Design and implementation of a free-space optical datacom laser-link: a photonics education project for Electrical Engineers

Lieven Desmet, Michael Vervaeke, Valerie Baukens, Hugo Thienpont

Department of Applied Physics and Photonics (TW-TONA), Vrije Universiteit Brussel, Pleinlaan 2, B1050 Brussels, Belgium (ldesmet@tona.vub.ac.be, phone: ++32 2 629 18 14, fax: ++32 2 629 34 50
http://www.tona.vub.ac.be

ABSTRACT

A team effort of 10 EE students results in the optical and mechanical design, simulation, implementation and testing of an atmospheric optical communication laserlink between two university buildings. We evaluate both the educational added value and pitfalls of this photonics project in the multidisciplinary domain of opto-electronics, optical system design, and optical datacommunication. As a result of our alternative method of teaching and coaching, our students did gain more practical insight in optical telecommunications and enjoyed it more than the traditional way of teaching. To summarise, this unique photonics project resulted in enhanced teamwork and teamspirit between Flemish speaking VUB and French speaking ULB EE-students; and also enhanced their theoretical and practical skills in the multidisciplinary domain of photonics.

1. INTRODUCTION

The idea of laserbeam free-space communications is not new. Proof-of-principle demonstrators date back to the early 60's. However high bandwidths could not be achieved because modulation of gas lasers was inherently slow. In 1947 the first transistor was invented and since then semiconductor industry kept on improving dramatically. In 1962 lasing in semiconductors was observed[1] and in the next decades edge emitting lasers were developed which could be modulated very fast. Also optical fibers emerged during the 70's and 80's[2] and low-loss fibers combined with semiconductor lasers proved to be a practical medium for long distance communications. So free-space laser links remained only a small niche application.

Today, atmospheric optical datacom is undergoing a revival[3] because of economical reasons. It was realised that free-space links could fill in new niche markets such as short-haul metropolitan area networks. For these type of networks of course fibers could do the job, but only at the expense of considerable time and money to dig up the streets and lay new cables. Free-space optics doesn't suffer these disadvantages. Its implementation cost is low and system setup time can be as short as a day[3].

It is with these advantages in mind that an educational project about optical free-space datacom was conceived at the Applied Physics and Photonics Department of the Vrije Universiteit Brussel. The project is an illustration to the theoretical course "Introduction to optical telecommunication". Several photonics courses, comprising laser physics, optical and advanced optical telecommunications, optical sytem design and practical classes, are combined into a single project. The project is intended to impart first and second year master students the necessary hands-on experience and practical and theoretical skills of the optical engineer, by designing, simulating, implementing and testing a free-space laser link.

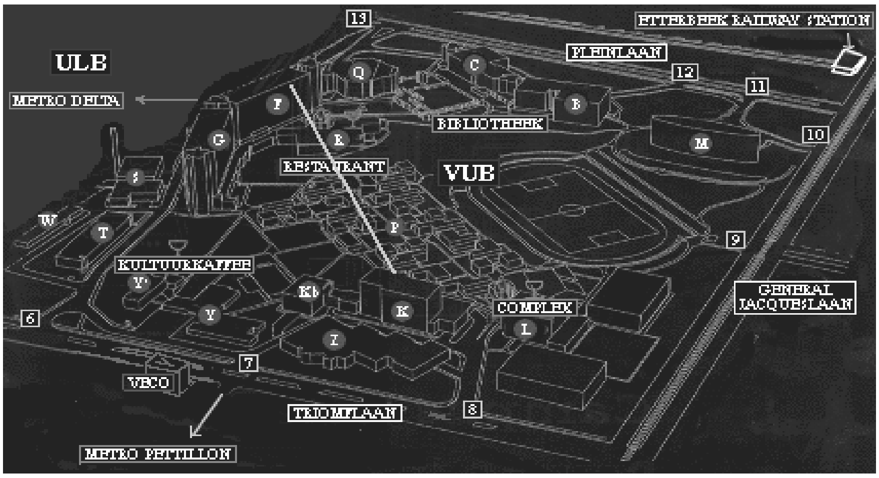
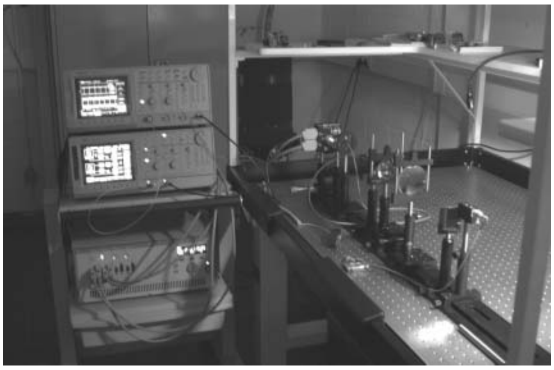


