ANALOG FREE-SPACE LASER COMMUNICATION SYSTEM FOR AUDIO TRANSMISSIONS

Grigore-Adrian IORDĂCHESCU
University of Piteşti, Romania
adi_iord@yahoo.com

Keywords: free-space communications, cordless, optical communications

Abstract: *This paper presents a very simple and efficient setup for cordless transmission of information through laser light. This type of setup could be used as didactic material in Optical Communications laboratory or for low fidelity cordless audio transmissions inside large rooms. The frequency response of the system will be measured and the optimum condition for some variable resistors will be found.*

1. INTRODUCTION

In spite of present-day large-scale application of optical fibers, the first transmission of information through the use of light was realized by free-space propagation. This can be traced to more than 2000 years ago to the ancient Greeks [1] who used torches and a complex signaling alphabet to exchange information.

Even in the modern era, the first transmission of sound through the use of light was firstly realized in free space, not through a guided medium. This happened in 1880 with the invention of the *photophone*, a device capable of transmitting a wireless telephone signal to more than 200 meters apart using light [2].

Since the 1980s, the advent of optical fibers [3] firmly surpassed the use of free-space optical communications. Nevertheless, the use of free space optical communications remains very popular in the military, where cable connections are frequently very difficult to install and easily interrupted by enemy forces. Large scale use of speech transmission by optical means appeared initially in the Second World War [4].

Other than the military, free-space optical communications could be used to communicate in outer space. Currently, the record for such a communication system has been recently set at a few thousand kilometers [5]. Nevertheless, such a system can be improved by the aid of optical telescopes to rich interplanetary distances [6].

Given the historical importance and the possible uses of such devices for interplanetary communications, every Optical Communications laboratory should have at least a session dedicated to studying a basic free-space communication link. Other than the reasons above, such a study could also be considered more intuitive by the student compared to the study of fiber optics links, as the beam is visible at all times during the functioning of the system. The historical development and the intuitive approach can also be considered good arguments for studying free-space links during the first laboratory sessions, before going further to optical fibers and media converters.

Following this short introductory section, this paper will present, in the next section, the electronic setup for an optical free-space link optimized for didactical purposes. This section will also contain some photos of the final devices on both transmission and reception sides.

The third section will be dedicated to different measurements of system parameters, including frequency response. These measurements can also be performed as part of a laboratory session.

The final section will list some conclusions alongside some recommendations for the practical uses of such a system.

2. ELECTRONIC SETUP

Before proceeding to the electronic setups for emission and reception, there can be seen in Fig.1 the current-voltage characteristics of the laser device used on the emitter side. This laser device contained, beside the laser diode, a series resistor of 90Ω used for protection of the circuit. The current voltage characteristic of the entire device (diode and series resistor) is shown with full line in Fig. 1. The characteristic of the laser diode alone is shown with interrupted line. From the slope of this later plot the dynamic resistance of the laser can be calculated. In the forward-bias region this resistance is approximately 30Ω.

There can be found many free-space electronic circuits on the internet. To find the right compromise between efficiency and simplicity is difficult enough. Because the designed system is intended for didactical purposes, the authors started the design of the circuit from the simplest schematic of an optical communication system [7]. After improving this scheme, the final schematic of the emitter is shown in Fig. 2. A simple amplification circuit using an operational amplifier was added. This operational amplifier was also responsible for collecting the signal onto the inverting input, before amplifying it. The voltage divider of the non-inverting input has the role of setting the continuous voltage of the output at half the continuous voltage of the power supply used. The signal from the inverting input will be superposed on this continuous voltage. Thus the operational amplifier makes obsolete the audio transformer from the initial circuit of [7].

Projecting the optimum values for the components of Fig. 2 was a long process. For the voltage divider the values of R_1 and R_2 were chosen at 20kΩ to reduce the current to under 1mA (Fig. 3). Their values could not be increased indefinitely as they must remain much smaller than the input impedance of the operational amplifier. The values for resistor R_3 and potentiometer P_1 (Fig. 3) were chosen as to obtain an adjustable amplification going from 1 to 10.

