

Implementation of a Fiberoptic Transceiver

1. Objectives

- Build a fiberoptic transmitter which takes as input an electric signal from a microphone and generates AM modulated light wave;
- Build a fiberoptic receiver which takes as input a light wave and generates electrical signal strong enough to drive a loud speaker;
- Get hands-on experience with wiring electronic circuits on breadboards;

2. Parts & Equipment

Part description	Part No	Quantity	Part description	Part No	Quantity
Microphone (Elctrit)	N/A	1	Resistor	47 Ω	1
Speaker (8 Ω)	N/A	1	Potentiometer (POT)	10K Ω	1
Fiberoptic cable	N/A	3 ft.	Capacitor	0.01 μ F	1
Resistor	1K Ω	1	Capacitor	0.1 μ F	2
Resistor	2.2K Ω	1	Capacitor	1 μ F	1
Resistor	4.3K Ω	1	Capacitor	10 μ F	1
Resistor	4.7K Ω	3	Capacitor	100 μ F	1
Resistor	5.1K Ω	1	Capacitor	220 μ F	1
Resistor	10K Ω	1	Operational Amplifier	LM358	2
Resistor	100K Ω	1	Operational Amplifier	LM386	1
Resistor	220K Ω	1	BJT NPN Transistor	N2222	1
Resistor	390 Ω	2	Photo-Receiver	SFH350	1
Resistor	150 Ω	1	Photo-Transmitter	SFH756	1

- **Equipment:**
 - Agilent 54261D Oscilloscope (for troubleshooting)
 - NI5411 Arbitrary Waveform Generator (optional)
 - NI4060 Multimeter (for troubleshooting)
 - 8102 Lodestar Power Supply

3. Motivation and Introduction

Light emitting diodes (LED) are used extensively in displays, remote controls and sensor systems (intruder alarms, etc. ...). You may be surprised to know that any pn diode emits light when biased, but only the LEDs are optimized to generate a lot of light and to allow this light to escape from the semiconductor.

A phototransistor is a transistor which is sensitive to the input light intensity. Basically, a small lens focuses the light to the base, and this light interacts with the semiconductor crystal and generates electrons (Fig. 3.1). The electrons are amplified by the transistor and appear as a

current in the collector/emitter circuit. This current is called the “photocurrent”. A phototransistor has only two leads since the base is internally left open and is at the focus of a plastic lens.

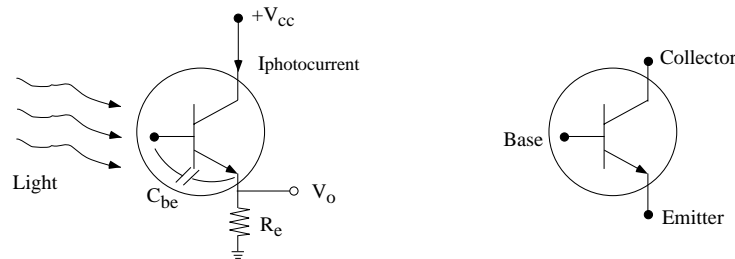


Figure 3.1: Schematic representation of a phototransistor. The base is generally not connected to the outside world.

In this laboratory you will build an AM photonic link which uses the LED as a transmitter, the phototransistor as a receiver, and uses a fiberoptic cable as a waveguide (medium which transports the light). The circuit will receive your voice through a microphone and convert your voice to an electric signal. Then the signal will be amplified and used to excite the LED which in turn will emit light. This light will be carried through the fiberoptic cable and received by the phototransistor. Then phototransistor will convert the light in a small electrical signal. This signal will be amplified and fed to an audio-amplifying circuit which will drive a loud speaker. So you will be able to hear your voice which traveled as light.

Although you will build a simple AM photonic link and use it to detect voice with a bandwidth of 20 KHz, you should know that the backbone of the terrestrial telecommunication system is based on this simple idea. The modern digital telephone system works this way (Fig. 3.2):

