

# STEM educational resource to send data via laser: using micro:bit and a USB GPIO module

U. Rivera-Ortega<sup>\*a</sup>

<sup>a</sup>Mechatronics division, Universidad Tecnológica de Puebla, Ant. Camino a la Res. 1002<sup>a</sup>, Puebla, Pue. 72300, México.

\*mecatronica00@hotmail.com

## ABSTRACT

Electronic communication is a very important and widely used topic in the field of Engineering and Physics. Due to this, it is relevant for educators and students to have an educational resource with the aim of easing the teaching/learning process regarding to the concept and basics of this topic. In this manuscript, it is presented a novel prototype that sends and receives single character or string via a laser and fiber optics, allowing the manipulation of the hardware and software involved. The characters are coded and sent by modulating the duration of the laser light pulses (pulse width) by using LabVIEW through a USB GPIO module; while the reception and decoding of the characters are achieved via a photoresistor module and a micro:bit board, respectively. A qualitative demonstration regarding to the application of light intensity and beam division is also included.

**Keywords:** STEM resource, communication, optical fiber, education.

## 1. INTRODUCTION

In general, the aim of communication technologies is to send/receive information accurately, quickly and without losses. The commonly used communication media in electronic systems is a conductive wire, lacking in some cases of these desired characteristics. Lasers have been used in communications for years, for instance, when reading a CD, DVD, blu-ray disk or a bar code. However, nowadays lasers are being used for point-to-point wireless communications. Compared to other light sources, laser beams are narrow and have less divergence; therefore, communications with lasers are less susceptible to interference [1]. So, they are used in different areas such as experimental laboratories, aerospace, telecom, space communications (NASA's Lunar Laser Communication Demonstration, LLCD, has made history using a pulsed laser beam to transmit data over the 239,000 miles between the moon and Earth at a record-breaking download rate of 622 Mbps [2] (megabits per second) and defense, to name a few.

Basic laser communication uses a transmission and reception module, which converts digital signals to laser light and senses-converts it back to a digital signal, respectively. Free-space optics is an example of this kind of communication technology. Nevertheless, alignment is an important issue to consider when using free-space laser beams in optical communication since a misalignment result in less efficient data transfer [3].

In order to overcome this drawback, optical fiber has revolutionized the world of communication throughout the last decades because of its multiple advantages, acting as a waveguide for light and working under the principle of total internal reflection; resulting in a significant improvement in the velocity of the transmission and the long distances that it can cover with a minimum data-loss.

It is known that there are currently various experiments and prototypes of different brands and costs that allow demonstrating the sending of data through a laser beam and fiber optics (generally sending audio). However, these do not allow the student or user to verify how the information sent is encoded and decoded (whether in amplitude, phase, or amplitude and phase). In addition, due to the fact that they are closed systems, they do not allow modifications to the hardware or software involved. Because of this, and due to the wide and vast use of laser and fiber optics in communications and in general in Engineering and Physics education, it is proposed a novel and interactive educational STEM resources with the aim of improving the understanding of these topics geared toward undergraduate engineering students; in which the drawback aforementioned are overcome.

## 2. GENERAL CONCEPTS

In a simple communication system, the input signal passes through a transmitter that modulates and encodes it to form the transmitted signal. The transmitted signal, in turn, propagates through a communication channel until it is delivered to the receiver, then demodulated to form the output signal [4]. Figure 1a) shows the general scheme of a communication system, while figure 1b) show its correspondence to the proposed educational resource setup.

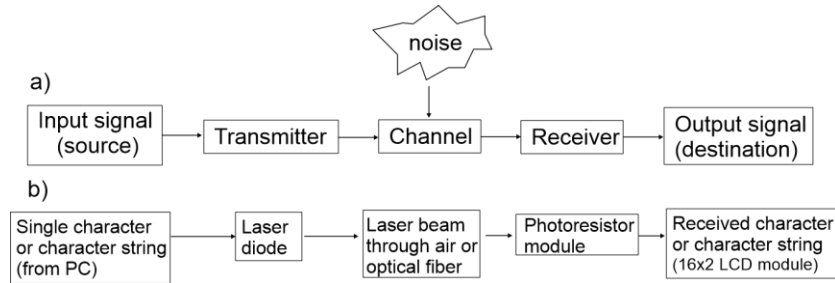


Figure 1. General scheme of a communication system.

