BRINGING OPTICAL COMMUNICATIONS TO THE GENERAL PUBLIC: AN INNOVATIVE BACHELOR THESIS

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Abstract

The United Nations "International year of light 2015" strives to highlight the importance of optical technologies in our everyday lives. Fibre optic communication is one such technology: the growth of internet and its associated services are enabled by the vast transmission bandwidth provided by optical networks. However, the general public is not well aware of the optical and electronic fundamentals of the underlying transmission systems. Here we present the development of a bachelor thesis in Telecommunication Engineering in which a small-scale fibre-optic link is built and the electronics required to transmit music over this link are implemented. The resulting system demonstrates, in a very intuitive way, how information is transmitted over an optical fibre.

Keywords: Optical communications, bachelor thesis, project-based

1 INTRODUCTION

As recognized by the United Nations "International year of light 2015" [1], fibre optic communication is a key technology in modern societies, enabling the continuous growth of internet services such as e-commerce, video streaming and social networks. Optical communications is thus a key subject in virtually any bachelor degree in telecommunications. Understanding and designing an optical communication link requires knowledge in a variety of topics, including:

- The physics of light propagation in an optical fiber (ray optics in multimode fibers, and modal analysis in single mode fibers).
- The electronics used to convert the signals between the electrical and optical domains (including light sources and detectors).
- The modulation techniques used to convey analogue or digital information over the optical link.

In a typical bachelor degree, each of the above topics is covered in detail in a specific course. A bachelor thesis can then offer a convenient framework to face the student with the problem of designing a (simplified) end-to-end optical communication system.

Given the temporal constraints of a bachelor thesis, which within the European Higher Education Area is limited to a few months' work, the overall system has to be relatively simple and well delimited in its implementation. At the same time, it should provide a strong motivation for the student, challenge a broad array of his/her skills and foster autonomous problem solving. Here we present a bachelor thesis carried out in the framework of a project in innovate teaching during the academic year 2014/2015 and that fulfills the above criteria. The project focusses on building a simple fiber-optic communication system that demonstrates the transmission of an audio signal, such as music or speech [see Fig. 1]. The resulting system is an educational tool on its own that can be used to introduce optical communication techniques to first-year students or the general public.

This paper is organized as follows. In section 2 we briefly describe the technical background that is required to carry out the project. Section 3 deals with the educational approach that was used to supervise the thesis, and section 4 summarizes the results. Finally, in section 5 conclusions are drawn.

