Hands-on Educational Experimentation with LEDs, Optical Fibers and Photodiodes in a Modern Technology Dependent Society

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Abstract. *In this paper we describe an experiment with LED circuit and photodiode circuit. We take measurements and study the device in both conditions: without and with optical fiber between LED and photodiode. With a second experiment, developed for demonstration purposes, we transport through optical fiber digital signal from transmitter of infrared light, suitably shaped, in corresponding receptor. We describe phenomena like light emission, the inverse square law of light emission, the photoelectric effect, the reflection and transmission of light. Also we mention the significance of LEDs, photodiodes and optical fiber applications in modern technology dependent societies.*

Keywords: Light, LED (Light Emitting Diode), Photodiode, Optical fiber, Fiber optics, Photon, P-N junction, Photoelectric effect, Photovoltaic effect, Emission, Total internal reflection

1. Introduction

The purpose of this study is to propose hands-on experiments with LEDs, optical fibers and photodiodes to non-major science university students. The didactical approach was applied during the academic year 2007-2008 to 143 students of Pedagogical Department for Primary Education of the University of Athens. [1], [2]

At the main experiment in the first case - without optical fiber - there is measurable current at the photodiode circuit only if LED and photodiode are very close each other (almost in touch). In the second case - with optical fiber - there is significantly increased current at the photodiode circuit. Is concisely mentioned the way of LED's and photodiode's operation, is pointed out their uses and is clarified from each other difference in the polarization and in the transformation of energy. Also there is a short report for the operation and the uses of each device. With a second experiment, developed for demonstration purposes, we transport through optical fiber digital signal from transmitter of infrared light, suitably shaped, in corresponding receptor. For the adaptation of voltage that it provides the photodiode is used an amplifier of common emitter while the LED is droved via amplifier of current from generator of square signals to optical fiber.

2. Theoretical framework

Modern fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber, a cable containing bundles of multiple optical fibers that is routed through underground conduits and buildings, multiple kinds of amplifiers, and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information generated by computers, telephone systems, and cable television companies.

In recent years it has become apparent that fiber-optics are steadily replacing copper wire as an appropriate means of communication signal transmission. They span the long distances between local phone systems as well as providing the backbone for many network systems. Other system users include cable television services, university campuses, office buildings, industrial plants, and electric utility companies. A fiber-optic system is similar to the copper wire system that fiber-optics is replacing. The difference is that fiber-optics use light pulses to transmit information down fiber lines instead of using electronic pulses to transmit information down copper lines. Looking at the components in a fiber-optic chain will give a better understanding of how the system works in conjunction with wire based systems. [4], [5], [6]

At one end of the system is a transmitter. This is

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the place of origin for information coming on to fiber-optic lines. The transmitter accepts coded electronic pulse information coming from copper wire. It then processes and translates that information into equivalently coded light pulses. A light-emitting diode (LED) or an injection-laser diode (ILD) can be used for generating the light pulses. The light (near infrared) is most often 850nm for shorter distances and 1,300nm for longer distances on Multi-mode fiber and 1300nm for single-mode fiber and 1,500nm is used for longer distances.The difference between LEDs and laser diodes is that LEDs produce incoherent light, while laser diodes produce coherent light. LED is a special diode that emits light when connected in a circuit and biased in the forward direction. Otherwise it is a semiconductor device that emits incoherent narrow-spectrum light when electrically biased in the forward direction. For use in optical communications, semiconductor optical transmitters must be designed to be compact, efficient, and reliable, while operating in an optimal wavelength range, and directly modulated at high frequencies.

The main component of an optical receiver is a photodetector which converts light into electricity using the photoelectric effect. The photodetector is typically a semiconductor-based photodiode. A photodiode is a type of photodetector capable of converting light into either current or voltage, depending upon the mode of operation.

A photodiode is a PN junction or PIN structure. When a photon of sufficient energy strikes the diode, it excites an electron, thereby creating a mobile electron and a positively charged electron hole. If the absorption occurs in the junction's depletion region, or one diffusion length away from it, these carriers are swept from the junction by the built-in field of the depletion region. Thus holes move toward the anode, and electrons toward the cathode, and a photocurrent is produced. When used in zero bias the flow of photocurrent out of the device is restricted and a voltage builds up. The diode becomes forward biased and “dark current” begins to flow across the junction in the direction opposite to the photocurrent. This mode is responsible for the photovoltaic effect, which is the basis for solar cells-in fact, a solar cell is just a large area photodiode. In photoconductive mode the diode is often reverse biased, dramatically reducing the response time at the expense of increased noise. This increases the width of the depletion layer, which decreases the junction's capacitance resulting in faster response times. The reverse bias induces only a small amount of current (known as saturation or back current) along its direction while the photocurrent remains virtually the same. The photocurrent is linearly proportional to the luminance.

Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communications. Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference. An optical fiber consists of a core, cladding, and a buffer (a protective outer coating), in which the cladding guides the light along the core by using the method of total internal reflection. The core and the cladding (which has a lower-refractive index) are usually made of high-quality silica glass, although they can both be made of plastic as well. Connecting two optical fibers is done by fusion splicing or mechanical splicing and requires special skills and interconnection technology due to the microscopic precision required to align the fiber cores. [4]

Light pulses move easily down the fiber-optic line because of a principle known as total internal reflection. "This principle of total internal reflection states that when the angle of incidence exceeds a critical value, light cannot get out of the glass; instead, the light bounces back in. When this principle is applied to the construction of the fiber-optic strand, it is possible to transmit information down fiber lines in the form of light pulses. The core must a very clear and pure material for the light or in most cases near infrared light (850nm, 1300nm and 1500nm). The core can be plastic (used for very short distances) but most are made from glass. There are three types of fiber optic cable commonly used: single mode, multimode and plastic optical fiber (POF). The light source is pulsed on and off, and a light-sensitive receiver on the other end of the cable converts the pulses back into the digital ones and zeros of the original signal.

3. Educational methodology

The experiments presented in this paper is a part of an application concerning the light and its applications. For the educational approach of the different actions that take place in this didactical approach, we suggest the scientific / educational

by inquiry model, which includes the following steps: 1. Trigger of interest 2.Hypothesis expression 3.Experiments 4.Formulation of conclusions and proposals - recording 5.Generalisation - feedback - control [1], [2], [3]. The application is a combination of software (simulations, visualizations, theory presentation) and experiments in laboratory (in the classical way). The platform of the lesson is the FrontPage program and the lesson has the five steps of the above mentioned educational model. Vvisualisations and simulations which contains are developed from us especially for this application-study in 3D Studio Max and Visual Basic 6.0. The experiment in the laboratory is based in a simple circuit with use of LED, photodiode and fiber optic. Also the experiment part is supported with seven visualizations and simulations related with the real experiment and explaining difficult topics such as stimulation of an atom, photon, emission of a photon, electric current etc. [2].
The intervention was performed at university students -3rd year students of Pedagogical Department for Primary Education, University of Athens, Greece during the academic year 2007-2008. The number of students participating in this study is 143, three classes of 36 each and one class of 35. In every class they are divided at 12 groups of 3 students each group. For the assessment of the proposal they fulfill pre, post and final tests. A pre-test questionnaire was used, consisting of 10 multiple choice questions, each with four answers (a, b, c, d). Duration of answering the questions: 20 minutes. After that there was a two hours laboratory lesson with the experiments presented.After one week a post-test questionnaire was used, consisting of the same 10 multiple choice questions as the pre-test. Duration of answering the questions: 20 minutes. Two months later there was a final-test consisting of the same 10 multiple choice questions as the pre- and post-test. Duration of answering the questions: 20 minutes. SPSS 10.0 was used for the statistical analysis. [2].

4. Experiments – Measurements

a. First experiment

Materials : power supply 12V or two batteries of 4.5 V, breadboard, cables, digital voltmeter, resistors, LEDs infrared and one red, photodiode infrared (BPW41), fiber optic cable 1m length.

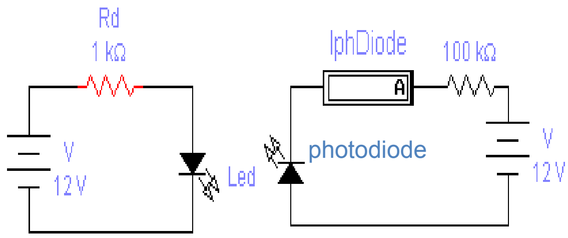

Figure 1 Circuit of the basic experiment

With the distance between LED and photodiode smaller than 2mm (almost in touch) we take the following measurements, whre IL is the LED current and Iph is the photodiode current

Table 1. LED current and photodiode current

R (Ω)	IL (mA)	Iph (μA)
120	26,4	111
220	13,9	110
470	7,13	109
680	4,90	108
1200	3,32	88
1800	1,96	56
2200	1,55	39

The LED is almost with transparent cover and placed very near the photodiode.

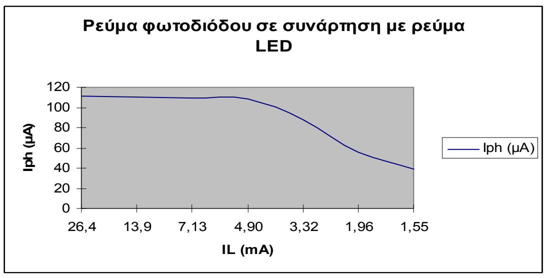

Figure 2. Graphic plot Iph (photodiode current) vs I_L (LED current)

We observe that roughly from value I_L = 4,90mA that corresponds in R=680 Ohm the current of photodiode that up to then was almost constant, it is decreased considerably. In the region 26,4mA> I_L > 4,90mA the number of photons that are incident to the photodiode is roughly constant, while for prices I_L < 4,90mA the number of photons that are incident to the photodiode is decreased considerably.