A simple way to demonstrate the ability of light to carry information can be seen in Graham Bell’s experiment. At the end of the XIX century, he attached a microphone to a mirror in order to transmit voice through hundreds of feet via reflected sun light and directed to the reception module [5].

Instead of using an electrical signal that travels through a conductive wire, communications with light as a transmission media is a way to increase the capacity to transport information through free space or waveguides such as optical fibers. Being the first true long-distance optical fiber application developed by Corning Glass in the early 1970’s [5].

Optical fibers can be made of glass or plastic and are composed of three main parts: the core, the cladding and the coating. The core is the center of the optical fiber which size can vary from 3.7  $\mu\text{m}$  up to 980  $\mu\text{m}$ , depending of the required application. The cladding surrounds the core and has a lower refractive index than the core (commonly  $n_2=1.47$  and  $n_1=1.49$  respectively). Finally, the coating is the layer that protects the optical fiber from shocks, nicks, moisture or other agents that can damage the fiber. The coating is usually made of acrylate, silicone, carbon, polyimide and other similar materials.

When light travels from a denser ( $n_1$  in the core of a fiber) to a less dense medium ( $n_2$ , in the cladding of a fiber), it tends to bend towards the media interface and refracts away from the normal line. So, when the approaching ray exceeds a critical angle ( $\theta_c$ ), the ray will be completely reflected back into the first medium (the core). In optical fibers, the acceptance angle  $\theta_a$  (the half of the angle of the acceptance cone) is the maximum angle of incidence within which an element accepts light. In this way, a ray that enters the fiber at a critical angle will propagate only with total internal reflections. It also allows the calculation of the numeric aperture of the fiber ( $NA = \sin \theta_a = n_2/n_1$ ), which is related to acceptance angle that ensures the total internal reflection of the incident light and also determines the size of the core [6-7].

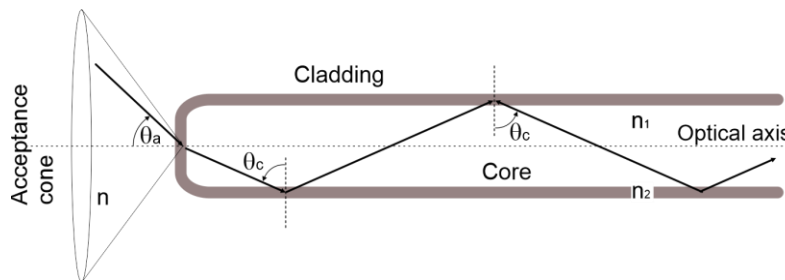


Figure 2. Principle of light propagation in optical fibers due to the difference in refractive indexes.

A very important process in communication systems is the concept of signal modulation, allowing signals to transmit information from two points through a communication channel. In this implementation, square waves with different pulse width were used to transmit digital signals containing single or character strings. Figure 3 shows a periodic wave signal, indicating its amplitude and period [8].

Amplitude defines the height of a pulse in a train, pulse width defines the width of each pulse and frequency defines the rate of each of them.

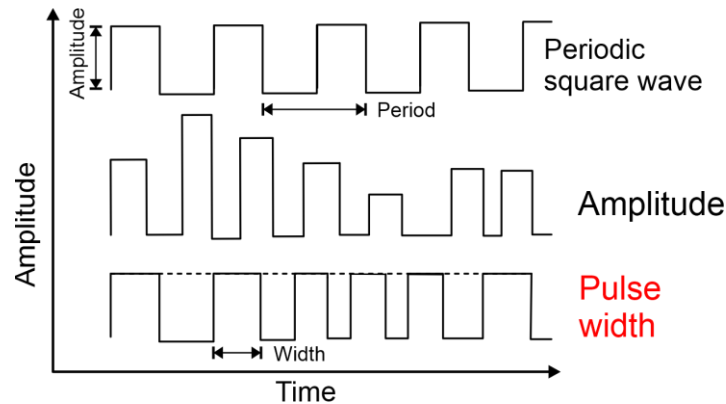


Figure 3. A periodic digital square wave with different amplitude and width.