1. Take several thousand users at the local switching office and digitize their voice (analog/digital converters) at a sampling rate of 6 KHz and an 8-bit resolution. This means that a single user generates a data stream of 48 Kbit/second (with no compression) and around 16 Kbit/second with compression.
2. Put several of these users on the same line. If you can transmit 1.0 Gbit/second, this means that every second you can put around 60,000 users on the same line! Actually, you need to put timing signals on the line and also the destination information. So, let us say that you can put 30,000 users on the line. The unit that does this is called a “multiplexer”.
3. Modulate a laser diode (equivalent to the LED) digitally with the 1 Gbit/second information and put the output light of the laser diode in a fiber-optic cable. This is pure digital AM with “1”s and “0”s.
4. Run the fiber optic cable from NY to Chicago making sure to amplify the signal every 20 or so miles (since the light is attenuated a bit in the fiber-optic cable). The amplifiers are called “repeaters”.
5. Use a photodiode (similar to the phototransistor) at the receive end and take the 1 Gbit/second information and divide it down into the 30,000 different users and the destination information. This is called a “demultiplexer”.
6. Send each of the 30,000 different users to their respective destinations. This is called a “switching network” or a “routing network”.
7. Just before it arrives to the final destination, decompress the signal and pass it by a digital to analog converter. You now have a connection between NY and Chicago!

8. And, imagine that this is all done in about one second after you finish dialing a number!

P.S: If you are sending internet information, then you do not need the A/D and D/A converters at both ends.

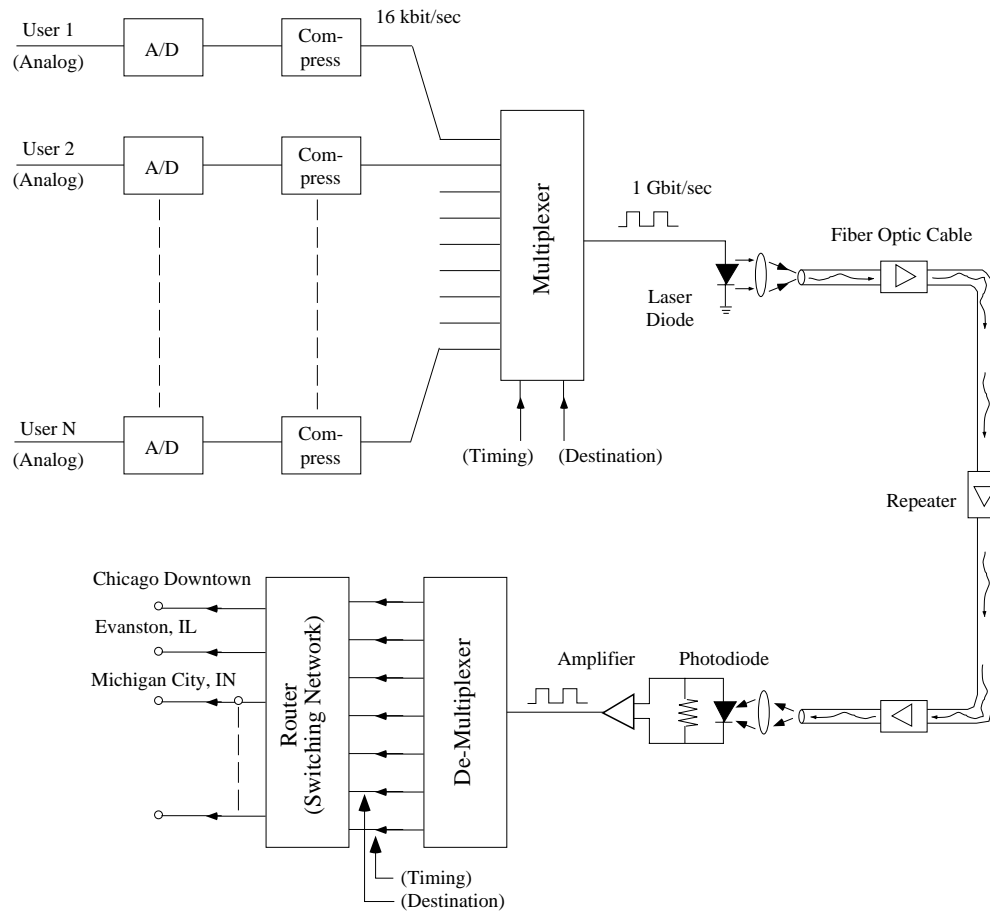


Figure 3.2: The optical digital telephone system.

4. Building the Transmitter Circuit

Figure 4.1 depicts the transmitter circuit together with the microphone and the amplifier. The figure has comments about each part of the circuit and what its purpose is. If you would like to find out more information about any part of the circuit use www.google.com to search the web. Use components names, i.e. LM358, or expressions like “single supply amplifier” etc.

