LAB 1. Optical Data Link: Sending Information on a Light Beam

Completed lab reports are due by midnight, one week after your lab section has met.[1] Please submit electronically via CANVAS. Using a word processor to prepare your labs is preferred, because of clarity, but if you have a strong preference for neat, hand-written reports, that would be OK.

1 Goal of This Lab:

We spoke in class about the use of an electromagnetic wave as a *carrier* of information that is superimposed on that carrier: for example, we can use **amplitude modulation, AM** or **frequency modulation, FM** of a carrier wave. Modulation is the process of varying one or more properties of a high-frequency signal (the carrier), with a lower-frequency modulating signal (the information to be transmitted). As we earlier discussed, the three key parameters of a high frequency signal are its amplitude (*volume*), its phase (*timing*) and its frequency (*pitch*).

Using an optical wave as the carrier offers many advantages over the lower-frequency electrical domain, including:

a. Low loss transmission over very large distances (kilometers) using ultra-low loss optical fibers;

b. A very large frequency **bandwidth** available for information transmission due to the high frequency of optical carriers: 200 THz compared to 10 GHz in the case of electronics. This allows for many different communication channels to be sent using the same physical channel (e.g. optical fiber) by using different frequencies (colors) of light;

c. Virtually no cross-talk (interference) between different channels since the probability of photon-photon interactions is much smaller then electron-electron interactions in electrical communication channels.

This lab will give you the chance to carry out modulation of a light beam (emanating from a *Light Emitting Diode, LED*) by imprinting a low frequency electrical signal (audio signal) onto the high frequency optical signal through the modulation of its intensity.

An **LED** will be used as the source of the carrier signal and a **Photo-transistor** will be used as a detector. The circuits you will use will be to combine both DC and AC signals. You will use breadboards to put these systems together.

[1] E.g. if your lab section meets on Tuesday, February 19th, then your lab report will be due by midnight, Tuesday February 26th.

Please provide answers to all the underlined questions in this document. More details on the format of your **Lab Report** will be given in a separate document. The report *will not* involve much more input or writing than is indicated on this document, and it should be possible for you to complete all of the measurements, and perhaps much of the analysis in your lab section alone.

2 The Carrier Signal: LED Characteristics

The *carrier* wave we will use for this experiment is the light generated by a *Light Emitting Diode*. Like a regular electronic diode, the Light Emitting Diode has a *non-linear* current versus voltage (I-V) signature, with a threshold value of voltage before the diode produces a substantial amount of current. As the current increases, so does the light emitted by the LED. In order to utilize the LED within the full circuit, it is important to analyze its I-V characteristics. The circuit we will use to carry out the analysis is shown in Figure 1. The circuit consists of an *ammeter* and a *voltmeter*; R_{bias} is placed in the circuit to limit the current through LED. The LEDs used in this experiment require currents that are on the order of 10 mA and we will use a *bias voltage* of 2-3 V. Therefore a useful value of $R_{bias} = 100\ \Omega$.

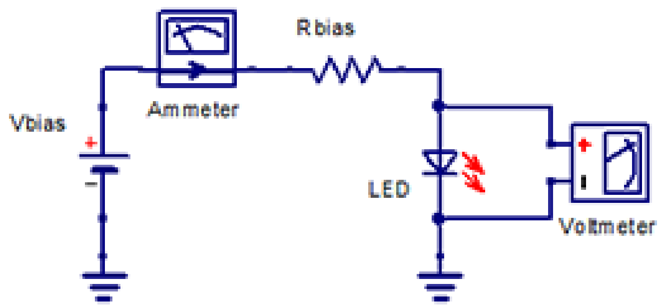

Figure 1: Circuit used to measure LED characteristics. You either use an external ammeter and voltmeter or you can read the values of current and voltage from your voltage source.

a. Using the circuit shown in Figure 1, measure the I-V characteristics of the LED to be used in this lab. You can increase the voltage in steps of 0.3V from 0 V to 3 V.

b. Draw the I-V characteristics of the LED using your data;

1. Identify the *threshold* of the LED, that is the voltage at which the LED current starts dramatically increasing.
2. Identify the voltage at which the LED start emitting light. Is the threshold the same as the one you identified for part 2.b.1?

You may have noticed that for the LEDs you are using, the current saturates at about 23 mA when voltages are >2.5V or so; this is due to the current limiting protection.

