The Night of Science: Optics and Photonics for All

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Abstract

Today, optics and photonics are widely regarded as among the key technologies for this century. Many experts even anticipate that the 21st century will be the century of the photon – much as the 20th century was the century of the electron. Optics and photonics technologies have impact on nearly all areas of our life and cover a wide range of applications in science and industry, e.g. in information and communication technology, in production, medicine, life science engineering as well as in energy and environmental technology. However, even if so attractive, photonics is not well known by the majority of people. In order to motivate especially the young generation for optics and photonics we took part already two times in the “Night of science" event with a lecture about optical data transmission. We prepared many practical activities and experiments to explain how modern communication through the optical network works. Combining hands-on teaching with having fun while learning about the basic optics concepts we aroused interest of not only the children but also the parents, with a very positive feedback. The "Night of science" is the only nation-wide research event in Austria where the institutions make science accessible to a wide population. Its objective is to present science and research in an innovative, understandable and entertaining way. In the frame of interactive presentations, lectures, guided tours and interactive stations, people of any age can discuss with researchers their latest research results and can perform their own experiments.

Keywords: (the night of science, FHV, Austria)

Introduction

"The night of science" is the only nation-wide research event in Austria, taking place every two years, where domestic institutions, going from basic research up to industry, make science accessible to a wide population (Fig. 1). This biggest event for science communication has the objective to present the science and research in an innovative, understandable and entertaining way with a free admission. An extensive program offers insights into the world of research: from school projects to cutting-edge research. In the frame of interactive presentations, lectures, guided tours and interactive stations, interested persons can discuss with researchers the latest research results and experiment on their own. The spectrum of exhibitors ranges from scientific institutions such as the Austrian Academy of Sciences, universities, colleges of education through the polytechnics and non-university research institutions to the big industrial companies [1].

Figure 1: Different activities offered to the wide population at "The night of science" event.

Optics and Photonics for All

Today, optics and photonics is widely regarded as one of the key technologies for this century. Many experts even anticipate that the 21st century will be the century of the photon, much as the 20th century was the century of the electron. Optics and photonics technologies have an impact on nearly all areas of our life and cover a wide range of applications in science and industry, e.g. in information and communication technology, production, medicine, medical technology and life science engineering as well as in energy and environmental technology.

However, even though attractive, photonics is not well known by majority of the people. In order to motivate especially the young generation for optics and photonics we prepared already four times the “children’s university” with the lecture about “optical data transmission” with a very positive feedback [2].
Since 2010 “The night of science” event takes place in Austria every two years. Our Research Centre for Microtechnology [3] at Vorarlberg University of Applied Sciences (FHV) participated in this event each time with an interactive optic and photonic stations related to:

1. **2010**: Laser and its applications (Fig. 2a): On May 16, 1960 the first LASER was produced on earth by Theodore Maiman assisted by Irnee D`Haenens and C. K. Asawa. A beam of red coherent light generated in a ruby crystal by **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation (**LASER**) shined a bright light spot onto the wall of Maiman`s laboratory at Hughes Research Labs in Malibu California. It is strange, the first person able to see this red light spot was D`Haenens because he was somewhat red color blind and could see red only very faint. The laser crystal at that time was not perfect and produced also plenty of red stray light causing Maiman and Asawa to be dazzled by the bright light flash. D´Haenens eyes suppressed the stray light and only the laser spot in the middle was sufficient brilliant to be seen by him. In 2010 was the 50^{th} anniversary of the invention of the laser and we built a model of this laser with a real ruby crystal for demonstration in “The night of science” event (Fig. 2a). Children and adults have been curious to see and learn how this first laser worked. A laser can be focused to a very small intense light spot and children were fascinated watching a CO_2 – Laser cutting give-away samples out of a fluorescent polymer. To emulate Maiman`s flash light we used a blue LED to stimulate the ruby in our laser model for red fluorescence light emission.

2. **2012**: Plants and flowers (Fig. 2b, c): The same blue LED`s are used in lamps to facilitate plants and flowers to grow better. David Schmidmayr, then a student at Vorarlberg University of Applied Sciences, explained that plants need blue and red light for growth (Fig. 2b). That is the reason plant leaves are green, out of the sun light plants “eat” blue and red light and reflect back the green light which we people can see best of all colors. The student developed a lamp to help plants grow better. For this purpose he did research on light conversion material capable to change just the right amount of blue LED light into red light. The result is a pink color lamp and plants like pink (Fig. 2c). He did this experiment in a mixing chamber, a so called Ulbrichtsche Kugel, to find the best pink for plants. David was very successful in his scientific work and now he could establish his own company together with a friend producing special lamps for plants. I hope the bonsai trees in Fig. 2b will not grow too well with the pink lamps and become finally mammoth trees.