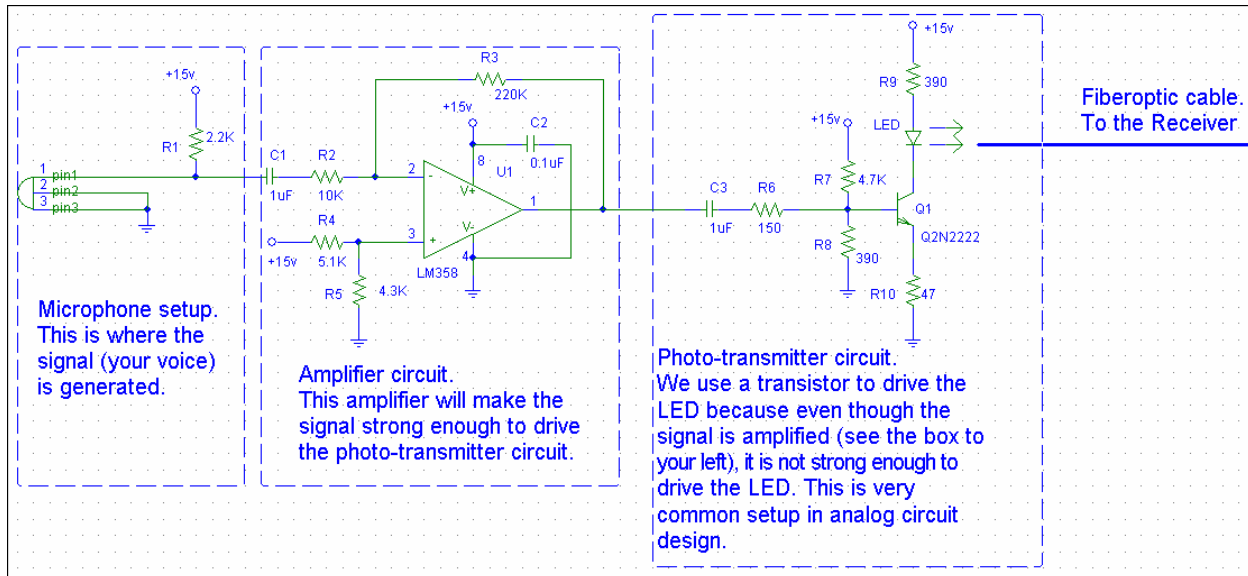


Figure 4.1: Schematic of the fiberoptic transmitter.

Wire up the circuit shown in figure 4.1. If you want a better picture of the schematic, there is a pdf file called “fiberoptic_transciever_schematic.pdf”. Here are the guidelines that you **must follow** when wiring up the circuit. **These guidelines are set in place so you will learn how to wire up neat and organized circuits on a breadboard!** We recommend that you follow these guidelines in all successive lab courses you take at MTU. **If you choose not to follow these guidelines, your T.A. will not help you with debugging your circuit.**

- **The blue line (top and bottom of the breadboard) is a common ground; Do not use it for anything else BUT ground;**
 - **The red line (top and bottom of the breadboard) is a common rail (+15V); Do not use it for anything else BUT +15V;**
 - **All wires going to ground are one consistent color (i.e. green, or black);**
 - **All wires going to rail are one consistent color (i.e. red or orange);**
- **Note on the use of decoupling capacitors in electrical circuit designs:** A common problem in all electronic systems is the inductance associated with power supply lines. When transistors in integrated circuits switch, the change in current can result in a significant voltage drop across power lines of a chip (dI/dt noise). DC supply voltage must be filtered from fluctuations and this is done by adding decoupling capacitors. The rule of thumb is to place a decoupling capacitor as close as possible to the pin on the chip that is connected to a power rail. In figure 4.1 in the “Amplifier Circuit” you can see that there is a capacitor wired between pin 6 (power) and ground. Note that pin 4 (ground) is also wired to ground. We recommend that you take a look at the data sheet for the LM358 to clear up any confusion that you (might) have. **From now on we will not show the decoupling capacitors in circuit diagrams. This does NOT mean that you can ignore them. You MUST put at least one decoupling capacitor per integrated chip, just like we have**

shown you in figure 4.1. Failure to do so will result in your circuit not working properly or even worse, working occasionally.

5. Building the Receiver Circuit

Following the guidelines outlined in section 4 wire up the circuit shown in figure 5.1. If you want a better picture of the schematic you can download the file “fiberoptic_transciever_schematic.pdf”.