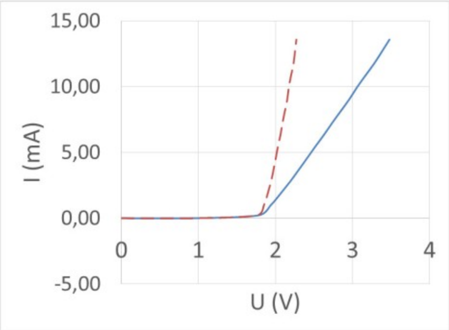


Fig. 1 Current-voltage characteristic for the laser diodes used in this project: interrupted line – laser diode; full line – laser diode in series with an integrated protection resistor of 90Ω

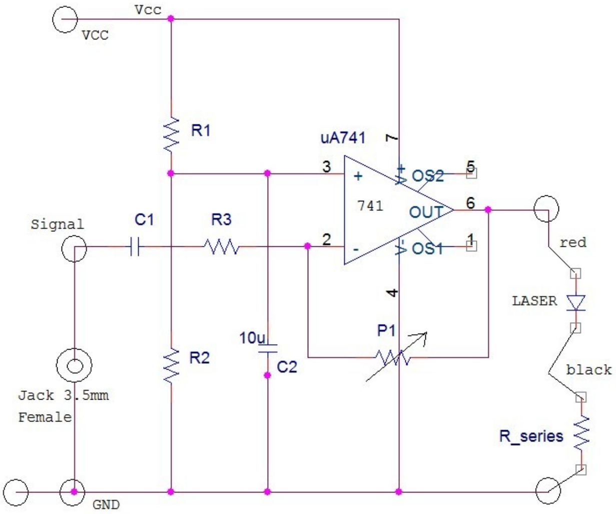


Fig. 2 General electronic schematic of the emitter circuit

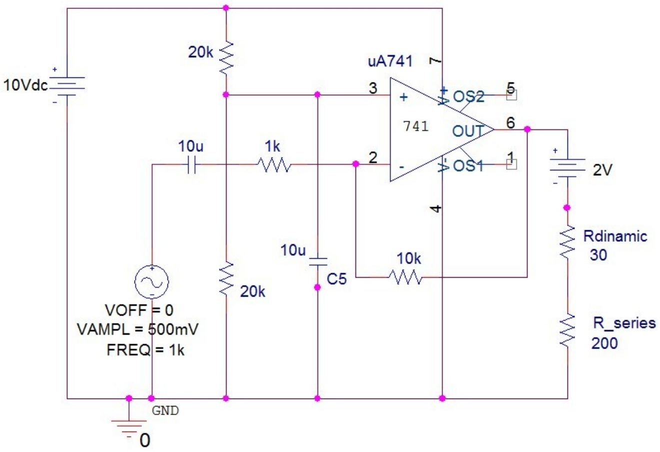
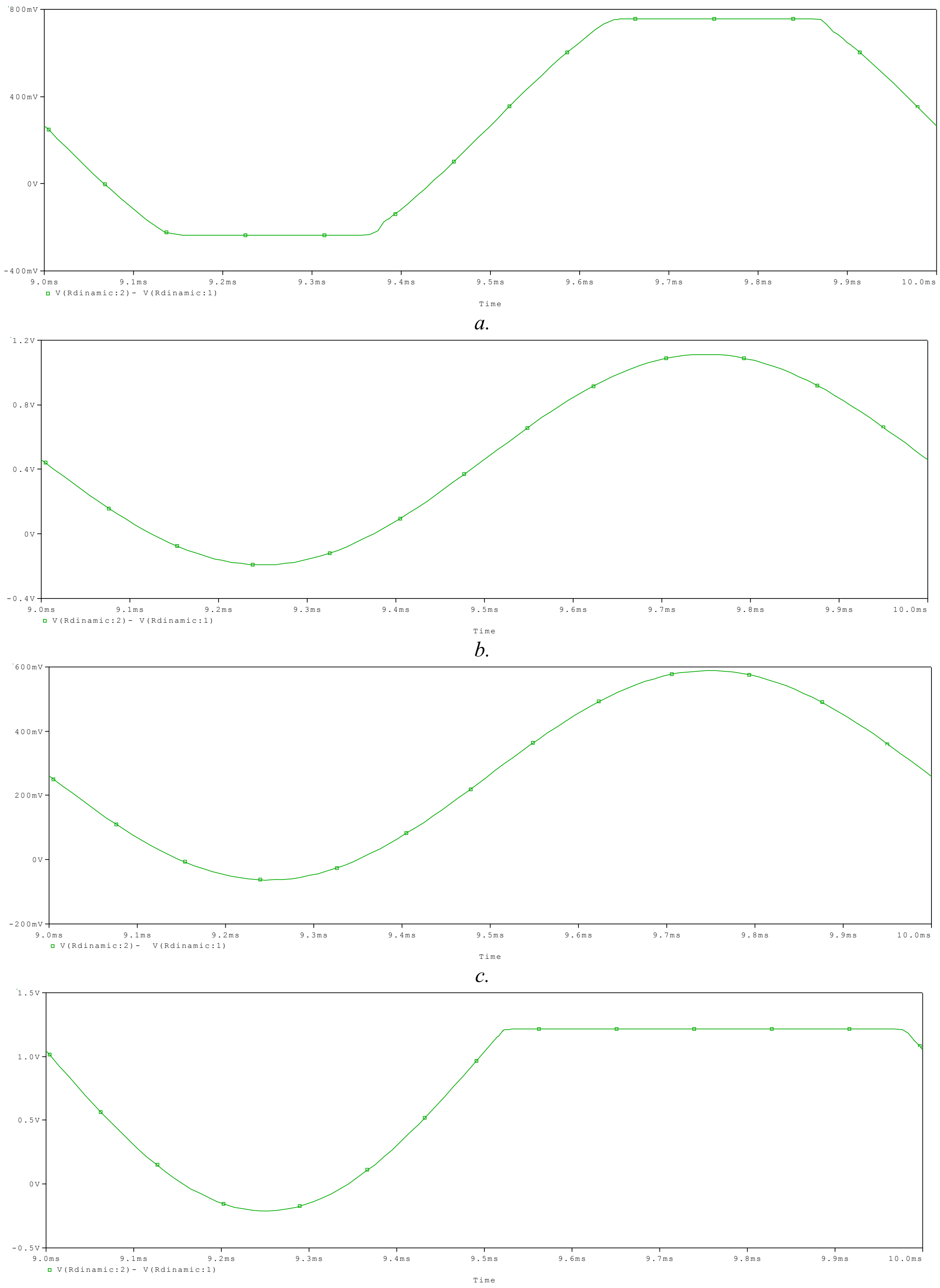