Fig. 1. Optical pathway with a clear line-of-sight between building F and G on the VUB main campus. (white line) Estimated link distance is 300meter.

2. THE "FABULOUS" PROJECT CONTENT AND WORKFLOW

The workflow of the workshop was a mixture of 60 hours of group discussions with assistants, assistant guided exercises on optical systems design, practical photonics lab exercises and a lot of self-study for the students. The project spanned 6 months. Apart from the educational aspect, the "fabulous" (Fiber and Air Based Unidirectional Link Of University Students) project had the technological goal to network computers of VUB campus building F and G. The laser link had to be transparant to the ethernet network. The group of EE students counted 6 students of the VUB and 4 visiting students of our neighbouring university ULB. The students targeted a 100Mbit/s ethernet communication datastream, but due to time restrictions, the effort and emphasis was placed on the implementation and design of the photonics part of the free-space link. The simplest type of such an atmospheric optical link is a laser transmitter pointed at a distant receiver. Our group of EE students decided to make the design a little bit more elaborate by incorporating a fiber between the laserdiode and sender collimating lens, thus adding flexibility to the system. At first the optical pathway between the targeted buildings was determined by OTDR experiments. Then the students used this parameter in the optical systems design to determine physical dimensions of collimating sender lens and focusing receiver lens. The free-space link was simulated using optical ray tracing software. The students also designed and assembled a coupler with a graded index lens to launch the light of the laserdiode into the fiber. They decided to keep the optical datacom system inside the buildings as a whole since outdoor equipment has the disadvantage of the need to be environmentally sealed to withstand extremes of weather. Also external optics may need a defroster to remove frost or dew and need appropriate housing to discourage birds from perching on it, and to avoid collecting dirt or debris that could attenuate the optical signal. The students had to calculate the optical power budget since the double-glazed windows introduced additional optical losses. The relative positions of buildings F and G were determined and allowed for beaming the laser through the double-glazing windows (the normals on the side walls of the buildings make an angle of ± 35° in the horizontal plane). The tightly focused laserbeam was designed to have an exit beam diameter of around 3 cm, allowing lower sensitivity to dust particles. Once the optical design was finished, students had to browse through catalogs and specifications and had to order the necessary lenses and opto-electronic components. Nonetheless, they had to meet a rather tight financial budget (1500 euro). At this stage of the project, the students also gave an intermediate oral presentation to

defend their design. After receiving the laser-link components, each student could individually pick out three project subtasks to characterise and build the laser-link. The subtasks comprised fabrication of lensholders and lenshousing, characterisation of the laserdiode, design and implementation of the link suspension, some electronics design, and much more. To facilitate pointing stability the laserbeam is kept slightly divergent, such that the beam diameter is close to 30cm in the plane of the receiver lens. The mechanical pointing system is passive, however many commercial systems use active alignment, which uses feedback from the receiver, to aid in installation and to stabilize the beam in operation. Active alignment of the link can be important because the tops of tall buildings can sway in winds or during small tremors. However no such problems were experienced during the OTDR experiments when a well-collimated gas laser was pointed to the target building. Another point of concern that was brought to the attention of the students was that the collecting optics must strongly exclude ambient light so that sunlight or other illumination does not overwhelm the information of the laser beam. The receiving optics therefore have a narrow field of view and include an optical bandpass filter that selects the laser wavelength while blocking other wavelengths coming from the sun. Todays commercial free-space optical datacom systems typically operate at wavelengths of 780, 850 or 1550 nm. For educational purposes and also because of economical reasons, the wavelength of the laser-link was dictated to be chosen in the red visible wavelengths. (670 nm in case of our “fabulous” laser-link). Inexpensive components are readily available for visible and near infrared wavelengths, but the optical power must be limited to meet eye-safety requirements. The students had to study these limitations and had to propose the necessary actions such as placing beamstops, safety labels and interlocks. They also had to calculate the maximum allowed optical power in the laserbeam. On the other hand, infrared emission such as the 1550-nm wavelength is inherently eye-safe, allowing higher transmitter powers for optical links, but the components are considerably more expensive.
The effort of the students has resulted in a demonstration of the free-space link on an optical workbench. A nice open eye-pattern was obtainable at 500Mbit/s, in fact the bandwidth of the system was only limited by the function generator and the limited communication distance. A future task for the project is to design and implement the necessary electronics to interface the laserdiode to a hub or ethernet interface of a PC and to design an active Peltier type cooler for the opto-electronics.