A fiber optic was also used with the aim of transporting and guiding the laser light that carries the signal (width modulated) containing the coded character string, which will be finally detected and decoded at the end of its path.

### 3. IMPLEMENTATION

The basic principle of the proposed STEM resource relies on the codification of a single or character string (typed on a “String to Send” LabVIEW window). This coded signal will be the input of a generic laser diode (650nm, 5mW) using an output pin of an 8-channel USB GPIO module (Numato Lab), also programmed in LabVIEW using VISA configuration. Then, the coded signal will be transmitted through air or using an optical fiber. When the light is detected by the photoresistor module, it is decoded (using a micro:bit board and MakeCode open source platform) and then converted again into the original signal. After this, the sent characters will be displayed in a 16x2 LCD. The elements included in a basic communication system with light, can be observed in Figure 4.

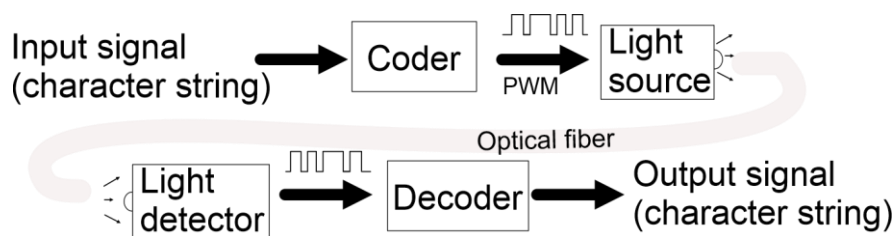


Figure 4. Basic elements of a communication system with laser with/without fiber optics.

As mentioned before, a single character or string will be coded in a digital pulse with the same amplitude but different width. To accomplish this task, each letter in the alphabet will be assigned to a single pulse with different width. Indicators for an empty space (“\_”) and to clear the LCD are also included in this assignation. This modulation can be interpreted as an “on-off” or duty cycle modulation. Figure 5 illustrates the assignation of different pulse width according to each character or action.

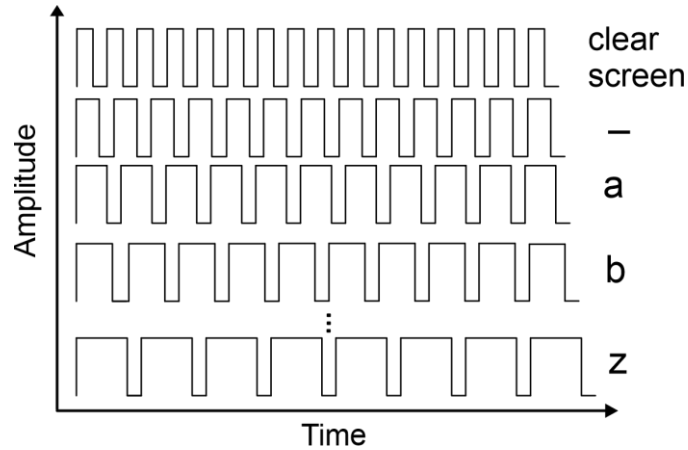


Figure 5. Square signals with different widths regarding to each character or action.

Once the data is sent via laser light, the light detected by a photoresistor module (receiver) is decoded by comparing its time-duration with the character or action assigned in a “text list” programmed in micro:bit MakeCode. Finally, the original message will be displayed in a 16x2 LCD.