Fig. 3 Specific electronic schematic of the emitter circuit, with the laser replaced by an equivalent circuit



a.

b.

c.

d.

Fig. 4.Signal distortions: a. Output signal on laser when power-supply is 8V and amplification is maximum b. Output signal on laser when power-supply is 11V and amplification is maximum c. Output signal on laser when power supply is 8V but amplification is medium d. Output signal on laser when power-supply is 11V and amplification is maximum, but R_{series} = 90Ω (instead of 200Ω). All plots of Fig. 4 were realized using OrCAD PSpice.

Then the process of choosing the right values for the power supply voltage and the series resistance R_{series} took into account distortion limitation. When passing from Fig. 2 to Fig. 3 the laser was replaced by the voltage drop across it when in forward-bias (Fig. 1) in series with its dynamic resistance.

Generally, for low amplitudes of the input signal (or the sinusoidal generator), the power supply can take smaller values than 10V.

Nevertheless, if the input audio signal has high amplitude (1V peak to peak) and the amplification ratio is 10 the signal on the dynamic resistance of Fig.3 will be distorted, as in Fig. 4a.

The solution is increasing the power supply voltage as in Fig. 4b to more than 10V or decreasing the amplification ratio as presented in Fig. 4c.

In this later plot, the amplification was decreased from 10 to 5.

Thus in Fig. 4c the peak to peak amplitude of the output signal is decreased from 1.3V peak to peak (Fig. 4b) to just 0.65V (Fig. 4c).