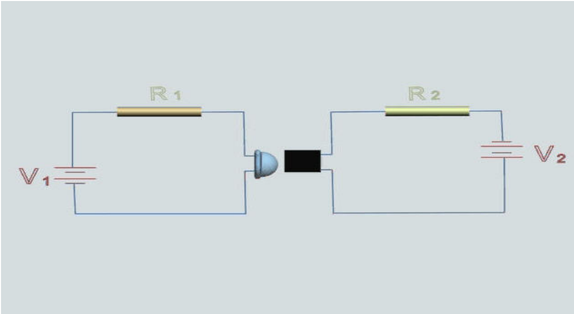

Figure 3. Design of the circuit (in 3D Studio Max)

If the distance between LED and photodiode is bigger than 1cm the photodiode current is very small (about zero). smaller than 2mm Is placed in the place of LED infra red with transparent cover a LED infra red with dark cover. Is not observed essential change in the current through the photodiode. Afterwards is placed in the place of LED infra red one red LED. Now the current through the photodiode is decreased too much. This happens because the photodiode is infra red, that is to say detects radiation in this range of spectrum ignoring the other radiation or presenting very small sensitivity in the other regions of frequencies. Removing LED infra red from the photodiode we observe that the current through the photodiode is annihilated. If however we connect the LED (transmitter) with the photodiode (receptor) via optical fibre then the circuit of photodiode has again current, which is smaller than that of initial topology (LED - photodiode in contact). This happens because in the fibre enters a “narrow” beam of total emitted from the LED radiation. But the light passes through the optical fibre and is transported through this without losses in big distances.

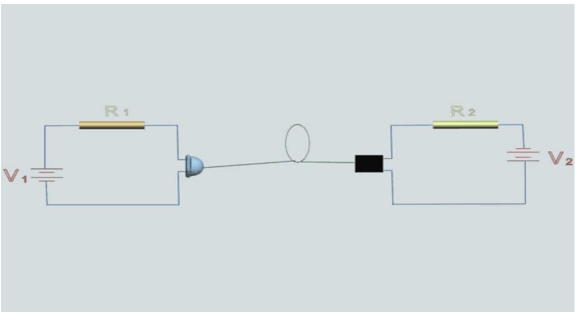

Figure 4. Design of the circuit with fiber optic

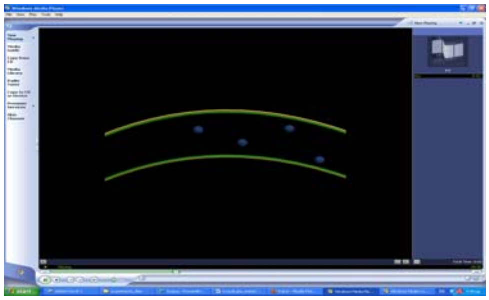

Figure 5. Visualisation of fiber optic and photons

b. Second experiment

Materials : power supply 12V, breadboard, cables, resistors, capacitors, transistor 2N2222A, LED infrared, photodiode infrared (BPW41), fiber optic cable 1m length, digital voltmeter, oscilloscope.

As demonstration experiment-generalisation, we transmit through optical fibre digital signal from transmitter of infrared light, suitably shaped, in corresponding receptor (IR link). For the adaptation of voltage that it provides photodiode (BPW41) is used an amplifier of common emitter while the LED is drived via amplifier of current from generator of square waveform. We regulate the frequency of generator in f=10 KHz with amplitude Vo = 1Vpp. It is used bias 12 V.

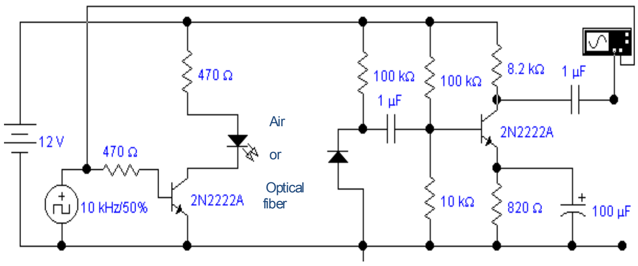

Figure 6. Design of the circuit

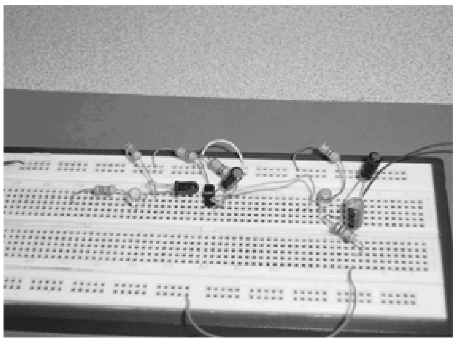

Figure 7. Circuit on breadboard for the second (demonstration) experiment

We observe at the screen of an oscilloscope the voltage waveform at the output (collector) of the transistor in the circuit of photodiode with optical fibre and without this.

