Lab 4:
Optical Data Link: Music Transmission Via Light Beams

1. Objective:

The main objective of this lab is to transmit music from one side to the other via a light beam. This lab will introduce you to the basics of light generation and detection. A LED will be used as a source of light. A Photo-transistor (and photo-diodes) will be used as a detector. We will also build high-pass filters and learn how they can be used to combine DC and AC signals in the same circuit.

In this lab we will build both an optical transmitter and receiver. You will use breadboards to put these systems together.

2. Theoretical Overview:

Signal modulation is often used to transmit information (digital or analog). Good examples are AM (amplitude modulation) and FM (frequency modulation) radio signals. Modulation is the process of varying one or more properties of a high-frequency signal - the carrier, with a modulating signal - the information to be transmitted. The three key parameters of a high frequency signal are its amplitude (”volume”), its phase (”timing”) and its frequency (”pitch”). Any of these properties can be varied in accordance with a low frequency signal to obtain the modulated signal. In this lab we will be varying “the amplitude” of the high frequency signal – the light intensity, to imprint the low frequency electrical signal (audio signal) onto the very high frequency optical signal (light intensity).

Information transmission in the optical domain offers many advantages over the electrical domain, including:

a. Low loss transmission over very large distances (kilometers) using ultra-low loss optical fibers. In fact optical fibers are the best information carriers known to mankind;

b. A very large frequency bandwidth available for information transmission due to the high frequency of optical carriers: 200THz compared to 10GHz in the case of electronics. (For comparison, what is the carrier frequency of your favorite AM or FM radio station?). 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 (e.g. due to induction, capacitive coupling, etc)

3. LED Characteristics

A LED (Light Emitting Diode) – you should all know by now☺, still remember the characteristics of a LED?

A LED emission is based on a spontaneous emission process, and is neither monochromatic nor coherent.

Remember that in previous labs you have characterized LEDs and done the same for resistors. We will determine the LED's threshold that is the minimum power required for the LED to "turn on". The schematic that can be used to perform this measurement is shown in Figure 5: A = ammeter, V = voltmeter; R_{bias} is used to limit the current through LED. Since the LEDs used in this experiment are on the order of 10mA, and bias voltages are on the order of 2-3V, we can use R_{bias} = 100Ω. Note, remember to include these resistors in the circuit :).

3.a) Using the circuit shown in Figure 5, 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 0V to 3V.

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

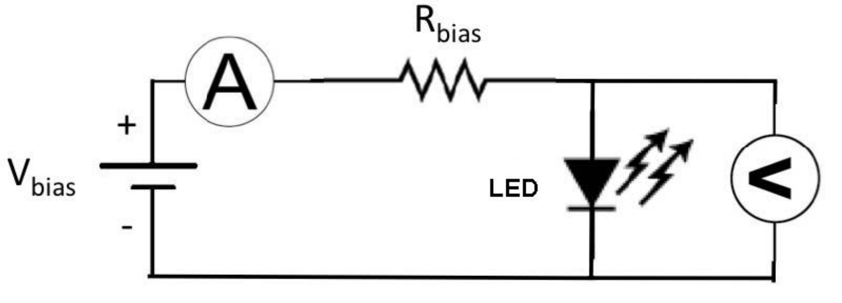

Figure 5: Circuit used to measure LED characteristics. You can use either an external ammeter and voltmeter or you can read the values from your voltage source.

i) What is the LED's threshold that is the voltage at which the LED current starts dramatically increasing?

ii) At what voltage does LED start emitting light? Are the voltages for part (i) and (ii) the same?

You may have noticed that the LED current saturates at about 23mA (for the LEDs used in the lab) when voltages are > 2.5 V or so, this is due to the current limiting protection.

4. Transmitter

Now that we know the I-V characteristics of the LED we are going to use, we can start having fun and transmitting some signals by modulating the intensity (amplitude) of the emitted light.

4.a) The simplest way to transmit the signal via a LED beam would be to hook up the LED directly to the pulse generator. Draw the schematic of this and try it. Start with a low pulse generator frequency of 3 Hz.

i) How large an amplitude do you need to use to turn the LED on? How does this voltage compare to the amplitude of a music signal at the output of your portable music device (~100mV level, or less)?
ii) Can the LED give off light when the driving voltage is negative?
iii) Can you see the light flickering? If you don't see it flickering, can you guess the reason? Try turning up the frequency of the modulator pulse to a few 10's of kHZ until you can no longer see the light flickering. What is the corresponding frequency?