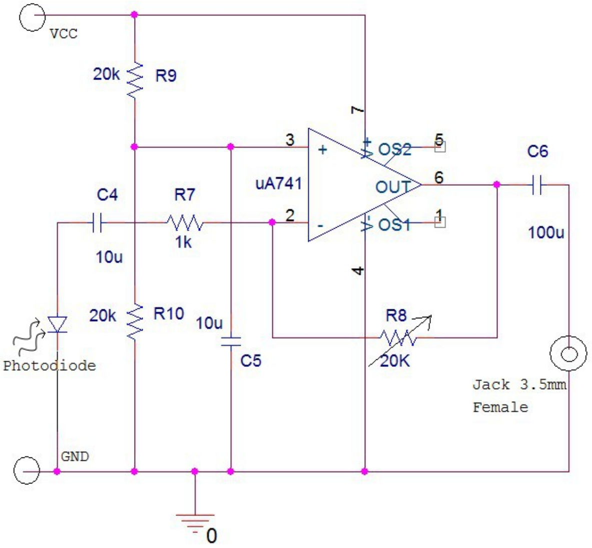


Fig. 5 Electronic schematic of the receptor circuit

Finally, the R_{series} resistance was chosen as to limit the maximum current required by the output, below the limit of short circuit current of the operational amplifier (for the case of LM741A operational amplifier, this limit is 40mA). For this purpose, the initial 90Ω series resistance integrated in the laser device was not enough. After a few calculations and simulations, a series resistance of 200Ω was chosen (Fig. 3). This 200Ω was the series resistance used to make the simulations from Fig. 4a, 4b and 4c. For Fig. 4d the initial 90Ω resistance was used.

It can be stated from Fig. 4 that when the distortion is created by too high a voltage signal, the distortion will be symmetrical like in Fig. 4a. This can be resolved by increasing the supply voltage or by decreasing the resistance of the potentiometer. Instead, when the distortion is on the upper part of the output signal, it is given by the current limitation of the operational amplifier. It can be resolved by increasing the series resistance R_{series}. If this is not possible, another way to resolve it is to decrease the amplification by decreasing the P_1 resistance.

The receptor circuit is presented in Fig. 5. It is very similar to the emitter circuit of Fig. 3. The difference is that the audio source of the emitter circuit is replaced here by the photodiode, and the output laser is replaced here by an output jack connecting our device to a 20Ω speaker or to a high-impedance amplifier. The amplification ratio of the inverting-amplifier can vary between 1 and 20, as the 10kΩ potentiometer of Fig. 3 was replaced here by a 20kΩ one.

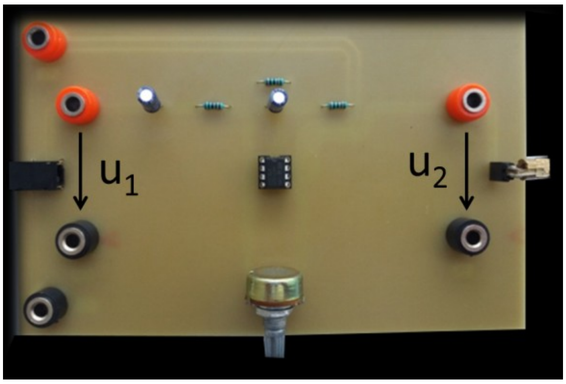


Fig. 6 Printed circuit board of the emitter circuit

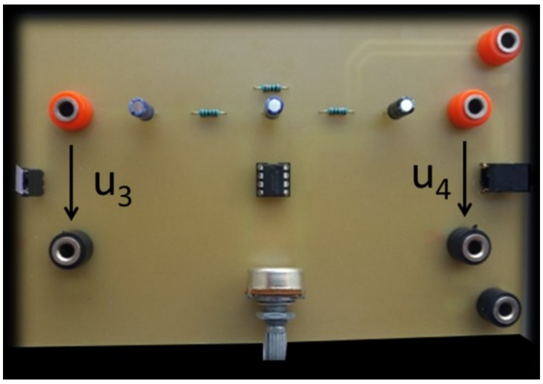
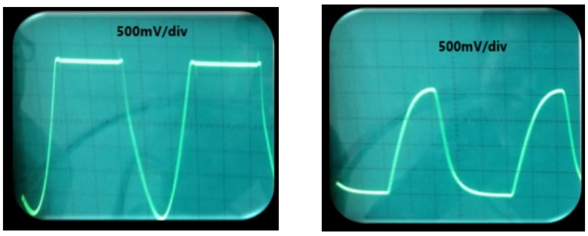


Fig. 7 Printed circuit board of the receptor circuit

The same limitation of ±40mA output current given by the LM741A applies here as well. If a small output impedance of just 20Ω is used, this means a peak to peak signal of 80mA·20Ω=1600mV. If maximum amplification of 20 is considered, this would result in a maximum peak to peak signal of 80mV on the photodiode. From practical experience this value was high enough for not complicating the receptor circuits with other limiting components. If distortions are produced because of too high an output current, the potentiometer R_8 of Fig.5 can be used to reduce the output signal. If instead of a small output impedance of just 20Ω, a high input impedance amplifier is used, there would be no more limitation caused by the LM741A output current.

