Experiment No. 5.

LEDs Phototransistors and an AM Photonic Link

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Purpose

To learn about light emitting diodes (LEDs) and phototransistors and to build a simple photonic link using amplitude modulation of an LED.
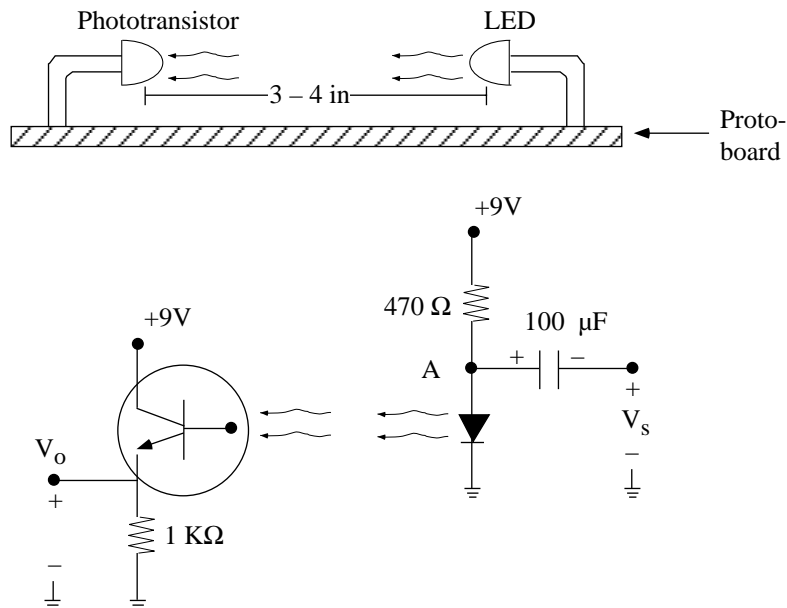
❑   Read this experiment and answer the pre-lab questions.

1.0   The LED and Phototransistor:

Connect the LED to the +9 V power supply using a 470 Ω resistor as shown below. Place a 100 µF capacitor (DC block) between the diode and the input signal source.

Connect the phototransistor to the +9 V supply using a 1 KΩ resistor at the emitter. Connect the emitter to the Agilent scope.

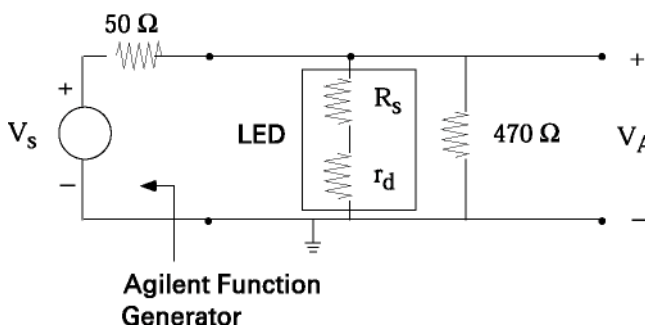Align the LED and the phototransistor as shown below.

1.   a. ❑ Draw the LED (complete circuit and ac circuit) and the phototransistor circuit in your notebook.

Put the scope trigger to <u>Line</u> so as to trigger at the 60 Hz AC frequency. (You will notice that the output has a ripple at 120 Hz due to the light picked up from the fluorescent lighting system in the room.)

b. ❏ On the scope, plot V_O (DC and AC) of the phototransistor with no input ac signal to the diode. From V_{ODC} (V_{avg} on the scope), calculate the DC photocurrent in the collector/emitter circuit of the phototransistor (this current is due to the light from the LED).

c. Put a black tube cover over the phototransistor to reduce the pick-up 120 Hz noise. It should be possible to reduce it to less than 2 mV_{ppk}. Align the LED and the phototransistor so as to result in maximum signal (DC voltage).