The schematic containing all the hardware used in the proposal (USB GPIO, micro:bit, photoresistor module and 16x2 LCD) is depicted in Figure 6.

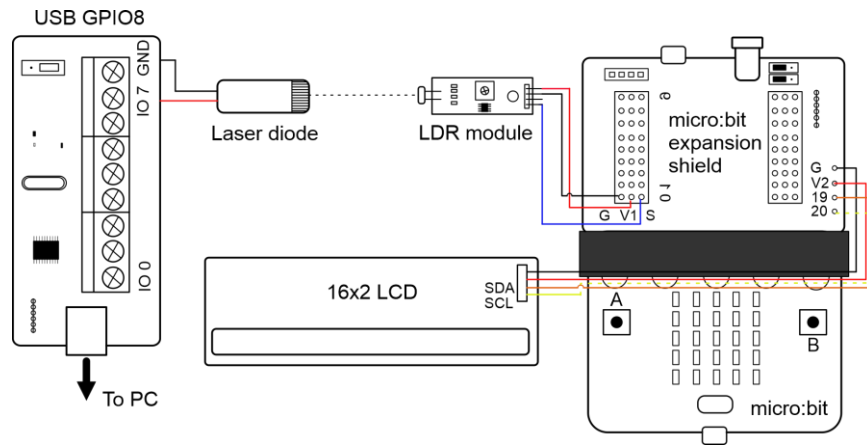


Figure 6. Schematic of the didactic resource.

The experimental setup was mounted over a monitor stand riser, using its holes to screw the electronic components as well as the 3D printed laser and sensor bases and holders (Figure 7). The holes in the stand ease the manipulation and alignments of the components. A version of the setup using optical fiber as a transmission media is shown in Figure 7 b).

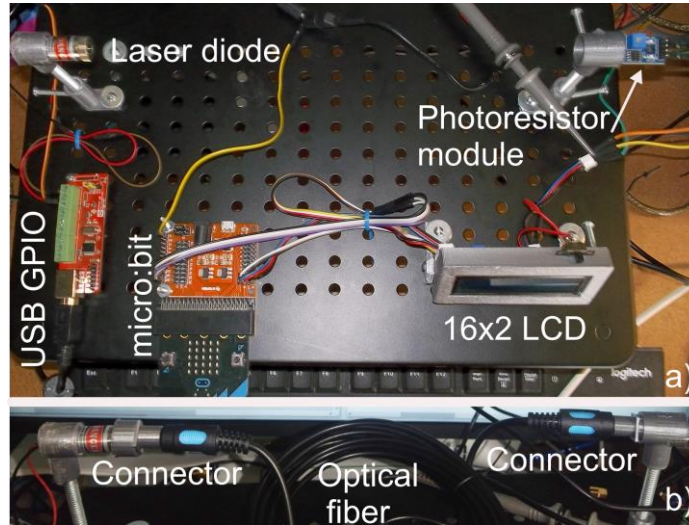


Figure 7. Experimental setup indicating all the hardware, connectors and optical fiber.

#### 4. CODING AND TESTING

This educational resource has two modalities of data sending: a) a single character typed with the computer keyboard, and b) a string typed in a “String to send” control. The computer programs corresponding to the coder and decoder stage are designed in LabVIEW and MakeCode, respectively. Figure 8 shows a section of the program written in LabVIEW regarding to the coding for the single character and string options.

The width of each letter pulse is assigned with a numeric value by using a “case structure”. This output pulse will be sent through the USB GPIO with a VISA resource (Figure 8 c)) and used as the input of a generic laser diode.