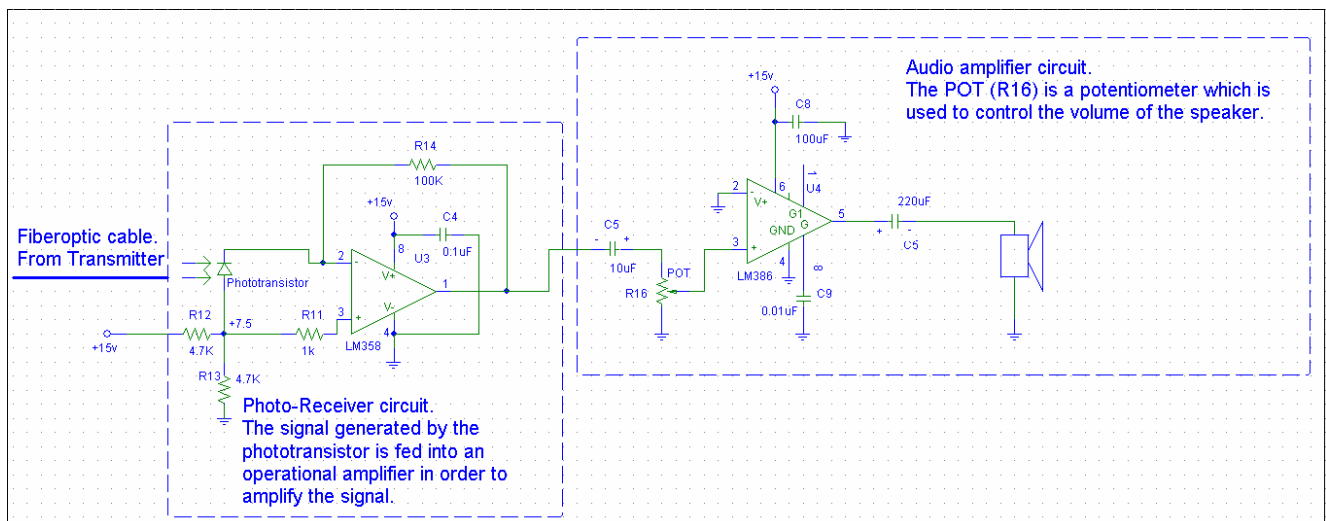


Figure 5.1: Schematic of the fiberoptic receiver circuit.

6. Testing Your Circuit

Before you power on your circuit have your T.A. inspect the circuit and sign the signoff sheet. When your T.A OKs your circuit, power it on! If your circuit is not functioning start debugging. Here are some helpful tips for debugging your circuit.

- Make sure the power is turned on;
- Using a voltmeter confirm that all chips on the breadboard are getting +15V on the proper pins. Refer to figure 4.1 & 5.1 to see which pins, on each chip, should be wired to +15V;
- Unplug the fiberoptic cable from the receiver end and see if there is red light emitting from the cable. If there is no light then there is a problem in your transmitter circuit; make sure your LED is connected correctly, in other words, the anode and cathode are connected as shown on the diagram in figure 4.1.
- If your receiver is receiving the red light from the fiber optic cable, make sure that the phototransistor is connected correctly.
- Check the POT (R16 in figure 5.1) to make sure the volume is not turned down all the way.
- Make sure all the resistors and all components are connected to the correct pins on each chip.

If all else fails get your T.A to help you with your circuit.

7. Consideration Questions

When writing the lab report for this experiment, answer the following questions:

1. What was the hardest part of this lab? Please elaborate!
2. From the experiment you saw that we can use light to send and receive information just like we do with wires. Name one thing that we can do with electricity that we cannot do with light. *Hint: A battery stores electric charge...*
3. What are decoupling capacitors?
4. Where are they used?
5. Does any PN diode generate light? What is the wavelength of the light generated by the LED that we are using in this experiment?

8. Reference:

LM386 – Data Sheet

LM358 – Data Sheet

Photo-transmitter (LED) – Data Sheet

Photo-receiver (Phototransistor) – Data Sheet

Appendix A

I. Introduction to LED's¹

Light emitting diodes (LED) are used extensively in displays, remote controls and sensor systems (intruder alarms, etc. ...). You may be surprised to know that any pn diode emits light when biased, but only the LEDs are optimized to generate a lot of light and to allow this light to escape from the semiconductor. The wavelength of the emitted light is proportional to the bandgap of the semiconductor and different materials are used to generate different light colors (Table 1).

