ECE 342 Fall 2016 Optoelectronic Link Project

Lab 4: LED Driver

Overview

An LED driver is a circuit which supplies a controlled amount of current to a light emitting diode. The optical output power of a light emitting diode is linearly proportional to its bias current, and exponentially related to its bias voltage due to the exponential nature of the I-V curve. Driving an LED with a voltage source will result in light output which is very sensitive to temperature and voltage variations. It would be better to use a current source whose output current varies linearly with a control voltage (i.e. signal), and does not depend on LED characteristics such as its saturation current I_S and ideality factor n.

The output of the ring oscillator from Lab 3 is closer to a distorted sinusoidal signal than a square wave. Thus, an interface circuit will be necessary to obtain the specified 50% duty cycle square wave for the optical link.

An MCP6001 (TLV6001) op-amp will be used to implement the LED driver. This op-amp provides nearly rail-to-rail output voltages. The 2N3904 NPN bipolar junction transistor will be used to provide the necessary drive current for the LED. The data sheets for these devices are located on the course web page. The MCP6004 (TLV6004) is a quad version of the MCP6001 (TLV6004).

The NGspice models (ECE342_models.zip) and symbols (ECE342_devices.tar.gz) for the MCP6001 and the LED can be downloaded from the course web page. You will need to download the spice model for the 2N3904 BJT transistor and create a symbol for this transistor in NGspice. We will discuss how to do this in recitation on Monday 30 October 2017.

The LED Driver

Figure 1(a) shows the optical output power vs. drive current for a typical IR LED. The IR LED diode is made from GaAlAs, not from Si. Figure 1(b) shows a typical I-V curve. The forward voltage drop across the forward biased GaAlAs diode will be approximately 1.3V.

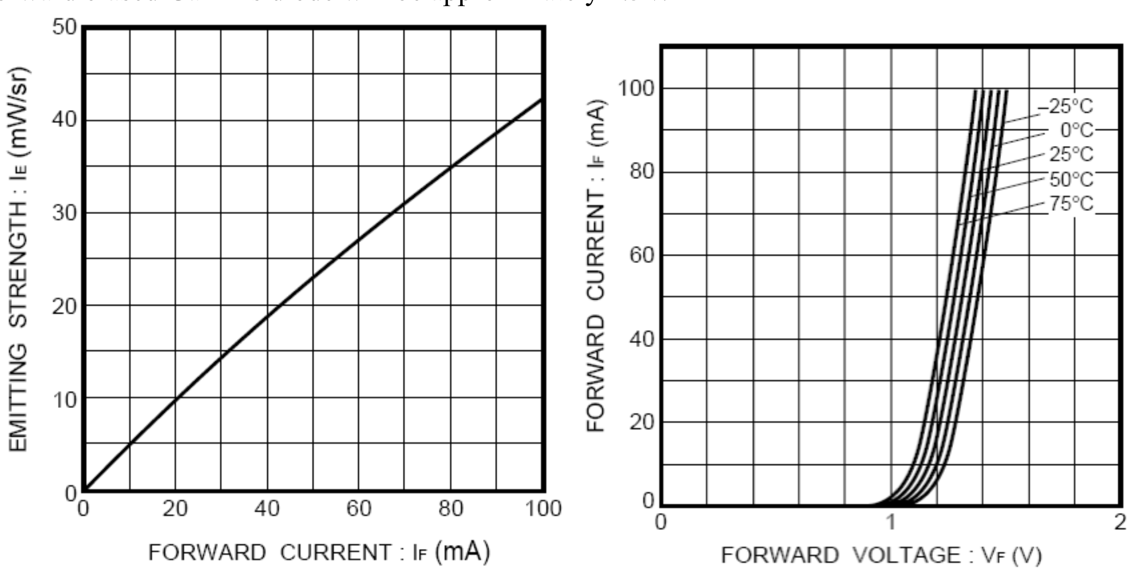


Figure 1. (a) L-I curve and **(b)** I-V curve for the SIR-563ST3F IR LED.

The maximum output current from the MCP6004 op-amp is 23 mA. This is below the continuous LED forward current for the transmitter. In order to obtain a larger drive current, the output of the op-amp is connected to the gate terminal of the BJT, and the LED is connected to the emitter terminal. A metal-oxide-semiconductor field effect transistor (MOSFET) could have been used instead.