3. **2014, 2016:** Optical data transmission, this is the main topic of this paper and therefore we will discuss it in detail.

We prepared many practical activities and experiments to explain how the laser and the modern communication through the optical network work. Combining the hands-on teaching with having fun while learning about the basic optic concepts we aroused interest of a wide audience.

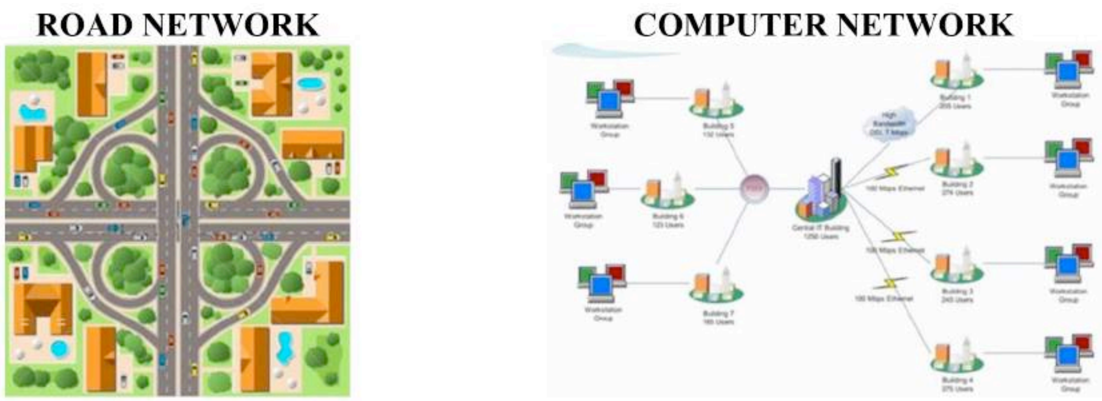
Figure 2: LASER (a), plant lamps (b) and fluorescence light (c), interesting and useful in our daily life.

Introduction into Optical Data Transmission

Today we can no longer imagine our lives without computers. We write messages to friends, surf the Internet, download music and videos or just play games online, all this belongs to our daily life. But do we also know what's behind that all?

The Internet Connects People as the Roads

The Internet is a huge network connecting millions of people. One can imagine it as the road network. Houses where we live are the computers in the network and the roads connecting the houses are just like the cables connecting all computers together. Cars that drive on the roads, is information that we send or download (Fig. 3).



a) b)

Figure 3: Road network (a) versus computer network (b).

The simplest network consists of two computers that are connected via an electric cable (Fig. 4, so called "point-to-point" network). All information (data) will then be transmitted in the form of electrical signals between computers. Whether an email, a song or a photo, all are first encoded in bits in the computer (translated into computer language), i.e. consist of many 0's and 1's (so called "binary code"). Each bit is then assigned to an electric signal (logical 1) or no signal (logical 0) and sent over the cable. The first computer is also called "transmitter" because it sends (transmits) the data. The second computer is called "receiver" since it receives the data. The received data is then decoded back into a text, a song or a photo.

As long as only two computers are connected via cable, the data transfer is very fast. But when multiple computers have to share a communication cable (Fig. 4, " point-to-multipoint" or even "multipoint-to-multipoint" network), the transmission is getting always slower. The biggest challenge lies in the communication cables that connect cities, countries and even continents. To solve this problem not only a "one-way street" (one electrical cable), but a "highway with many lanes" must be built to serve so many cars (huge amount of data) that simultaneously drive (are simultaneously transferred).

Well, the question is how to do it?

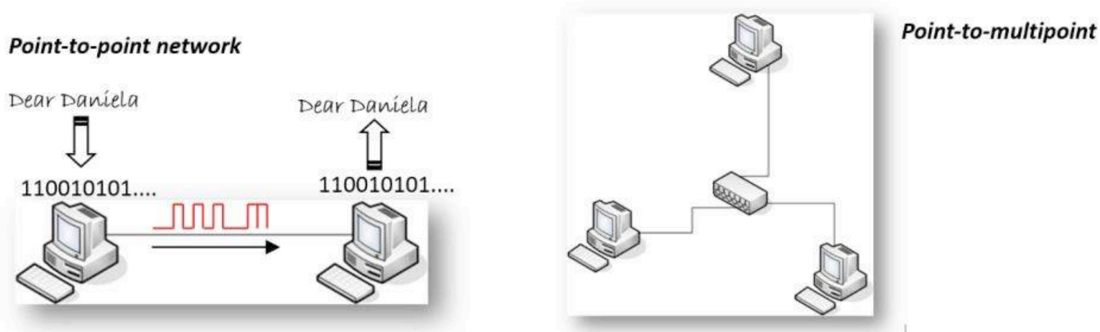


Figure 4: Point-to-point and point-to-multipoint network.