Also we have a demonstration experiment with photodiode in zero bias and in reverse bias. We use an LED TSAL6100 and a photodiode BPW41N. We observe at the oscilloscope monitor the voltage waveform across the resistor in LED circuit and the resistor in photodiode circuit. First, in zero bias - this mode is responsible for the photovoltaic effect which is the basis for solar cells - we have the following figure.

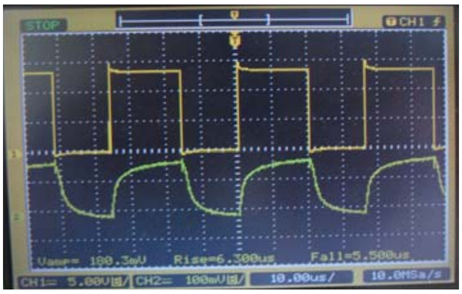

Figure 8. LED (up) and photodiode (down) voltage waveform with photodiode in zero bias

In photoconductive mode the diode is often reverse biased, dramatically reducing the response time.

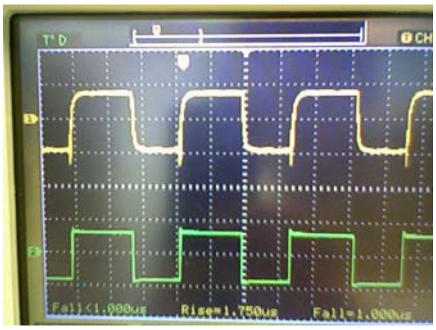

Figure 9. LED (up) and photodiode (down) voltage waveform with photodiode in reverse bias

5. Experiments' discussion –Main points

a. An LED is a special diode that emits light when connected in a circuit and biased in the forward direction. [1] b. A photodiode is a type of photodetector capable of converting light into either current or voltage, using the photoelectric effect. [2] c. An optical fiber consists of a core, cladding, and a a protective outer coating, in which the cladding guides the light along the core by using the total internal reflection for very big distances. d. The losses of light are negligible in his way in optical fibre concerning his way in air. The optical fibre bent in circle does not even present difference in its operation (light continues propagating). e. Light emission in the air follows the inverse square law. [3] f. Fiber-optic communication systems generally include an optical transmitter to convert an electrical signal into an optical signal to send into the optical fiber and an optical receiver to recover the signal as an electrical signal. The information transmitted is typically digital information. g. In photoconductive mode the diode is often reverse biased. h. We observe that the dynamic characteristics of receptor are improved with reverse bias.

6. Results from the tests

The mean value of degrees in pre-test was 5.89 and the mean value of degrees in post-test was 8.81. The mean value of degrees in final-test was 8.69 so slightly lower from it in post tests, which was expected.

7. Conclusion

In general the students worked with interest, systematically and most instructive objectives were achieved. Difficulties had the students in the use of multimeter. Before the exercise the students ignored the way of operation and use of LED, photodiode and optical fiber. The results were very encouranging. The activity is also proposed for the students of High school that have been taught the nature of light and basic

References

[1] Nikolaos Voudoukis, Sarantos Oikonomidis and George Kalkanis "Hands-on Activities with LEDs and Light" HSCI2006, 3rd International Conference on Hands-on Science, University of Minho, Braga, Portugal, September 4-9, 2006

[2] Nikolaos Voudoukis, George Kalkanis, "An Application and Assessment of a Model for Teaching / Understanding Photoelectric Effect in Non-Major Science University

Students / Prospective Teachers Education – – A Proposal for Scientific to Educational Models Transformation”, ESERA conference, IIstanbul, Turkey, August 31st - September 4th 2009

[3] Nikolaos Voudoukis, Sarantos Oikonomidis, Dimitrios Sotiropoulos, Nikolaos Voudoukis and George Kalkanis “Four Hands-on Activities Obeying the Inverse Square Law”HSCI2006, 3rd International Conference on Hands-on Science, University of Minho, Braga, Portugal, September 4-9, 2006

[4] John M. Senior, “Optical Fiber Communications Principles and Practice”, Prentice Hall International, 1992

[5] Paul E. Green, “Fiber Optic Networks”, Prentice Hall, 1993

[6] Govind P. Agrawal, “Fiber Optic Communications Systems”, John Wiley & Sons Inc., 1997.