Figure 2 shows a particular implementation of the LED driver with a 2N3904 NPN BJT (Q1) used in an emitter-follower configuration. The operation of the circuit is straight forward. The positive terminal of the op-amp is connected to the control voltage through a resistor divider; the negative terminal is connected to the feedback loop which includes the LED. When a positive voltage is applied to the positive input terminal, the op-amp will output a voltage to turn on the transistor. The emitter current of the transistor will flow through the LED and the resistor, R_{sense}. The feedback loop is designed so that the voltage drop across the resistor R_{sense} is linearly proportional to the control voltage. The resistive voltage divider formed by R_1 and R_2 is for reducing the 5V-peak control voltage to a level such that the peak current flowing through the sense resistor R_{sense} will be the required current needed to drive the LED. The transistor can source the current levels required to drive the LED.

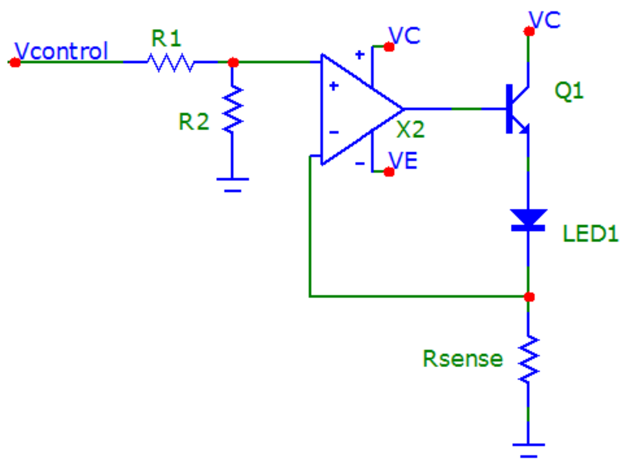


Figure 2. LED driver circuit.

The common-emitter BJT configuration has a very small (small signal) output resistance and a lower voltage overhead than the discrete MOSFETs available in the Al Whitney Electronics lab. The voltage overhead is the additional voltage the op-amp must supply to turn on the transistor. The sum of the BJT base-emitter voltage drop (V_{BE}), the LED voltage drop (V_{LED}) and the resistor voltage drop is the total output voltage required from the op-amp. The BJT and LED voltage drops will be approximately 0.7V and 1.3V, respectively. Thus, the voltage across the sense resistor will be about 2V less than the op-amp output voltage. It should be noted that an alternative implementation, using the common-emitter configuration, would have placed LED1 between the collector of Q1 and the 5 V supply.

Signal Conditioning Circuit

The output of the ring oscillator from Lab 3 is not a 50% duty cycle square wave, but more of a distorted sinusoidal signal. The ring oscillator signal needs to be converted to a 50% duty cycle square wave. This can be sone using a Schmitt trigger circuit, as discussed in ECE 214, or an amplifier circuit, such as that shown in figure 3, where the op-amp is driven deep into saturation. Since the MCP6001 op-amp is almost rail-to-rail, amplifying the input signal converts the sinusoidal signal to a square wave. A gain for this non-inverting amplifier of 10V/V should be sufficient.

The reference voltage of an op-amp amplifier would normally be mid-way between the positive and negative supply voltages. That is, for a +5V single ended supply, the normal reference voltage would be

+2.5V. However, the ring oscillator output is most likely not centered at +2.5V, but at some other value. In order to obtain a 50% duty-cycle control signal, the reference voltage of the amplifier should be shifted to +2.5V. R_{pot1} and R_{pot2} represent a single a single potentiometer. The potentiometer allows the reference voltage to be adjusted until a 50% duty cycle output is achieved.

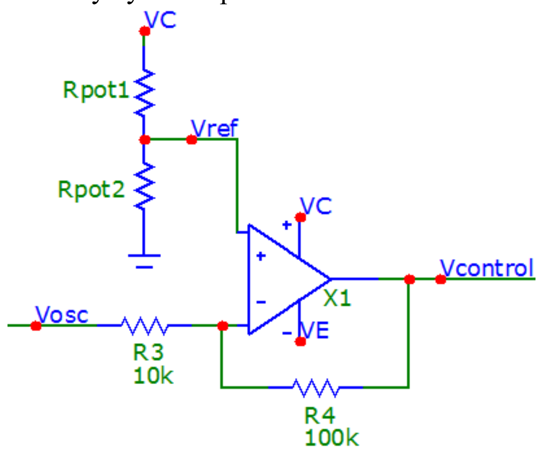


Figure 3. Signal conditioning circuit.