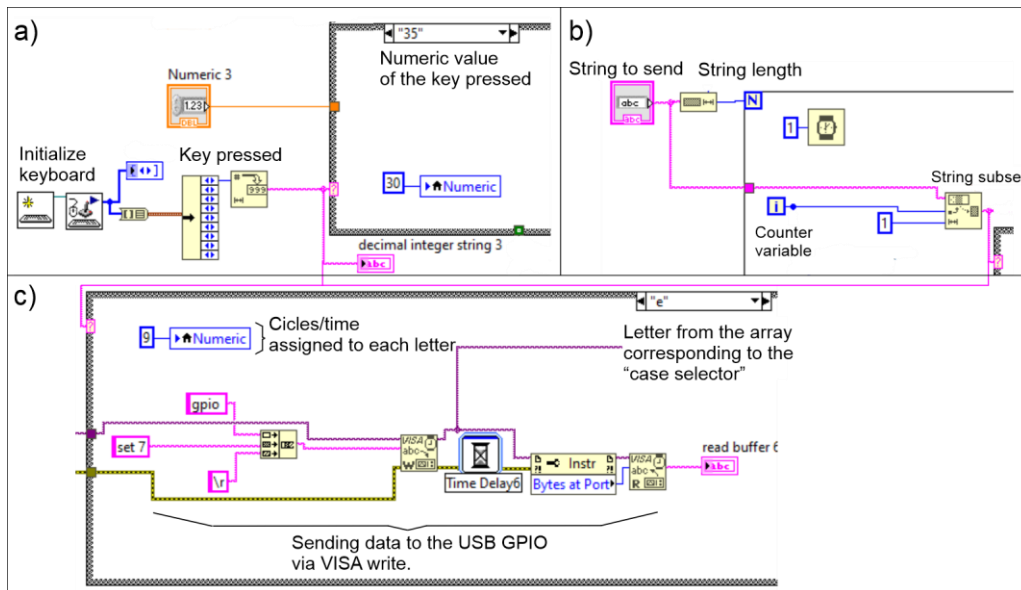


Figure 8. a) Section of the LabVIEW coding algorithm regarding to the single character or b) string. c) The time assigned to each letter with a “case” structure, including the VISA write.

Figure 9 a) depicts a section of the decoder stage programmed in micro:bit MakeCode. The light emitted by the laser will be received by the photoresistor module. Its sensing time duration will generate an input decoded pulse, by comparing it to a preset letter position in a “text\_list” (array). When the photoresistor stops detecting light, the LCD cursor will move one position to the right in order to write the next character (Figure 9 c)) and one position will be incremented in the array to continue writing the following character.

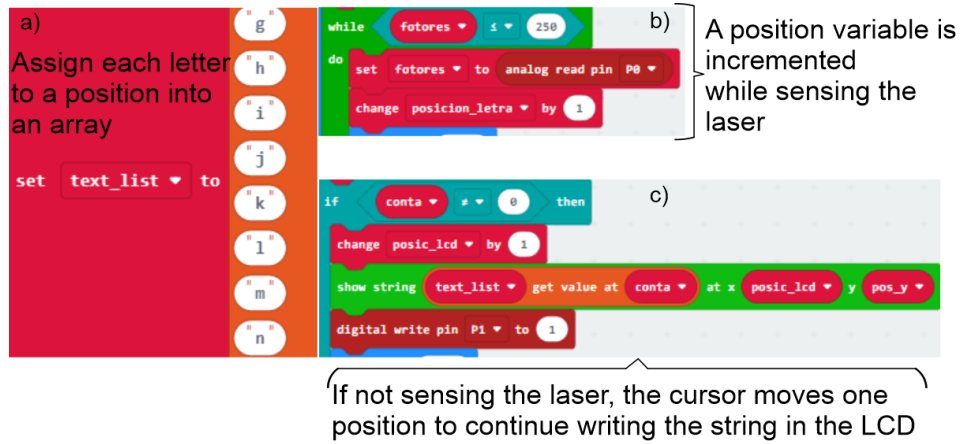


Figure 9. Section of the decoding program and letter positioning, written in MakeCode.

## 5. USER INTERFACE

By following the coding methodology explained in the “implementation” section and depicted in Figure 5, the experimental output and input signal (measured with the use of an oscilloscope) are shown in Figure 10. In this figure, the signal in the top (yellow) represents the output coded signal carrying the message “hello there”. The width of each pulse regarding to each letter is also indicated. In the bottom of the figure (blue), the received light from the laser is depicted, being possible to observe that the pulse width is the same as in the original signal (it is shown inverted because of the configuration of the photoresistor module).