Light Signals are the Solution

The solution to this problem lies in the application of a new technology that uses optical signals rather than electrical signals for the data transmission. To achieve this, our point-to-point communication system from Fig. 4 must be extended (see Fig. 5). In this new system, as a first step the electrical signals (coming from an electrical part of the network) need to be converted into optical signals. To this purpose, the transmitter is used, consisting of light sources such as a light emitting diode (LED) or a laser. This source is modulated, that is turned on or off to represent the binary digits (1's and 0's) from the electrical part of the network. The output are the optical signals. A glass fiber in a fiber optic cable then transmits these signals (light pulses) over long distances. Of course, since the computers can only work with electrical signals, the received optical pulses are converted back into electrical signals again. Photodetectors are usually required on the receiving side. The last part of our optical communication system is the regenerator. When the light signal has to be transmitted in an optical fiber over long distances, it is attenuated and begins to lose its shape. The result is that the signal cannot be recognized at the receiving end. Here so-called regenerators are used.

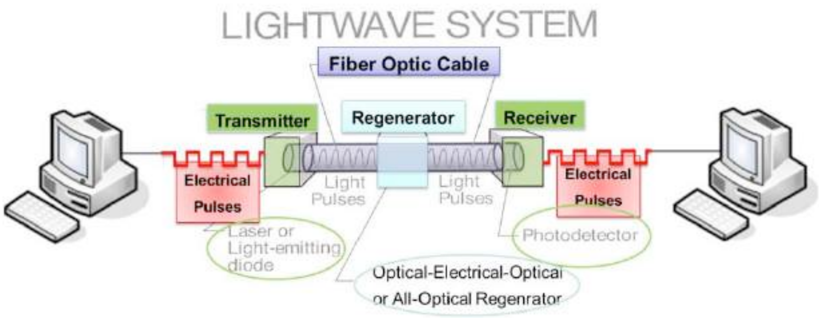


Figure 5: Point-to-point optical system.

Fiber Optics: a New Technology Revolution on the Internet

This new technology is called "Fiber Optics": "Optics" - because the light signals are used as an information medium and "Fiber", because glass fibers are used as the transmission medium. In the model image of our streets the light signals are passing cars and the glass fibers are like a "virtual highway", in which you can increase the number of lines without having to rebuild it, thereby taking advantage of the fact that the light is coloured. Each colour is as a line on the highway (a separate transmission channel). The more colours we use, the more data we can send through a single fiber at the same time without interfering with each other. Already using two different light signals, we can double the transmission capacity. That is one of many benefits of this technology. This new technique is called Wavelength Division Multiplexing (WDM) (Fig. 6).

Computer 1	Computer 2	Computer 3
01000100	01100001	01101110
D	a	n

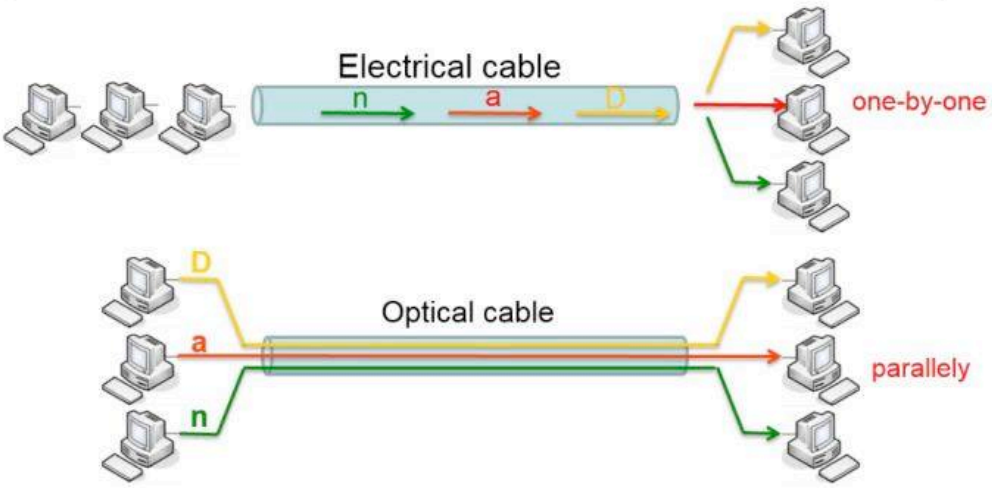


Figure 6: Wavelength Division Multiplexing technique.