Voltage Regulator

The transmitter circuit will be powered from a 9V battery. However, the circuits used in this Lab require a 5V supply. The LM7805 voltage regulator will be used to convert the 9V battery voltage to a 5V circuit supply voltage. You do not need to include the LM7805 voltage regulator in your circuit simulations.

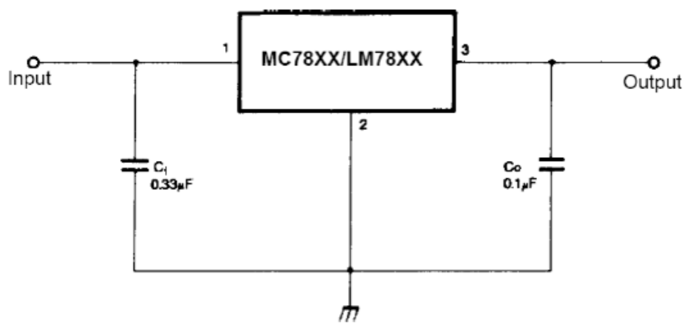


Figure 4. LM7805 set up, as recommended by Fairchild in the LM78XX datasheet.

The TA doing the final check-off of your complete optical link project will provide the 9V battery and connector. While testing your circuit in Task 5, use a DC power supply set to 9V.

Tasks

1. ***LED Driver Design:*** Design the LED driver based on the circuit shown in figure 2. Assume the input signal is a 5V square wave with a 50% duty cycle at 20 kHz. Choose R_{sense}, R_1 and R_2 to ensure the required current through the LED.

2. ***Signal Conditioning Circuit Design:*** Design the signal conditioning circuit based on either a Schitt trigger circuit or the circuit shown in figure 3. Choose R_3 and R_4 to obtain a gain between 10V/V and 20V/V at 20 kHz.

3. ***Transmitter Simulation:*** Simulate your transmitter, including the LED driver, signal conditioning circuit and the ring-oscillator from Lab 3. You will need to include the oscillator circuit in your simulation to see how varying V_{ref} (i.e. the potentiometer) will impact the duty cycle of the final output signal. Determine the V_{ref} which will result in a 50% duty cycle LED current, with the required

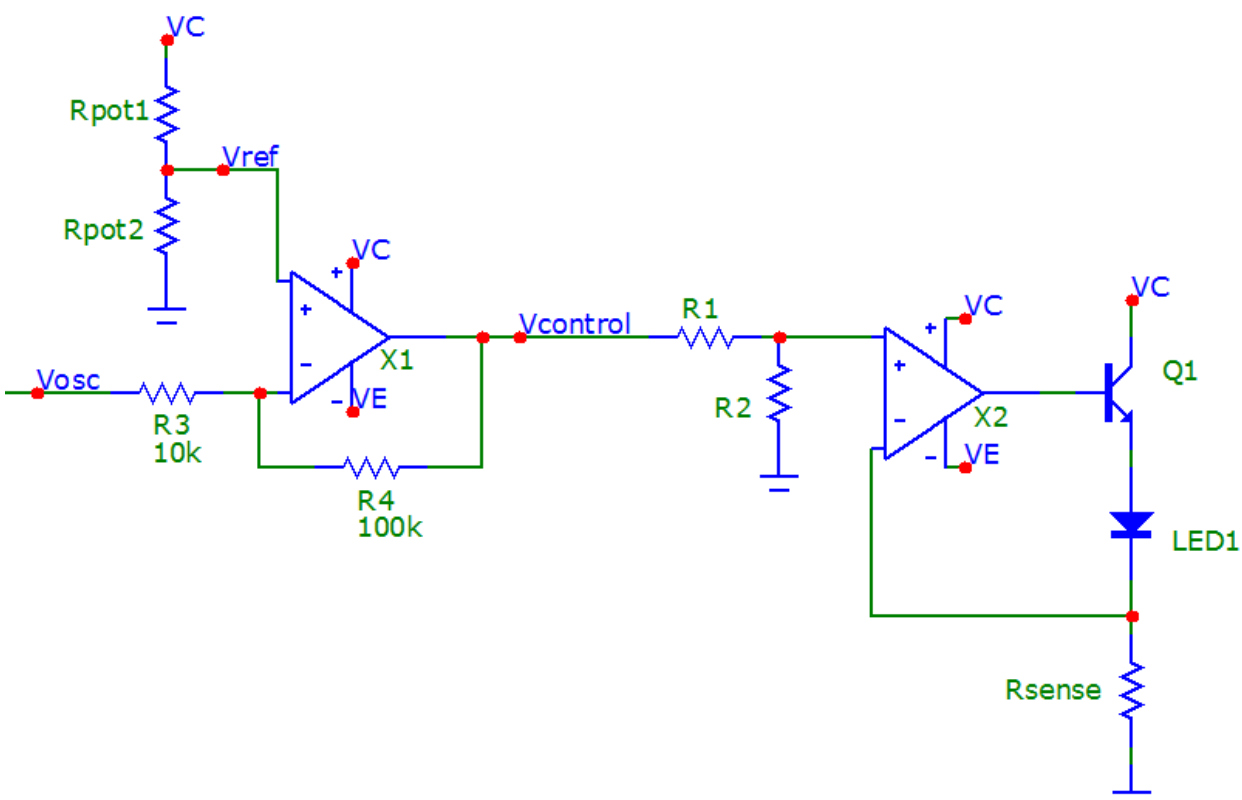
drive current.