3 Transmitter

Now that we know the I-V characteristics of the LED we are going to use, we can progress towards actual transmission of signals by modulating the intensity (amplitude) of the emitted light.

a. You will incorporate the LED into the circuit shown in Figure2. In order to understand the circuit better, particularly with an input of an AC signal (V_{signal}), let's carry out the following analysis. The equations for the impedance of a capacitor and resistor may help you:

$$Z_C = \frac{1}{j\omega C}, \quad Z_R = R \tag{1}$$

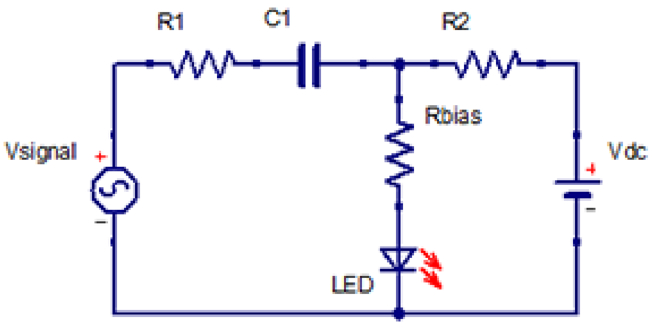

Figure 2: Signal Modulation Circuit

1. Draw the equivalent circuit **at very low frequencies (DC limit)**. Use the value of Z_C at low frequencies to help here.
   (a) What is the value of the DC current going through the capacitor C_1 and AC voltage source V_{signal}?
   (b) What is the purpose of the capacitor C_1?
2. Draw the equivalent circuit of the transmitter **at very high frequencies**. Does the capacitor act as an open or short circuit?
   (a) Assume that $R_1 = R_2 = 100\Omega$ and $C_1 = 10\mu Fd$. Calculate the *cut-off frequency* f_C above which the capacitor C_1 acts as a short. The cutoff frequency is given by $f_c = 1/(2\pi RC)$.
   (b) Now build the circuit shown in Figure 2. If you want you can assume $R_{bias} = 0\ \Omega$.

3. The capacitor C_1, for your circuit will be an electrolytic capacitor. These capacitors ARE NOT symmetric, and their negative electrode (labeled with "-" sign on the package) has to be connected to the lower voltage in the circuit. (Can you think of a reason that non-symmetric capacitors are important in this circuit?) Otherwise, they may blow up (!). For your circuit, connect the negative electrode to V_{signal}, since V_{signal} less than V_{dc}.

4. Attach oscilloscope Channel 1 in parallel with the LED to measure the voltage across it. Please select DC coupling on the scope in order to see the DC and AC signals into the LED simultaneously.
   Please take a photo of the oscilloscope screen that shows both the DC and AC signals.
   (If you choose AC coupling, you will see only AC component of the signal, with DC removed. This is useful when you have a small AC signal riding on top of large DC bias, as it will be the case later when we transmit music). To see the voltages properly, please make sure that Channel 1 has $V_{offset} = 0\text{V}$ on the scope. You can do this by selecting *Ground* in the Coupling menu for Channel 1 and using the dials, bring the yellow trace on top of the x-axis of the scope.

5. V_{signal} will come from the pulse generator. Please set the amplitude of the pulse generator to V_{signal}= 500 mV and its frequency to f= 30 Hz.

6. Now, let's figure out how large a value of V_{dc} we need so that the LED operates in the linear region. You can approach this with pen and paper or, as a true engineer, experimentally. To do the latter, you can use the oscilloscope to monitor the DC signal across the LED while adjusting V_{dc}. The goal is to have the LED voltage be in the middle of the linear range that you previously found.
   Please state the value of V_{dc} you have chosen to use, with a few words describing why this was your choice.

   IMPORTANT: You will probably be using the Agilent E3631A DC Power Supply. Using the 6 V option on the supply, connect the *Ground signal* from the DC power supply to the "-" terminal. If you happen to use the 25V option, then connect the *Ground signal* to the COM terminal, which is the ground for this set-up. This will assure proper grounding of the whole circuit; otherwise, you may have problems with *ground loops* (ask your TF about these) and you may pick up 60 Hz noise coming from the power outlets.

b. If you did everything right, your LED should be on and will be blinking with 30 Hz frequency! (If you can't see it blinking, call your TF over and try raising the pulse generator voltage.) Note that since our calculations above were only estimates, you may have to play a bit with DC voltage to get the most out of your circuit and have the best transmission possible. This will be especially true if you use different values of **R** and **C** in the circuit, which is perfectly fine! Often, engineers need to work with what is available in the lab and approximate things!