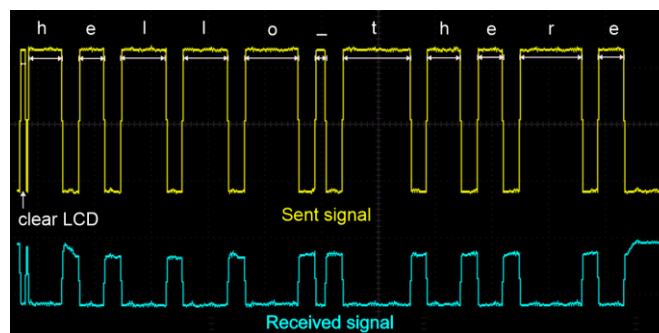


Figure 10. Experimental sent and received signal measured with an oscilloscope.

Before starting the LabVIEW user interface, the VISA module should be configured with the right COM port (VISA resource name). Figure 11 a-b) depicts the user interface corresponding to the single character and string application, respectively. In the first application, each character will be typed by using the computer keyboard, till the desired output string is formed. In the second application, the “string to send” must be typed before running the VI (LabVIEW virtual instrument). Then, it can be argued that a group of simple characters form a string.

The program will show the current character being sent (“Sending character”) and, when it is successfully sent, a green indicator will be turned on. The program will automatically stop when the “string length” is reached (also indicated with a blue boolean indicator).

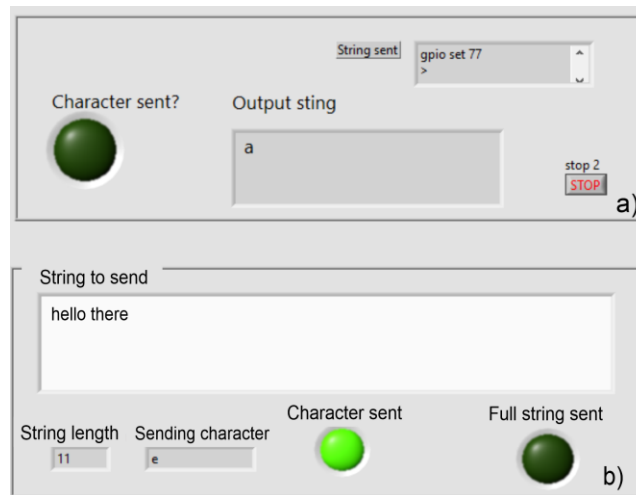


Figure 11. LabVIEW user interface regarding to the a) single character and b) string sending.

## 6. BEAM SPLITTER AND LIGHT INTENSITY

Two essential topics in the field of Optics and optical communication are: light intensity (power from the source per unit area [9]) and beam division. Both can be qualitatively explained with this demonstration by dividing the beam into two beams of equal intensity using a 50R/50T (50% of the total intensity for transmission, and 50% for reflection) beam splitter. The intensity division will not affect the encoding since the encoding is based on pulse width modulation and not intensity modulation. However, the intensity threshold sensed by detector PR1 and PR2 will change and it will be necessary to modify the analog input parameter in the programming code. So, including a beam splitter (BS) will allow the student to have qualitative and empirical knowledge of how a change in light intensity can affect, for instance, optical communications.

Figure 12a-c) represents some commonly used BS in optical workshops, such as cube BS, half-silvered mirrors and pelicle BS, respectively.

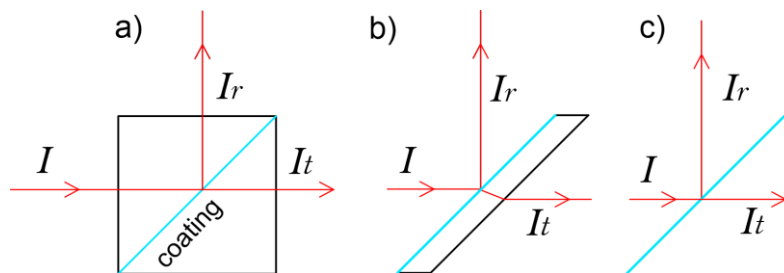


Figure 12. Some examples of light beam splitters.