2. Connect the LED to the Agilent function generator (sinewave, 1 KHz, 400 mVppk).

   a. ❏ Measure the voltage (V_{avg} and Vppk) across the LED at node A. You will find that V_A is much greater than 20 mV! However, only a small part of this voltage (V_A) appears across the LED junction since R_s ~ 15 Ω and r_d~3 Ω.

Equivalent AC Circuit of the LED:
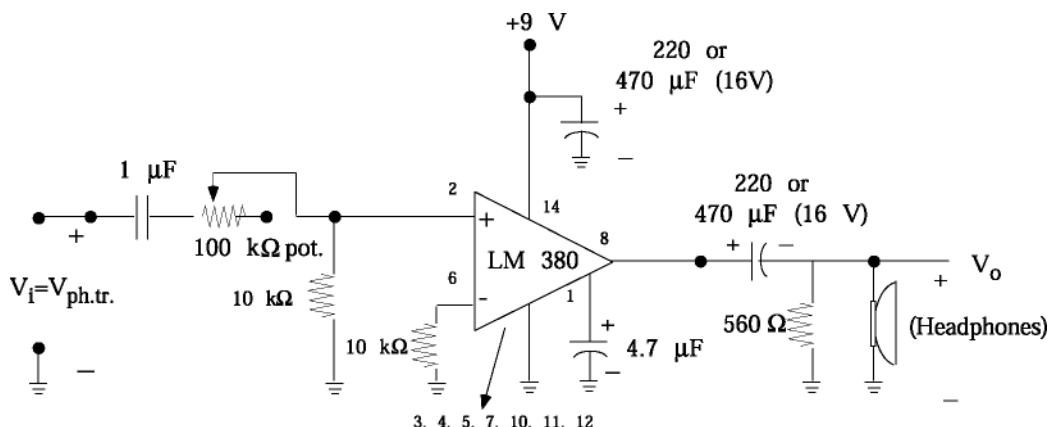

Agilent Function Generator

   b. ❏ Plot V_O (of the phototransistor) in time (V_{ppk} and V_{avg}) and frequency domains (f_o and several harmonics if possible). From the harmonic levels, is the LED operating in the linear region?

3. ❏ Repeat 2 but with Vs = 800 mVppk and 1.2 Vppk. You will notice that the diode output intensity becomes non-linear as the voltage increases and that you pick up second and third harmonic components (at the phototransistor) due to the v^2 and v^3 terms.

4. a. ❏ Set V_S = 600 mVppk, and using the knob, quickly sweep the frequency from 1 KHz to 40 KHz. In time or frequency domain, measure the phototransistor V_O and determine its 3-dB corner frequency (it should be around 25 KHz). Do not measure the frequency response.

   b. ❏ Change the waveform to a square wave at 1 KHz and expand the phototransistor output on the scope. Measure the risetime of the square wave (should be around 10 μs) and check that the risetime value agrees with the 3-dB corner frequency measured above (check problem 3 in Pre Lab #1).

5. a. ❏ The phototransistor will deliver the same current independent of the load resistor R. Replace the 1 KΩ load resistor with a 5.1 KΩ resistor and measure V_O at 1 KHz (with V_S = 600 mVppk). Is it 5x larger than the measured voltage with a 1 KΩ load?

   b. ❏ Do a quick frequency response and risetime measurement using the 5 KΩ load. What do you notice?

   c. ❏ Put back the 1 KΩ resistor in the phototransistor circuit.

2.0   A Photonic AM link:

First, we need to build an audio amplifier capable of driving the headphones which are supplied to you. This is very similar to Experiment #3 in the EECS 210 Lab.