The next important advantage of this technology is that the optical signals can be sent over hundreds of kilometres. Nevertheless, how is it possible that the light remains trapped in the fiber and does not get lost?

How does the Fiber Work?
The fact that the light can be guided in a fiber almost without losses over hundreds of kilometres, is based on two physical phenomena: reflection and refraction of light at the boundary between two optically different media. Considering these two phenomena, under particular conditions, the so-called total internal reflection takes place (Fig. 7a). In other words, the light will not enter the other optical medium but stays inside the fibre (Fig. 7b).

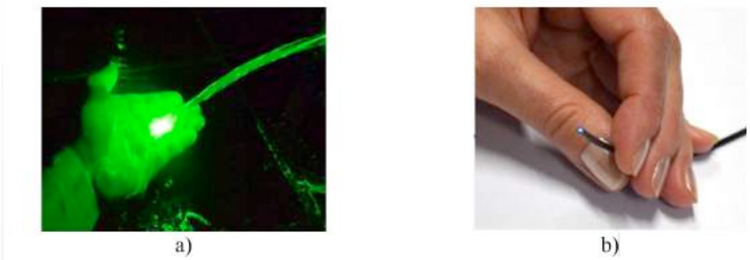


Figure 7: Total internal reflection (a) and optical fiber (b).

Optical Data Transmission for All

The activities at our station were split into three parts:
1. Optical data transmission and optical fibers,
2. Jelly optical waveguides,
3. Photonics explorer.

Optical Data Transmission and Optical Fibers

This activity was split into two parts:

1. **Theory:** To show that we use the optical data transmission everywhere, we started the presentation with an advertising spot from the TV about A1, an Austrian telecom provider, which shows very clearly the use of the optical data transmission in our everyday life (Fig. 8a). This spot also shows the laying of the optical cables in Austria to connect the people (Fig.8b).

Figure 8: a), b) An advertising spot in the TV about A1 (Austrian telecom provider); c) an explanation of bits and bytes.

To explain how any information can be sent through the optical cables ("internet") we discussed in the next step what is the computer and where it can be used. To this topic we prepared a couple of questions like "What do you usually do with the computer at home?", "What is an E-mail?" or "Which parts consists computer of?". This was the simplest part of the presentation since people are very familiar with using computers. With these questions we moved onto the more challenging part, namely "What language do computers really use?". We were talking about that the people speak different languages, they use different symbols and numbers and this overall is too complicated for computers. Therefore, a brand new language was developed for the computers to understand and communicate with each other. We discussed the bits, Bytes and binary code and their representation in the computer (Fig. 8c). The translation from our language to the computer language and back was also discussed. Finally, we explained how can data be transferred physically through the network: The original way was to send them in the form of electrical signals. However, such data transfer strongly limits the network capacity since the data can be sent through communication links only on one-by-one basis (Fig. 6). If the electrical signals are replaced by the optical signals, they can be easily recognized, e.g. they can be sent simultaneously in one fiber without interfering with each other. This technology, known as Wavelength Division Multiplexing (WDM), is of considerable importance and has one major advantage, namely that even without new infrastructure and using as few as two colours, the transmission capacity of the glass fiber cable can be doubled. The more wavelengths used therefore means the more data can be transferred (Fig. 6).

We discussed also how the optical fibers work and explained total internal reflexion (Fig. 9a). At the end of the presentation we showed an experiment (Fig. 9b (left), 9b (middle)) of Daniel Colladon, young professor of physics at the University of Geneva in the 19th century, so called "Daniel Colladon's Light fountain or Light Pipe". He was the first person, who demonstrated the total internal reflection in the water beam (Fig. 9b (right)) [4].

a)

b)

Figure 9: Demonstration of the total internal reflexion in optical fibres [3].