$I$ ,  $I_r$  and  $I_t$  are the total input, reflected and transmitted intensity of the light beam after reaching the splitter. Each BS is designed to reflect and transmit certain percentage of the input beam intensity. In the present implementation, a 50R/50T BS was used. This means that in the computer coding, the input parameter for the photoresistor sensors PR1 and PR2 should be the same.

The intention of dividing the laser beam that carries the coded text message into two beams of the same intensity is to emulate a fiber optic beam splitter which distributes the input signal among two or more fibers, used in most fiber-optic networks. In figure 13, an optical line terminal (OLT) sends a message “abcd” trough an optical fiber, which sends the

same message through different lines by means of the splitter. Finally the message reaches different optical network terminals (ONT).

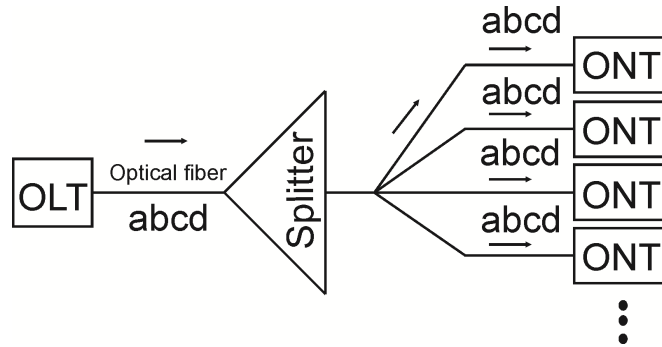


Figure 13. Optical fiber splitter.

In order to emulate the use of an optical fiber beam splitter, a 50R/50T flat light beam splitter was used in the experimental setup. The light beam carrying the text message will be divided into two beams of the same intensity and detected by PR1 and PR2, such as in a 2 way fiber optic splitter. Since both sensors receive the same message, it will be decoded and shown in LCD 1 and LCD 2, as shown in the experimental setup depicted in Figure 14.

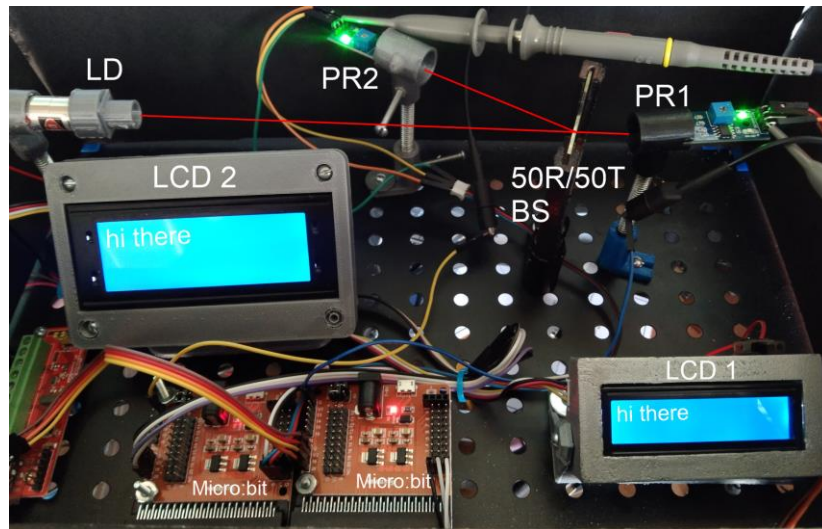


Figure 14. Experimental setup with the beam splitter.

Figure 15 shows a coded signal (“hi there”) divided by the BS, received by PR1 and PR2 and measured by means of an oscilloscope. Both signals detected by Sensor 1 and Sensor 2 presents the same width and amplitude as it was expected by passing through the BS.