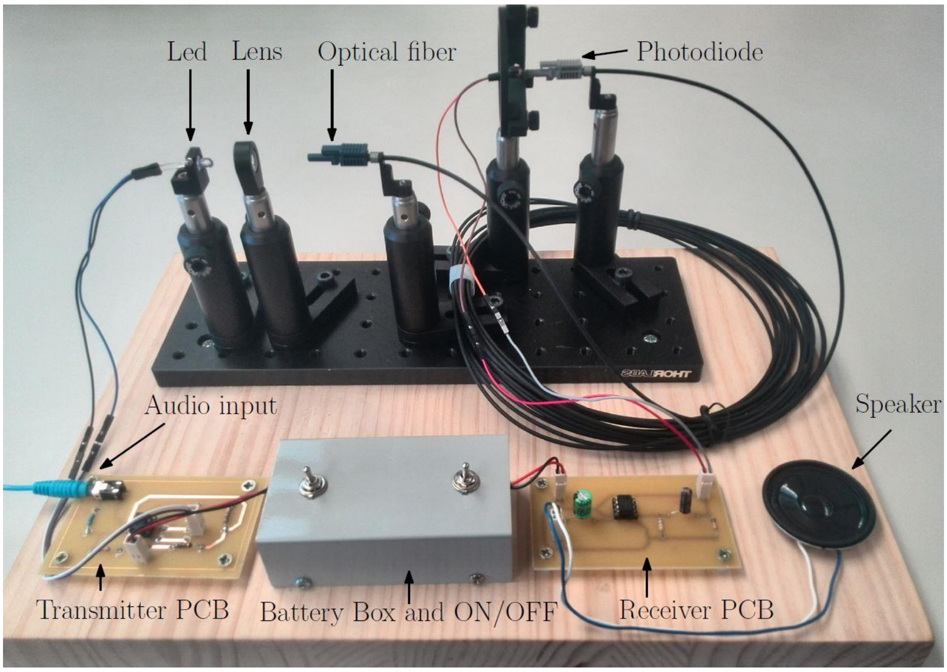

Fig. 1: Complete model of a fiber-optic transmission system, including transmission and reception electronics and a simple optical system to couple light from the transmitting LED into the multimode optical fiber. Adapted from [2].

2 TECHNICAL DESCRIPTION AND COMPONENTS

This section briefly describes the technical background and components that are required to carry out this project. The overall system and its functionality are discussed in section 2.1, while the optical and electrical sub-systems are detailed in section 2.2 and 2.3, respectively.

2.1 Overall system

The functionality of the system that the student will built is to transmit music over a simple optical link, receive this information and play it back on a speaker. The original audio signal can come from any source with analogue output using a mini-jack connector (such as a smartphone or an mp3 player). The transmitter circuit (on the left hand side in Fig. 1) amplifies this signal, and then modulates a visible light emitting diode (LED) with the (baseband) audio signal. A convex lens is used to couple light from the LED into a multimode optical fibre. The optical signal propagates along the fibre and is converted back to the electrical domain in a photodiode. The receiver circuitry amplifies the photodiode current and drives a speaker that reproduces the audio signal. The system is powered through separate batteries for transmitter and receiver.

Using the system for a basic demonstration is straightforward. When the input signal has a frequency of only a few cycles per second, the modulation of the LED is clearly visible to the naked eye. As the frequency is increased the modulation becomes visually imperceptible, but the transmitted tone is increasingly audible. Partially blocking the transmission of light with a sheet of paper produces an attenuation of the tone, showing that it is indeed carried by the optical beam.

2.2 Optical sub-system

The optical elements (shown in the top part of Fig. 1) were mounted on an optical breadboard (Thorlabs MB1030/M) using height adjustable poles (Thorlabs TR75/M-P5) to ensure mechanical stability. A 1mm diameter multimode fibre (Farnell HFBR-RLS010Z) and a large area photodiode (Farnell OSD15-E) were used to facilitate the alignment. The light source was a red LED (Thorlabs LED631E) coupled to the multimode fibre through a biconvex lens (Thorlabs LB1092). Given the educational purpose of the final system, the components are not arranged to occupy minimal space, but so that they are easily accessible and different parts can be readily identified.

Setting up the optical elements for minimal loss involves an interesting trade-off, because the LED is considerably larger than the core of the optical fibre and its radiation pattern is non-uniform [3]. If no lens at all is used only a small fraction of the light from the LED is coupled into the fibre. In order to reduce the spot size of the LED and thus increase the amount of light coupled to the fibre, a convex lens can be used. From the ray-tracing model in Fig. 2(a) it is clear that the image of the LED will be magnified by an amount $M=d_2/d_1$, where d_1 is the distance between the LED and the lens, and d_2 is the distance between the lens and the fibre. To achieve focus, we furthermore require $d_2 / d_1 = f / (d_1 - f) = M$, where f is the lens' focal length. A small value of M, as required to reduce the spot size of the LED, thus implies large values of d_1. However, when the LED is placed far away from the lens, only a fraction of the light it emits will actually pass through the lens (because of the lens' finite diameter), implying additional losses [see Fig. 2(b)]. The power that is actually captured by the lens can be calculated by integrating LED's intensity over the solid angle defined by the lens $P=\iint I_{LED}(\theta)\cdot\sin(\theta)d\theta d\varphi$. A trade-off between the power captured by the lens and reducing the spot size of the LED thus has to be found.