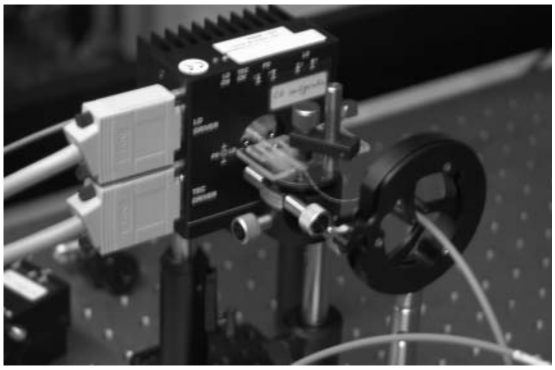


Fig. 2.: (left) Proof-of-principle demonstrator of the free-space laserlink. (right) Coupling of the laserbeam into the fiber using a grin lens, components are aligned using a custom fabricated PMMA Vgroove.

3. ADDED VALUE AND PITFALLS OF THE PROJECT

At the end of the project, the workshop was evalutated by research assistants and students. An inquiry was filled in anonymously by the students. The inquiry consisted of a list of 59 yes/no/no-idea type of questions. From the students point of view, the project enhanced teamwork and teamspirit. They disliked the preparatory lab exercises, but on the other hand they stated more insight was gained during the project in the theory and practical implementation of optical telecommunications. The students also expressed they got excellent personal coaching and they appreciated our new approach to teaching very much. From the research assistant point of view, especially the project start was stressful since there was no preparation and the workshop topic was not directly related to their research activities. However they could enhance their coaching skills. The project was in their opinion rather ambitious for the students, and it was realised the project time span was a critical factor. Time stress factors included the fabrication of the mechanical components, and the timely delivery of the necessary opto-electronics components. Although also the time management of the project was handled by the students, this turned out not to work very well. In general assistants should keep on posing strict milestones and deadlines in such elaborate projects to deliver them in time.

CONCLUSION

Commercial free-space optical links have come a long way and look particularly good for dense urban areas, university campusses, disaster zones; where distances are short, line-of-sight is available, and construction is costly. The idea of free-space optical datacom has been used in an educational project for photonics engineering students at our university. The parameters of the students design of the free-space laserlink have been found to be in close agreement with those found in commercial systems. The actual “Fabulous” free-space optical link is currently under construction and is envisioned as future demonstrator for practical classes about photonics courses. From an educational point of view, is was a very good idea to mix EE students with different majors. The tight financial budget of the project gave them some responsibility on their design. In the beginning of the project it was also agreed all students would get the same marks and this enhanced teamwork and teamspirit. We also tried to give the students as much intellectual freedom as possible, meaning that we did not much interfere with their design. However, in such an ambitious project, deadlines on subtasks are needed and should be posed by the assistants. The students also trained and therefore enhanced their presentation skills by giving oral presentations and write a scientific report. Moreover the mixing of students with different mother tongue resulted in enhanced communication skills. Finally the combination of several photonics courses into one single project was very much appreciated as a new approach to teaching.

REFERENCES

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