Table 1: CHARACTERISTICS OF VISIBLE LIGHT-EMITTING DIODES (from M.G. Craford, "LEDs Challenge the Incandescents," *IEEE Circuits and Devices Magazine*, September, 1992).

Structure	Material	Bandgap type	Peak wavelength, nm (color)	Typical performance, lm/W
Homojunction	GaAsP	Direct	650 (red)	0.15
	GaP: Zn, O	Indirect	700 (red)	0.4
	GaAsP: N	Indirect	630 (red) 585 (yellow)	1
	GaP: N	Indirect	565 (yellow-green)	2.6
	GaP	Indirect	555 (green)	0.6
	SiC	Indirect	480 (blue)	0.04
Single heterojunction	A1GaAs	Direct	650 (red)	2
Double heterojunction	A1GaAs	Direct	650 (red)	4
	A1GaP	Direct	620 (orange)	20
	A1InGaP	Direct	595 (amber)	20
	A1InGaP	Direct	570 (yellow-green)	6
	GaN	Direct	450 (blue)	0.6
Double heterojunction with transparent substrate	A1GaAs	Direct	650 (red)	8

A cross-section of an LED is shown in Figure A.1. The small V-shape reflector behind the pn junction reflects the light emitted to the backside and therefore increases the forward light intensity. Also, a magnifying dome lens is placed in front of the diode to concentrate the emitted light in a narrow angle (typically 20-90°) from the boresight.

¹ This introduction was written by Prof. Gabriel M. Rebeiz, EECS Department, University of Michigan, Ann Arbor. All Rights Reserved

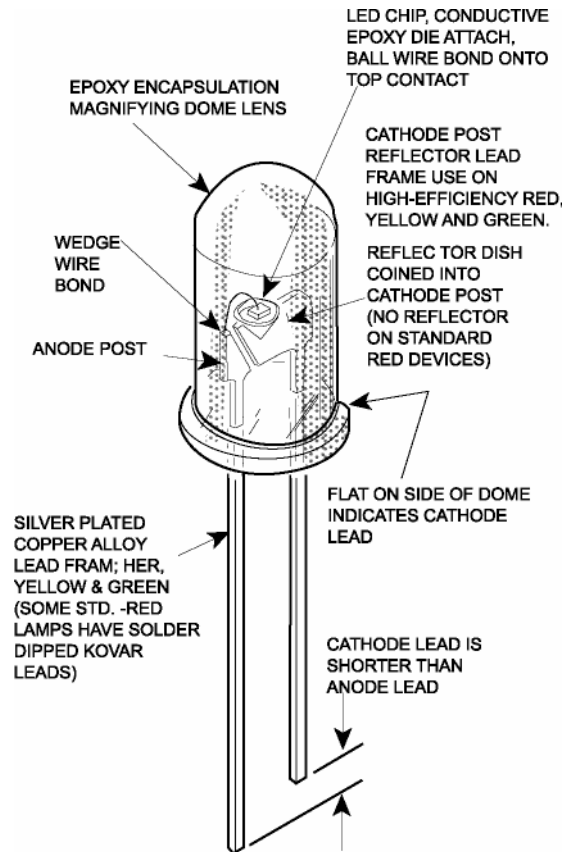


Figure A.1: An LED and its domed lens structure. (Courtesy of Agilent Technologies).

One of the main most confusing notations in LED (and photometry in general) is the Lumens and Candlelight units. The basic unit of power in SI units is W (or mW). When you have radiation, the basic unit of power is W/m^2 , (or mW/cm^2) and specifies the power density of light (or electromagnetic radiation) produced at a certain distance from the source. This means that if an LED produces an on-axis power density of $0.1 mW/cm^2$ at a distance of 10 cm from its location, and there is a detector with a capture area of $0.2 cm^2$, then the detector will capture 0.02 mW of power (Fig. A.2). This is easy and intuitive and all of the wireless/RF/microwave field relies on these units.