In Fig. 6 and Fig. 7 the PCBs containing the circuits of Fig. 3 and 5 are shown. A great number of black and red terminals are used as the primary role of these circuits is didactical in nature. The elements are spaced apart to be easily identifiable by the students. For the emitter circuit of Fig. 6, the laser is the yellow element at the right side of the circuit. In the receptor circuit of Fig.7, the photodiode is the white element at the left side of the circuit.



a.

b.

Fig.8. Different distortions observed with an oscilloscope

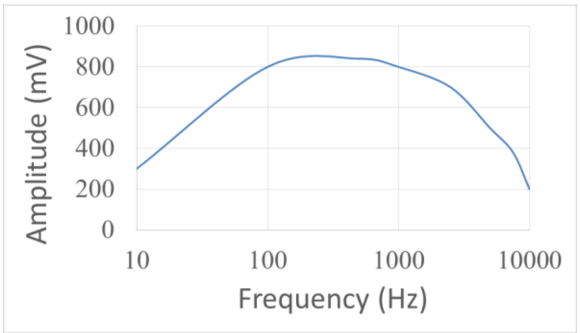


Fig.9. Frequency response

3. MEASUREMENTS

There can be devised many interesting experiments using the circuits of Fig. 6 and Fig. 7. A didactical approach would be a comparison between the simulated distortions and the real distortions observed by projecting the signals on an oscilloscope. The distortion observed in Fig. 8a was seen on the output of the operational amplifier (u_2 of Fig. 6) and is consistent with the type of distortion observed in the simulation of Fig. 4d. As in simulation, it can be resolved by decreasing the resistance of the emitter potentiometer. The signal of Fig. 4b is the result of propagating the signal of Fig. 4a along the circuit until it reaches the output (u_4 of Fig. 6).

The frequency response of the entire circuit was also measured and the results are displayed in Fig. 9 for the case of high output impedance. For this test, signals of same amplitudes but different frequencies were one by one added at the entry of the system (u_1 of Fig. 6). The amplitude of the output was then measured for each frequency (u_4 of Fig. 7). Because the response is very selective in the audio bandwidth, this system can be considered a low fidelity audio system.

4. CONCLUSIONS

After an introduction showing the history and importance of free-space optical communications, this paper presented a didactical circuit for enabling the students to understand the basic principles of optical communications. This circuit can be used to transmit audio information to some speakers in a very large room without using wires. Because the low price of such a system, it can be copied several times to coordinate a large number of speakers in the room.

In the measurement section, the frequency characteristic of such a transmission system and some real distortion photos were presented.

A video test of the system presented in this paper can also be watched on the internet [8].

5. ACKNOWLEDGMENT

The author would kindly wish to thank Eng. *George Iulian Marin* for executing on board the circuits of Fig. 6 and 7.

Another great help in this project was my student *Nicolae-Narcis Nedelea*, who acquired the raw components and made the test video [8].

6. REFERENCES

[1] Polybius, "*The histories of Polybius*", volume 2, Macmillan, 1889

[2] Bell A.G., "*On the production and reproduction of sound by light*", American Journal of Science, Third Series, October 1880

[3] Buzelli S., et al. "*Optical fiber field experiments in Italy: COS1, COS2 and COS3/FOSTER*", International Conference on Communications, Seattle, 198

[4] Rollema D.W., "*Optical Communications – 1935 style*", Electronics & Wireless World, August 1985

[5] ESA - European Space Agency, "*Another world first for Artemis: A laser link with an aircraft*", Accessed 11.05.2017: http://www.esa.int/About_Us/ESRIN/Another_world_first_for_Artemis_a_laser_link_with_an_aircraft

[6] Jørgensen S.E., "*Optisk kommunikation i deep space – Et feasibilitystudie i forbindelse med Bering-missionen*", Dansk Rumforsknings institute, University of Copenhagen, October 2003

[7] Sci-Toys.com, "*Chapter 7: Light and Optics*", Accessed 12.05.2017: http://sci-toys.com/scitoys/scitoys/light/light.html

[8] Dr. Ing. Adrian Iordachescu, "*Analogue free-space audio transmission by laser*", Accessed on 20.07.2017 with Firefox 52.0: http://upit.eu5.org/laser1.html