1. Your scope should be showing a nice signal that consists of a 30 Hz sine wave on top of DC level. Please take a photo of that scope image.
2. Select *AC coupling* in the *Coupling menu* for Channel 1 of the scope to see the AC component only. Does the signal look like what you would expect? Please take a photo of that scope image.
3. Replace the pulse generator with input from the headphone jack of the lab computers (or your phone!). Can you see the music signal on the scope as well? Please take a photo of that scope image.

4 Receiver

In order to receive the music signal, we need to "extract it" from the "amplitude" of the light (this is also known as *demodulating the signal*). To do this we will need a photo-converter, a device that converts light signals to voltages or currents. The photo-converter to be used in this lab is a **photo-transistor** (e.g. MRD 360, op830Wsl, or equivalent) shown in Figure 3. This is an integrated circuit that consists of two transistors in a so called *Darlington pair* configuration: the first transistor receives photons and converts them to electrons, while the second transistor amplifies this small current and provides a much larger current at its output. Therefore, the phototransistor acts as a *light-controlled current source*!

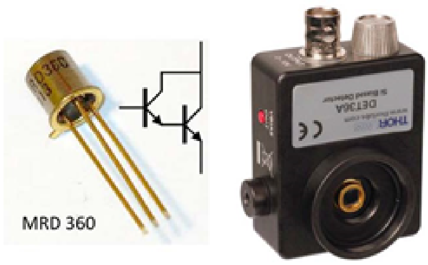

Figure 3: Phototransistor, MRD 360

a. Study the data sheet for your photo-transistor and find out if it can respond to the LED light wavelength. Also, figure out which pin corresponds to base (B), emitter (E) and collector (C). (*Base, emitter and collector are components of a bipolar transistor: photons that are detected by the base modulate the current between the emitter and the collector*).

b. Build the receiver circuit according to the schematic shown in Figure 4. You can assume $V_{cc} = 3$V (please use two AA batteries), $R_3 = 100\Omega$ (though anything in the range $30 - 300\Omega$ would do), $C_2 \geq 100\mu F$ (anything in the range $10 - 100\mu F$ would do). For the speaker, we will use 16 Ω speakers. Due to the very low resistance of the speakers you will not get much of a signal out. To fix this you could use higher-resistance headphones, or even better, amplify the signal using an audio amplier.

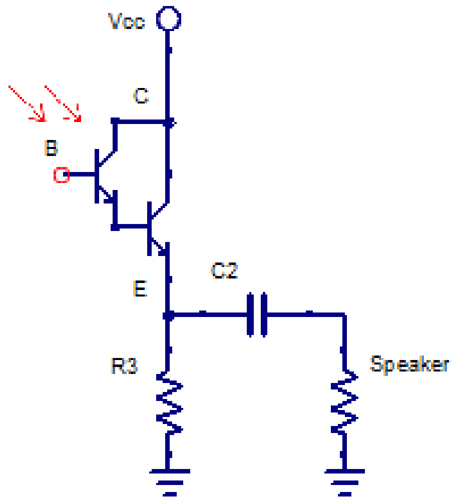

Figure 4: Receiver Circuit

1. Hook up the oscilloscope in parallel with R_3 to measure the voltage across it. First use DC coupling to see the overall signal and then AC coupling to see the time-varying component only.
2. Discuss what purpose you think capacitor C_2 serves in this circuit.

5 The Working System

Now you are ready to launch and received your modulated signal! Apply a 1 kHz, 500 mV sine wave to your transmitter and point the light from the LED onto your receiver. Also, please disconnect the speaker temporarily (this will give us larger signal on resistor R_3. Why?)

a. Can you see the received signal on the scope? If not, move the photo-detector or LED around to get good alignment between the two.

b. Play with the bias on the transmitter end so that the received signal looks as much as a sine wave as possible. Please take photos that illustrate a few conditions of different bias.
What happens when the bias is too large or too small?
What explanation can you give for that behavior?

c. Now put the speaker back into the circuit. Notice that received voltage signal will drop, and actually may look better - more sine-wave like: this is due to the fact that transistor now has an easier time driving the small resistor (speaker) and does not saturate.

d. You should also be able to hear the sound now! Play with the frequency of the sine wave on the transmitter end and see if you can hear the change. If you have the time, go for the **real deal**: Replace the pulse generator with your portable music player or a computer, can you see the music signal on the scope? Can you hear music?

e. **Experiment with the "robustness" of your system"**
This part calls on YOUR creativity: devise and describe a few simple experiments that can give further information on the robustness of your system.

   i. Over how great a distance can you transmit a signal?
   ii. Can you send signal around corners?
   iii. How large a signal can you transmit?