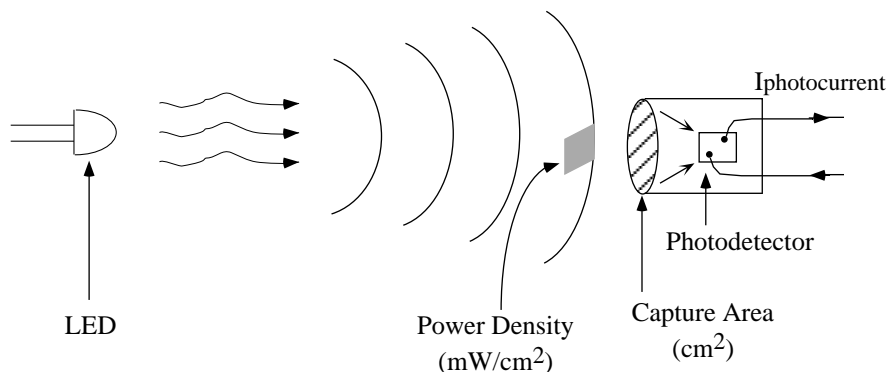


Figure A.2: Schematic representation of power density and capture area.

However, life is not that easy when the human eye is involved since its response is very sensitive to the wavelength of light (Fig. A.3a). The eye is most sensitive to 555 nm (greenish/yellow colors) and has about 20 times less sensitivity to the red or blue colors. So, if two LEDs, a green/yellow and a red one, are emitting the same amount of optical power in mW (or mW/cm²), then the green/yellow one will appear 20x brighter than the red one! Fig. A.3a is called the CIE curve (Commission Internationale de L' Eclair), a French commission which has set this standard since more than 100 years. So, rather than specifying an LED diode by the amount of optical power it produces in nice SI units such as mW (or mW/cm²), it is specified in *Lumens* or *millicandella (mcd)* and it is the unit of power as *perceived* by the eye.

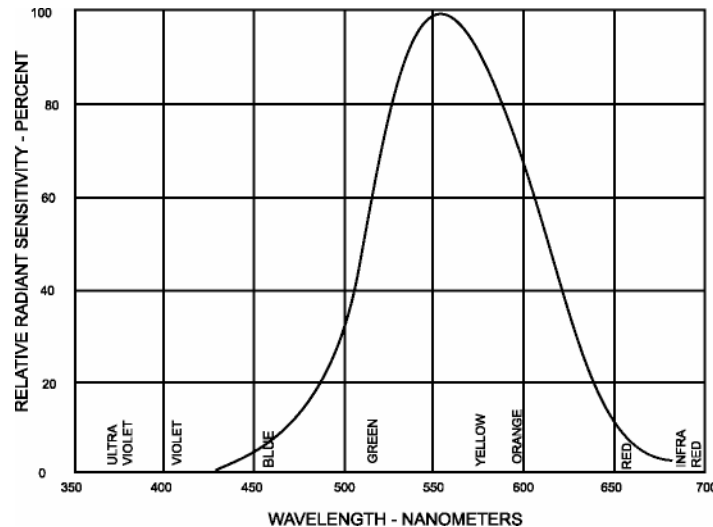


Figure A.3a: The CIE curve. From *Optoelectronics*, Vaughn D. Martin, p. 12.

II. Introduction to Phototransistors²

A phototransistor is a transistor which is sensitive to the input light intensity. Basically, a small lens focuses the light to the base, and this light interacts with the semiconductor crystal and generates electrons (Fig. A.4). The electrons are amplified by the transistor and appear as a current in the collector/emitter circuit. This current is called the “photocurrent”. A phototransistor has only two leads since the base is internally left open and is at the focus of a plastic lens.

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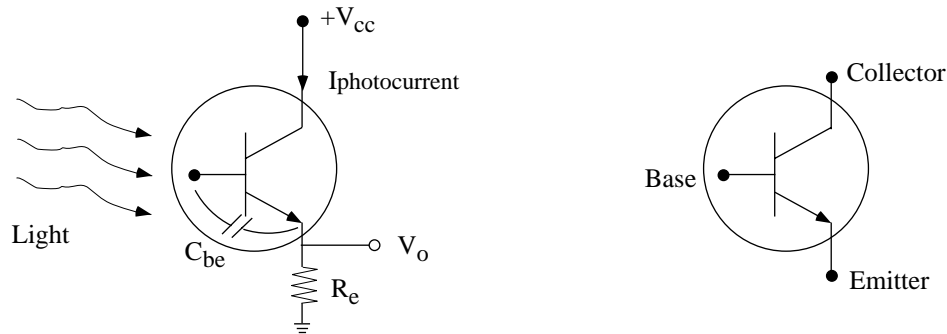


Figure A.4: Schematic representation of a phototransistor. The base is generally not connected to the outside world.