4.b) Clearly, driving the LED directly using the pulse generator only is not a very good idea since the signal is distorted due to the non-idealities (nonlinearities in the I-V characteristics) of the LED. For LED-transmission to work well, without distortion of the signal, we need to first bias the LED using a DC voltage, and then apply a small AC signal (our information) on top of this DC bias. This can be done simply by adding an AC signal (from the pulse generator) in series with a bias DC signal.

i) Draw the circuit that corresponds to the description of the bias and modulation given above.
ii) What DC voltage would you use so that you can apply as large an additional AC signal as possible and still have the LED operate in the linear regime?
iii) Now build the circuit you designed and try this in practice. Play with different DC biases and AC amplitudes and observe the effects that they have on the output voltage of LED. If you want to see the LED blink you can reduce the frequency of pulse generator to about 10-30 Hz.

4.c) The problem with the simple circuit discussed above is that you will have a DC bias current going through your AC source. While the pulse generator can handle this DC current, since it is a robust laboratory instrument, your portable music player (e.g. iPod) may not be able to do so. In order to overcome this obstacle, and still be able to bias the LED and apply an additional AC signal (music), we can use circuit shown in Figure 6. We haven't worked very much with capacitors, so to understand how this circuit works let's do the following:

i) Draw the equivalent circuit at very low frequencies (DC limit). What is the DC current going through the capacitor C_1 and AC voltage source $\mathbf{V}_{signal}$? What is the purpose of the capacitor C_1?
ii) Draw the equivalent circuit of our transmitter at very high frequencies. Does the capacitor act as an open or short circuit? Assuming that $R_1 = R_2 = 100\Omega$ and $C_1 = 10\mu F$, find the cut-off frequency f_c above which capacitor C_1 acts as a short. What kind of filter is this (high-pass or low-pass)?

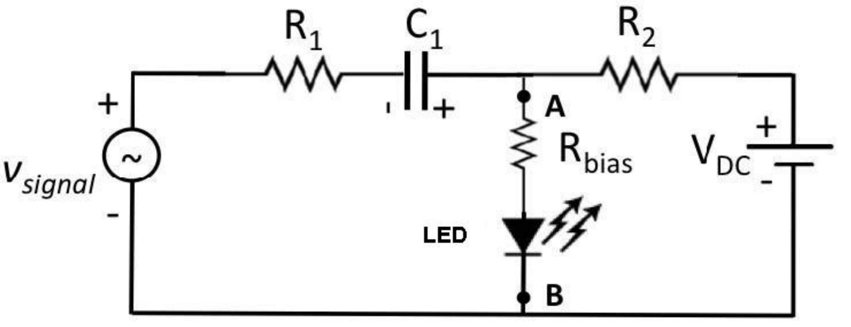

Figure 6:

Now build the circuit from Figure 6. If you want you can assume $R_{bias} = 0\Omega$.

iii) 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 (!). In our case, connect the negative electrode to v_{signal} since $v_{Signal} < V_{DC}$ and the polarity of C_1 is therefore as indicated in Figure 6.

iv) 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. (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 0V offset on the scope. You can do this by selecting ”Ground” in the ”Coupling” menu for the Channel 1 and using the dials, bring the yellow trace on top of the x-axis of the scope.

v) v_{signal} will be from pulse generator. Please set the amplitude of the pulse generator to $v_{signal} = 500mV$ and its frequency to $f = 30Hz$.

vi) 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.

IMPORTANT: You will probably be using the Agilent E3631A DC Power Supply. Using the ’6V’ 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, your may have problems with ”ground loops” (ask your TFs about these) and you can pick up A LOT of 60Hz noise coming from the outlets.

If you did everything right, your LED should be on and will be blinking with 30Hz 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’s and C’s in the circuit -which is perfectly fine! Often, engineers need to work with what is available in the lab and approximate things!

a. Your scope should be showing a nice signal that consists of a 30Hz sine wave on top of DC level.

b. Select ”AC coupling” in ”Coupling” menu for Channel 1 of the scope to see the AC component only. Does the signal look like what you would expect?

c. Replace the pulse generator with radio or portable music player. Can you see the music signal on the scope as well? Neat, isn’t it!