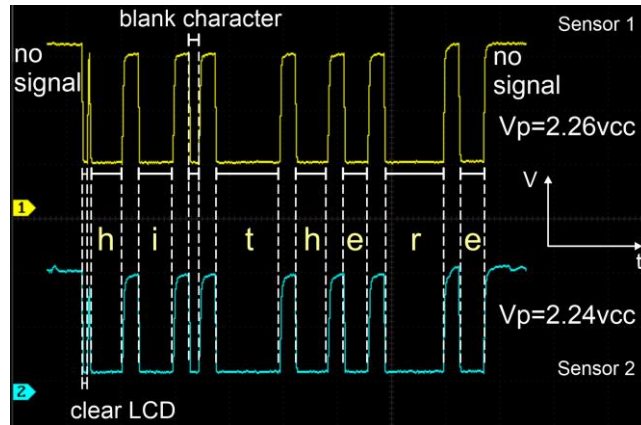


Figure 15. Experimental splitted signals measured with an oscilloscope.

As a suggestion, the light intensity can be kept approximately constant so that it does not affect the sensing, if the experiment is enclosed in a black box (for example, using cardboard painted black, as shown in Figure 16).

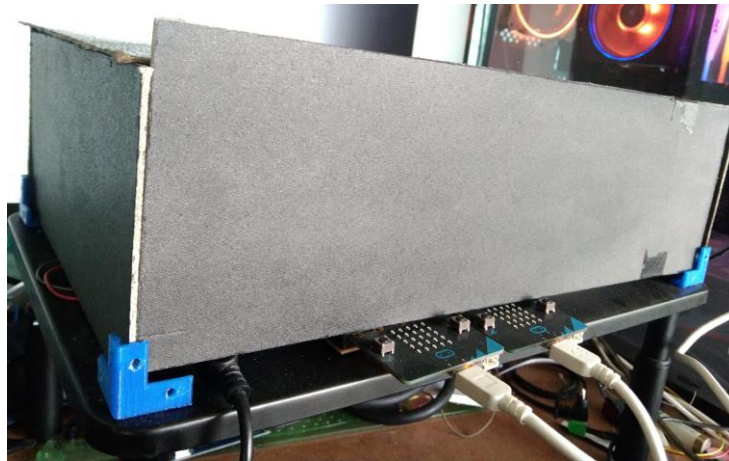


Figure 16. The setup enclosed in order to keep a constant light intensity.

## 7. GENERAL CONCLUSIONS

It was presented a simple and interactive educational STEM resource with the aim of easing the teaching/learning process [10-12] regarding to the topic of communication with light, having as a particular case, the data transmission through light from a laser diode. The emission and reception were carried out using air or optical fiber as its transmission media. However, due to the hardware, software and programming languages used in the complete implementation, this educational resource also encourages graduate or undergraduate students to get involve in other areas of knowledge, such as: general physics or experimental physics, electronics and programming.

Light intensity and division of a light beam has also been qualitative covered in this implementation by showing their application when sending data through optical fibers by coding a message via laser pulse width modulation. Since the laser beam has been divided into two parts (not necessarily equal in amplitude depending on the beam splitter used), the information carried by each of the beams is the same, although not necessarily in their amplitude.

It must be noted that this resource was implemented in a single computer for demonstrative purposes, however, the method can be replicated by using two different computers in order to increase the distance between the emitter and the receiver, so that the reliability over long distances of the optical fibers can be widely demonstrated. Also, it would be possible to setup get a two-way communication system, by adding a receiver and transmitter in the transmission and

reception section (also including the hardware that it implies), respectively. In order to accomplish this task, the software should also need to be modified. However, it should not be a difficult task by following the methodology proposed in this implementation.

Finally, it should be noted that many of the component mounts were 3D printed, thus reducing the cost of assembly and encouraging the student in CAD design for scientific applications.

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