4. ***Transmitter Construction and Testing:*** Construct the complete transmitter, including the oscillator, signal conditioning circuit, LED driver and the voltage regulator. Use a potentiometer to obtain the reference voltage, and adjust its value until you obtain a 50% duty cycle signal. Adjust your component values until you achieve the specified LED drive current. Does the LED drive current ever go to zero?

5. ***Report and Demonstration:***
   - Your *full* report should clearly describe your design process, and present your theoretical, simulated, and experimental results. All lab partners should collaborate in the writing of the report.
   - Your *draft report* should be submitted to your TA electronically as a PDF file by Monday, 13 November 2017 at 2:00 PM. The TA will comment on your report by Wednesday 15 November 2017.
   - The *final report* for this task should be submitted to your TA electronically as a PDF file by Friday, 18 November 2017 at 2:00 PM. Make sure that you make necessary corrections as indicated by Prof. Payne as well as the TAs.
   - You'll be asked to schedule a short demonstration of your amplifier in the week of the due date. Each lab partner will be asked to reproduce a measurement from the report, and show where the measurement and measurement technique was recorded in their lab notebook. (Lab partners each receive a separate grade.)

Hints and tips:

1. The Digilent Analog Discovery cannot be used to measure the LED drive current directly. But it can be indirectly measured by measuring the voltage across R_{sense}.



Time Management and Lab Notebook Documentation
ECE 342 Fall 2016 Lab 4

Group #____________ Names:________________________________

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Use this form to collect signatures from the TA as you complete the tasks below. Signatures must be collected on or before the due date. Include this completed form with your lab notebooks and final lab report.

Friday 27 October	**Watch the lab briefing and review the deadlines given below**.
Thursday 2 November 2017 4:50 PM	***(10 pts)*** **Circuit design and simulation results completed.** All designs must be entered into lab notebooks *TA's: Rate from 1(worst) to 5 (best)...* Clarity of Design Process: 1 2 3 4 5 Lab Notebook Procedures: 1 2 3 4 5 Simulations Completed: 1 2 3 4 5 Clarity of Simulation Results: 1 2 3 4 5 Successful Design Complete: 1 2 3 4 5 Early Check-off: 1 2 3 4 5 Signature: Date:
Thursday 9 November 2017 4:50 PM	***(10 pts)*** **Experimental measurements completed and entered into lab notebooks.** *TA's: Rate from 1(worst) to 5 (best)...* Experimental Procedures Clearly Described: 1 2 3 4 5 Lab Notebook Procedures: 1 2 3 4 5 Preliminary Analysis of Results: 1 2 3 4 5 Clarity of Results Presentation: 1 2 3 4 5 Successful Design Demonstrated: 1 2 3 4 5 Early Check-Off: 1 2 3 4 5 Signature: Date:
Monday 13 November 2017 2:00 PM	***(10 pts)*** **Rough draft of report completed by 2:00 PM**. Text should be complete, requiring editing primarily for grammar, consistency, or presentation. Submit as a PDF file.
As Scheduled:	***(30 pts)*** **Demonstration:** Reproduce a measurement from your report for a grader. Expect to show the grader where the requested measurement and measurement technique was recorded in your notebook.
Friday 17 November 2017 2:00 PM	***(40 pts)*** **Final Report Due, 2:00 PM.** Turn in your final task report as a PDF file. Reports are not accepted late.