1.   a. ❏ Draw the LM380 amplifier circuit with the phototransistor in your notebook.

       b. Connect the LM 380 as shown below on a close part of the circuit. Make sure to put the 470 µF capacitor between V_{CC} (+9V) and ground, and the 4.7 µF bypass capacitor at pin #1. (I did not put them in and the LM 380 oscillated!). The 100 KΩ potentiometer/10 KΩ resistor at the input is for gain control.

       c. Test the LM 380 audio amplifier at max. and min. gain settings (by putting a signal source at V_i and looking at V_O on the scope) at 1 KHz independently of the LED and phototransistor. After you are sure that it is working properly, connect the headphones to the output of the LM 380 audio amplifier.

2.   a. Connect the LM 380 (via the 1 µF capacitor) to the phototransistor and modulate the LED with a 200 Hz to 10 KHz sinewave with $V_S = 400$ mV$_{ppk}$ across the LED. Adjust the gain of the LM 380 to hear a clear undistorted tone. (You may also hear a hummmm and this is the 120 Hz pick up from the neon lights in the room.)

       b. Set V_S to 600 Hz and increase its amplitude to 1.2 V_{ppk}. Listen to the distorted signal. You are now driving the diode into the non-linear region and are hearing the second and third harmonic components of the audio signal.

       c. The TA will "shine" on you his/her transmitter which is connected to a tape player. Point your phototransistor in his direction and pick up the music. Write down which song/music did you hear.

       d. If you have a portable tape/CD player, bring it to the lab and connect it to the LED via the headphone jack. Change the volume level on the tape/CD player and listen to the music (and distortion for loud volumes). You can display the music in time or frequency domain by looking at the output of the phototransistor or the LM 380 amplifier.

3.0   A Really Cool Boy (and Girl) Scout Experiment:

The 20 mcd Agilent 3316 LED is quite powerful around the campfire, and can transmit/receive over a couple hundred feet with inexpensive plastic lenses (the type that you used for bug-boxes when you were a kid). Notice that the experiment above only required 9 V and therefore, can be built using two 9 V batteries. The input to the LED could be a tape/CD player, or simply a small electric microphone which you can buy at Radio Shack. If you have

small mirrors, you can deflect the LED beam around corners and trees and this is a cool experiment for kids of all ages.

Cost: The cost is minimal, less than $12 for the whole system.

LED:	$0.39
Phototransistor:	$1.00
LM 380 or LM 386:	$1.25
Resistors/Capacitors:	$2.00
Microphone:	$3.00
Headphone:	$3.50
Plastic Lenses (2x):	$0.50

(The LM 380 or the LM 386 are excellent audio amplifiers. The LM 380 has a fixed gain of 50 while the LM 386 has a variable gain from 20 to 200).

4.0   A Not-So-Cool Experiment:

You can actually build the same thing but with an infrared LED and therefore, the light is not visible. Using this simple AM link, you can communicate with an accomplice on exams, a very shameful and dishonorable thing that I hope you will never do (or you may very well be expelled from UM). The dollar cost is still $12 but it may cost you a lifetime!
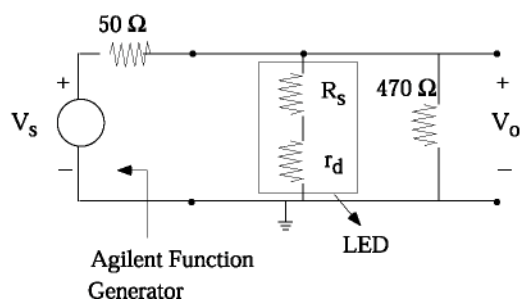

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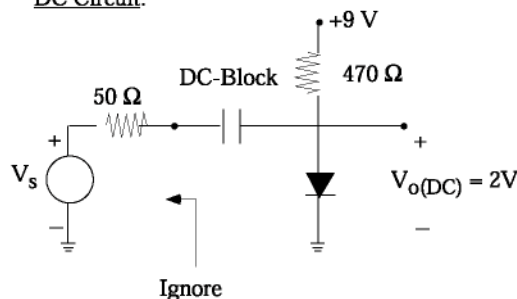
LEDs Phototransistors and an AM Photonic Link

Pre-Lab Assignment

1. An LED is biased at 15 mA from a 9 V battery using a 470 Ω resistor. The DC voltage across the diode is 2 V. It is driven by a 50 Ω ac-source at 2 KHz with $V_S = 400$ mV$_{ppk}$. The measured ac voltage across the LED is 80 mVppk. (The measured total voltage across the diode is $V_0 = 2$ V $+ V_{ac}$).