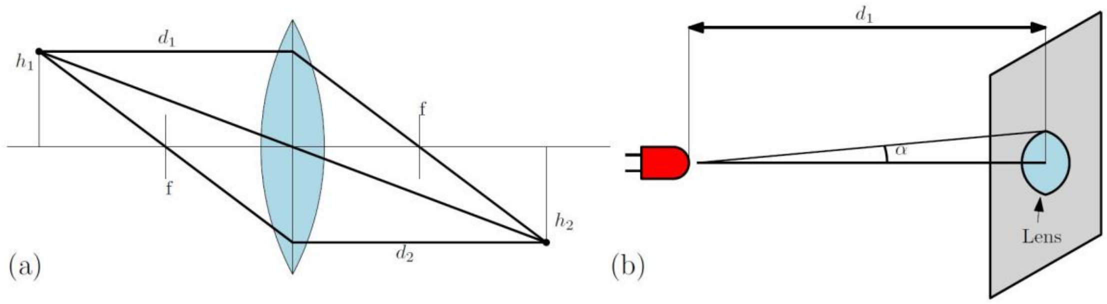

Fig. 2: (a) Ray-tracing model of the convex lens used to couple light from the LED to the optical fibre. (b) Calculation of the amount of light collected by the lens. Adapted from [2]

2.3 Electrical sub-systems

We will now briefly describe the two electrical sub-systems: the transmitter and the receiver. Both sub-systems are powered with 9V batteries, using single-supply operation.

2.3.1 Transmitter

The transmitter circuitry is shown in Fig. 3 and essentially produces an amplitude modulation (AM) of the optical carrier with the audio signal. The circuit comprises two operational amplifiers (we used Texas Instruments' TLC272C).

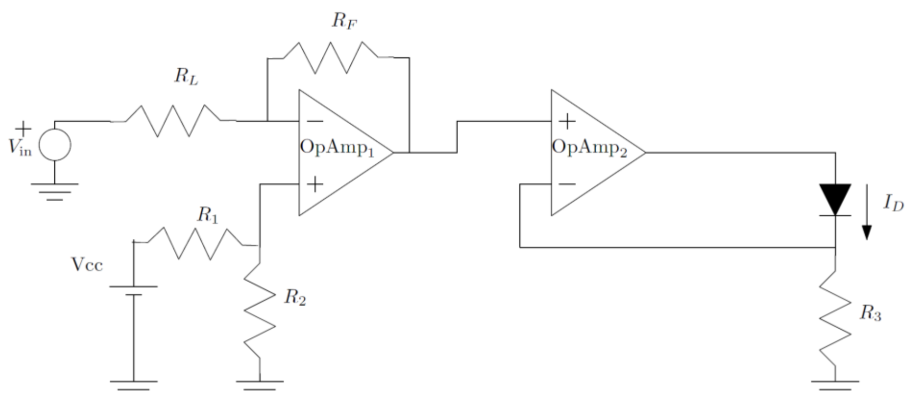

Fig. 3: The transmitter circuitry consists of two stages, with the first one providing amplification (resistors R_L and R_F) and offset (resistors R_1 and R_2), and the second one driving the LED. Adapted from [2].

The main purpose of the first amplifier is to adapt the input signal (Vin) coming from the audio source (a smartphone or mp3 player) to the characteristics of the LED. This requires:

- offsetting (adding a DC value) to the signal so that it is always positive, since LEDs only work with forward currents. The resistors R1 and R2 provide this offset.

- amplifying the weak input signal to drive the LED between its minimum and maximum current so as to achieve the strongest possible modulation index, which in turn will result in a high signal to noise ratio. The resistors RL and RF provide the desired amplification.

Using the superposition principle the voltage at the output of $OpAmp_1$ can be found to be: $(1+R_F/R_L)\cdot[R_2/(R_1+R_2)]\cdot V_{cc} - R_F/R_L \cdot V_{in}$

The second amplifier is simply a driver for the LED, with resistor R_3 limiting the current passing through the diode.