5. Receiver

In order to receive the music signal we need to”extract it” from the “amplitude” of the light. To do this we will need a photo-detector - a device that converts light signals to voltages or currents. In ES 50 we have all kinds of photodetectors available: photo-diodes, photo-resistors, photo-transistors, amplified photo -detector units, solar cells, etc. Photo-resistors and solar cells would not be a good choice for this lab since they are slow (they are optimized to detect light for very different applications). In this lab you will use the photo-transistor (e.g. MRD 360, op830Wsl, or equivalent) shown in Figure 7. 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!

5.a) Study the data sheet for your photo-transistor and find out if it can respond to red light (what is the wavelength of red light?). Also, figure out which pin corresponds to base (B), emitter (E) and collector (C).

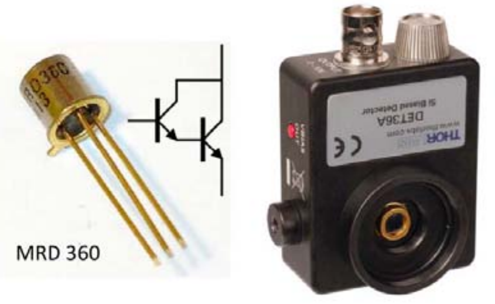

Figure 7: MRD 360 Phototransistor (or equivalent, eg. op830Wsl) will be used as the main detector in this lab. In ES 50 lab we also have nicely packaged detectors shown on the right of thefigure (DET 36A, Thorlabs corporation) based on photodiodes. These stand -alone units are easy to use but are more expensive.

5.b) Build the receiver circuit according to the schematic shown in Figure 8. You can assume V_{CC} =3V (please use two AA batteries), R_3 = 100Ω (though anything in the range 30–300Ω would do), C_2 = 100μF (anything in the range 10– 100μF would do). For the speaker, please use either yellow (4Ω) or small (8Ω) speakers. Chances are, however, that due to the very low resistance of the speakers you will not get much of a signal out. (Have you seen this problem before?) Tofix these you can use hi gher-resistance head-phones (ES50 ones or your own), or even better, amplify the signal using an audio amplifier (remember those? :)). Did you build your own amplfier in Lab 3? You can use it now! Or use amplifiers that the TFs have made for you.

i) 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.

ii) What is the purpose of capacitor C_2 in this circuit?

Now we are ready for some fun! Apply a 1kHz, 500mV 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?)

5.c) 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.

5.d) Play with the bias on the transmitter end so that received signal looks as much as a sine wave as possible. What happens when the bias is too large or too small? Why?

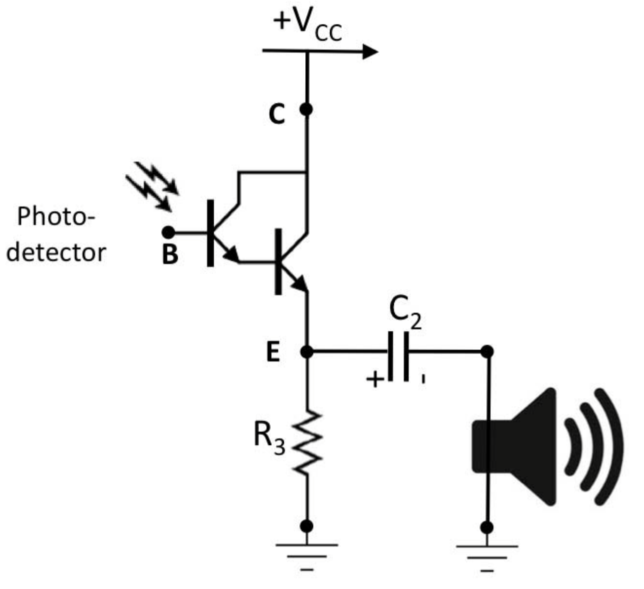

Figure 8:

5.e) 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.

5.f) 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. Also block the LED beam and see what happens :). Cool, no?

And now 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?

You can also send the music to your friends across the lab. Try sending two LED beams at the same time to the same receiver. What happens?

And guess what? You just completed Lab 4. Congrats!

If you have time and are interested in this, you can solder up everything, add amplfier to the receiver (use the version with the transistor at the output for more power) and impress your roommates! :)

LED – Light Emitting Diode
LASER - Light Amplification by Stimulated Emission of Radiation