AC Circuit: DC Circuit:

Agilent Function Generator   Ignore

    a. Calculate the DC LED current and the ac diode resistance (r_d) for n = 1.5.

    b. Calculate the total ac resistance of the LED ($R_S + r_d$) knowing V_S and $V_{o(ac)}$. What is R_S?

    c. Calculate the ac current, I_{ppk}, in the diode. Calculate the voltage across the diode junction across (r_d). Is the diode operating in the linear region?

2. The speed of the Agilent 3316 LED is 90 ns (risetime). Knowing that the total ac (junction and series) resistance of the LED at a 15 mA bias current is around 18 Ω, calculate the effective ac capacitance of the diode? (You will see that it is much higher than the quoted capacitance of 11 pF and is due to the "diffusion capacitance" for the 15 mA bias current. You will study this in detail in EECS 320).

3. The Siemens BPX81-3 phototransistor response is given as $I_{photo} = 0.5$ mA for an incident power density of 0.4 mW/cm^2 at 830 nm (see data sheet).

    a. Calculate the phototransistor responsivity, k (A/W), at 830 nm and 620 nm, knowing that the acceptance diameter is 1.6 mm.

    b. The Siemens BPX81-3 phototransistor has a 6 µs risetime for a 1 KΩ load. Calculate the 3-dB corner frequency (see problem 3 of the Pre Lab #1). Calculate the effective C_{be} seen by R_e, the 1 KΩ emitter resistor. (You will see in EECS 311 that it is better to calculate the effective R_e seen by C_{be} and not the way we do it now).

    c. Does the photocurrent (I_{photo}) depend on R_e? Calculate the output voltage of the phototransistor (emitter voltage) for $R_e = 1$ KΩ and $R_e = 20$ KΩ with an incident power density of 0.1 mW/cm^2 (look at the data sheet. Do *not* use the acceptance diameter given above). Why would you choose a 1 KΩ load and not a 10 KΩ load?

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Lab Report Assignment

1. a. From the measured ac voltage division ratio at the LED for V_S=400 mVppk, calculate the total ac resistance of the Agilent 3316 LED. For n = 1.5 and the DC bias current in the LED, calculate the junction (r_d) and series resistance (R_S) of the LED. Calculate the ac current and the ac voltage across the diode junction (across r_d).

    b. Repeat (a) but for V_S = 800 mV$_{ppk}$ and 1.2 V$_{ppk}$. When does the diode start operating in the non-linear region?

    c. Write the measured fundamental and harmonic levels of V_O (at the phototransistor) and calculate the total harmonic distortion generated by the LED for V_S = 400 mV$_{ppk}$, 800 mV$_{ppk}$ and 1.2 V$_{ppk}$. Correlate your answer with (b) above.

2. The measured output resistance of a portable tape-player is 16 Ω. Calculate the maximum tape-player voltage (V_{ppk}) so that the LED does not generate a lot of harmonics.

3. a. Plot (approximately) the measured response of the phototransistor vs. frequency for R_e = 1 KΩ and R_e = 5.1 KΩ in dB/log f.

    b. Make sure that the measured risetimes for R_e = 1 KΩ and R_e = 5.1 KΩ agree with the measured 3-dB corner frequency.

4. The TA is shining his/her LED on you and you cannot pick up the signal well with the phototransistor and the LM 380 amplifier. If there is one and one single component that you can change to increase the signal on the headphones, which component would you choose and what is the maximum value that you would choose? Explain your answer.