2.3.2 Receiver

The receiver circuit is rather simple: it consists of a resistor that converts the current generated by the photodiode to voltage, followed by a high pass filter that eliminates the direct current component of the received signal. Finally an audio amplifier (Texas Instruments LM386) is used to boost the signal and drive a small speaker. Eliminating the direct current component is important, because otherwise it can saturate the amplifier.

3 EDUCATIONAL METHODOLOGY

In this section we will review some of the key points we used to guide the student through this project, from its very beginning to a successful conclusion.

First and foremost, this being a rather experimental project it is advisable to discuss with the student if he/she will be comfortable spending time in the lab and solving (mostly) hardware related challenges. If the student is indeed prepared, providing the initial motivation is straightforward: the student will built simple but fully functional optical communication link, demonstrating the transmission of music using visible light over an optical fibre. The project is attractive because it provides a very visual demonstration and because it enables the student to put into practice a wide range of concept acquired in different courses. Furthermore, the final demonstrator will be put to use for educational purposes. As in any project the student should be presented with positive expectations about the outcome of the project: while the project is challenging, with some advice from the supervisor, the student will be able to lead it to a successful conclusion.

The general methodology is to first set intermediate milestones that will require of the order of one or two weeks of work for the student. Feedback about his/her progress is gathered in two ways: a) informal meetings that take place every few (1 to 3) days b) formal meetings related to the previously set milestone. The informal meetings simply consist of a “How are you doing?” in the lab. The formal meetings require the student to prepare a short presentation (5 to 10 slides maximum) detailing his advances, highlighting problems and suggesting possible solutions. Such presentation have several benefits: the student has to think about what has been done and how to summarize it, he/she practices presentation skills and the slides serve as a logbook of his/her activity and results that can be used when preparing the final report.

Whenever the student encounters difficulties he/she should first be encouraged to try to solve them on his/her own, thereby fostering autonomous problem solving. In order to avoid stagnation the supervisor can provide hints at how to proceed or how to narrow down the problem.

It is preferable to start the project with the design and alignment of the optical elements, including the LED and the photodetector. Depending on how much time is available, the different loss mechanisms along the transmission path (illumination of the lens, coupling to the fibre, coupling from the fiber to the photodetector) may be studied both theoretically and experimentally in more or less detail. Once the optical elements are in place, a basic version of the project is also complete: by switching the LED on and off and observing the resulting photocurrent in the photodiode a simple digital transmission system can be demonstrated. The transmitter is targeted next; once it is completed a simple sine-waveform can be transmitted and observed at the receiver end with an oscilloscope. The hardware is completed with the design of the receiver and testing of the full system with an audio signal at the input. Finally, the student may be tasked to design a short demo to explain the system to the general public. As outlined in section 2.1, this may consists simply of using different input signals, and/or showing the effect of blocking the optical path.

Writing the final report is a vital part of any bachelor thesis. The general approach here is to ask to the student to write a first chapter (generally a technical one; the conclusions and introductions are preferably written at the end), which is then thoroughly reviewed by the supervisor. This usually reveals some systematic writing errors that can then be discussed with the student and corrected, reducing the amount of corrections required in sub-sequent chapters.

4 RESULTS

The bachelor thesis that we have described so far was carried out during the second semester of the academic year 2014/2015. The student successfully completed the thesis (obtaining the maximum grade) while simultaneously attending five courses. While the highly experimental nature of this project required some additional efforts from both the student and the supervisor, it has been a very positive experience, and follow-up projects are already planned. The system itself has been used at two "open door" events at the University of Málaga, with very good reception from the audience.

5 CONCLUSIONS

We have described the development of a bachelor thesis in telecommunication engineering in which the student builds a simplified optical communication link capable of transmitting audio signals. The resulting system can, in turn, be used for educational purposes for the general public or first year bachelor students. The project has provided a high level of motivation for both the student, provided an attractive platform to apply knowledge acquired in an array of courses and helped develop autonomous problem solving skills.

ACKNOWLEDGEMENTS

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