The photocurrent is specified in terms of Lumens (L_x) or in terms of incident power density (mW/cm^2), and is around 0.5 mA for an incident power density of $0.4 \text{ mW}/\text{cm}^2$. Another important spec. is the “dark current”, and as its name indicates, it is the current which flows in the collector-emitter circuit for no input light. This is basically the internally generated noise of the phototransistor and is the limiting factor to the sensitivity of the photo-receiver system. The speed of the phototransistor is limited by the base-to-emitter (C_{be}) capacitance and is specified in terms of the rise-time of the device. Since C_{be} interacts mainly with the load resistor (R_e), the rise-time is linearly dependent on R_e . For $R_e = 1 \text{ K}\Omega$ the rise-time is $6 \mu\text{s}$, meaning that it can follow accurately a 100 KHz square-wave modulation. Phototransistors are not fast devices, and for a faster response, it is best to use a *photodiode*. A photodiode is basically the input section of the phototransistor (collector-to-base section) and does not have an emitter and therefore, does not suffer from the C_{be} effect. However, it produces 40-200x less photocurrent and therefore must be always followed by a differential amplifier. It is possible to build photodiode-based optical receivers with response times of sub-ns and these systems can detect GHz modulation speeds. These detectors are used in high-speed fiber optic systems.

II.A Phototransistors and Square-Law Detection

The photodetection process is inherently a non-linear process since the output current, I , is proportional to input power (or light intensity), P , and therefore to the input voltage squared.

$$I = kP \text{ proportional to } V^2$$

where k is the detector responsivity and has units of A/W .

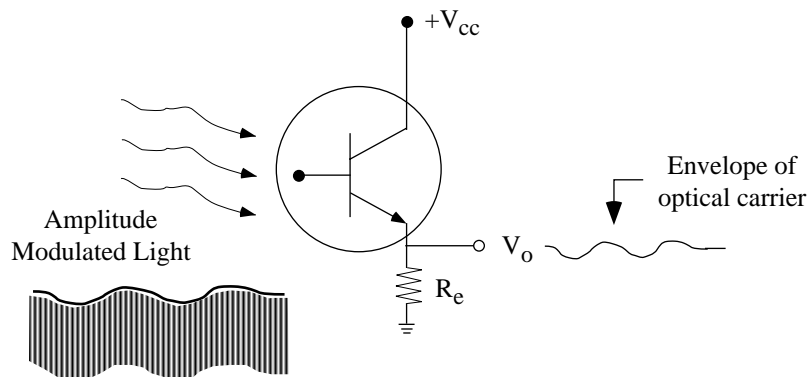


Figure A.5: A phototransistor as an AM demodulator (envelope detector).

Since the detection process follows the square-law rule, it automatically demodulates any amplitude modulation on the optical carrier, just as the diode AM demodulator! The output voltage across R_e is therefore the demodulated signal (Fig. A.5). If there is no amplitude modulation on the optical carrier, then the output voltage is a DC voltage and the phototransistor is acting as a square-law power meter (output dc voltage is proportional to the input power (or light intensity)).

With phototransistors, it is easy to explain the AM detection process using the time-constant approach. Remember that the phototransistor is a slow device and can only respond to changing signals of 1 MHz maximum. This means that it will surely not respond to the instantaneous optical signal (at 300 THz) and only to its envelope which is changing at KHz frequencies. Well, here it is, you have an *envelope detector* and therefore an AM detector!

T.A. Sign-off Sheet; Week - 1 -

Group Members:

1. The circuits shown in Figure 4.1 and Figure 5.1 are wired properly (or at least they will not blow up when powered up);

2. Demonstrate the functionality of the fiberoptic transceiver circuit;

Pre-lab Questions – Week 1

Student Name: _____

1. Read Appendix A of this document and draw the symbol for a diode (same as an LED). Label the anode and cathode on the diagram.

2. Draw the connection diagram for the LM 386 integrated chip. Number all of the pins and show the power connections to the proper pins (V_S and GND). Also show where you would place the decoupling capacitor and what value would you use.

3. Draw the connection diagram for the LM 358 integrated chip. Number all of the pins and show the power connections to the proper pins (V_S and GND). Also show where you would place the decoupling capacitor and what value would you use.

4. Draw the connection diagram for the 2N2222 transistor. Label the Base, Collector, and Emitter pins.