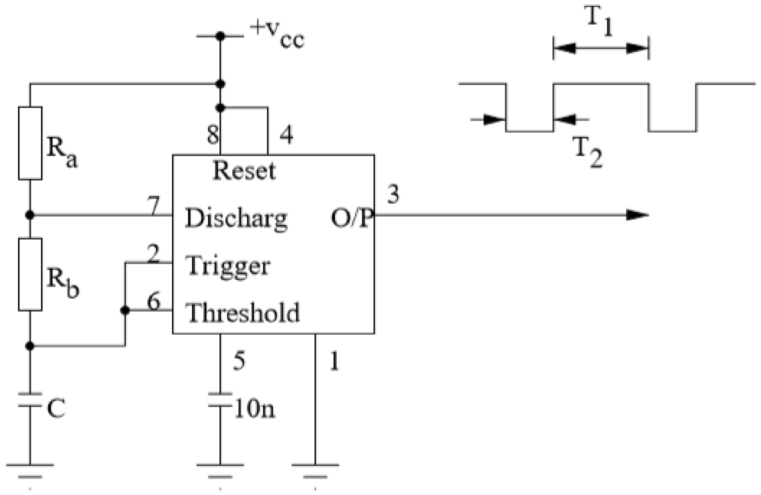
Point 2:

We are asked to drive the LED in pulsed mode at a cycle frequency of 1kHz such that its duty cycle is 50mA/1A=5%.

From this information we can derive the timing requirements, as following:

Cycle frequency of 1kHz means we need a cycle period of 1ms. The duty cycle further tells us the the on-time needs to be 5% of 1ms, which is 50µs.

Consulting the 555 timer Datasheet, we can use the formulas for **<u>Astable</u>** mode to calculate the auxiliary component values.



$$T_1 = 0.7(R_a + R_b)C$$

$$T_2 = 0.7 R_b C$$

Convenient values for Ra, Rb and C can be chosen with the help of Figure 16 of the datasheet.

For this example, we obtained: C = 22 nF, Ra = 56kΩ and Rb = 3.3kΩ.

Point 3:

Under full illumination the photodiode will pass a current equal to 12V across a 120MΩ equivalent resistance, which is 100nA in this case.

Since the input of the OpAmp is ideally of infinite impedance, all this current flows through R_L.

For the output voltage to reach 2V at such current, R_L needs to be 2V/100nA, which is 20MΩ.

Bonus Question:

During DC operation, the feedback capacitor has no impact on the circuit functionality. Problems can arise, however under AC and transient operation, since the photodiode usually exhibits considerable parasitic capacitance. This parasitic capacitance at the input causes the risk for oscillation in the OpAmp feedback arrangement. The feedback capacitor is used to compensate this effect and eliminate oscillation risk.