2. **Application of the theory:** Understanding the theory, in the second part of the presentation the visitors of any age could play the computers where they used real fibers to send the information (one letter) to the others. Some of them played the computers sending the data (transmitters, Fig. 10a) and the others were receiving the optical signals and decoding them into useful information again (receivers, Fig. 10b,c). This was the most interesting and amusing part of the presentation about the optical data transmission.

a)
b)
c)

Figure 10: Sending the optical signals through the fiber: a) transmitters, b), c) receivers.

Jelly optical waveguides

This demonstration was included to give an overview of the physical phenomena that lead to waveguiding, using as waveguides pieces of edible transparent jelly cut out in suitable shapes. It allows, too, to look at the waveguiding of light in a large, easy to see system.

The inspiration for this demonstration comes from conversations, which took place about ten years ago, of one of the authors with Prof. Matthew Anderson (then a postdoc at the University of Rochester, now at San Diego State University). The idea is cutting optical waveguides out of edible jelly. In this way large, fairly transparent waveguides can be obtained and the demonstration has a “house-made” flavour which – hopefully – makes it more attractive. The path of a light beam inside the jelly can be easily followed with the eyes and several basic effects can be shown.

We found one important detail for the preparation of the jelly in an online document of the U.S. organization NNIN (National Nanotechnology Infrastructure Network) [5]: it is better to prepare the jelly in a more concentrated form as in the recipe found on the package; in this way the jelly is firmer and easy to handle. We used a concentration twice higher than the recipe and we kept the jelly in a refrigerator overnight. Another practical tip is the following: cut the jelly with a hot knife to obtain smooth edges [6] (heating the knife in hot water was sufficient for us). With this preparation it is possible to follow the path of the beam of a laser pointer, sent into the jelly, for four or five bounces before scattering destroys it – scattering takes place mostly at the walls but some scattering centers inside the jelly can be found as well (see Fig. 11). Playing a bit with the position and direction of the laser beam one finds quickly a path along which the beam propagates fairly undisturbed for a distance of 15 to 20 cm. We used a green class 2 laser, which is eye-safe except for prolonged direct radiation - which is usually impeded by the natural aversion response to bright light [7]. The beam path inside the jelly for this laser is easily visible in a room with moderate lighting.

The visitors, like for the other demonstrations, came in little groups of about five to twenty persons throughout the evening. Our initial demonstration was quite essential: show the beam bouncing inside an approximately 15 cm long waveguide, explain that light cannot go through the jelly-air interface (and show that no light comes through the wall using small pieces of paper), bend the jelly showing that light can be guided into different directions.

The demonstration became a bit richer in the course of the evening thanks to questions and stimulating proposals by the audiences. One of the participants expressed his wonder at how can light escape through the wall if a disturbance is present on the other side, close enough to the interface (he was referring to the phenomenon of frustrated total internal reflection [8]). We were – of course – not able to reproduce the phenomenon in this demonstration, as it requires sub-micrometer precision in the placement of the external disturbance; we were though able to demonstrate that an external disturbance that touches the wall disrupts the reflection – we placed a small piece of jelly next to the waveguide wall, at a location where the beam hits it, and the reflected beam (with an almost "magical" effect) disappeared. In retrospect, it would be nice to test the same thing with different materials and see the effect on the beam; we noticed only that water droplets roll quickly off the jelly surface, so that one cannot follow with the eyes their effect on the beam. We took anyway the occasion to talk about an application of waveguiding as a rain sensor (the rain is the external disturbance) or more in general as a surface sensor.

This demonstration led to a next step, in which we cut a waveguide with a slanted entrance edge and we placed its slanted edge in contact with the side of the first waveguide; the slanted edge makes the direction of the second waveguide different from the direction of the first. By pressing the waveguides one against the other or pulling them slightly apart light can be sent into one or the other channel (one can show it with a piece of paper held at the end of either waveguide), which makes for a rough but fun demonstration of optical switching. A couple of children asked then to join more waveguides, and, despite the quite large scattering losses, it was still possible to see light coming out of the far end – just by looking at the paper, they were quite convinced that it was possible to lead light through a couple of "jelly joints", without any need for words from the demonstrator.

A final step was the demonstration that waveguiding can be achieved only inside the densest medium. In order to do this, we placed two waveguides parallel to each other, with a gap in the middle of approximately the width of each waveguide. We then sent the laser beam inside the gap, trying to get it to bounce at the walls – one could immediately see the path of the light that escaped through the walls of the side-waveguides. The descriptions were different for different groups of people, following the interests of the participants and the intuition the demonstrator had about these interests. We talked about the low absorption of optical fibers and gave a rough comparison with household glass (we stated that 10 km of optical fiber is very roughly as transparent as a few meters of household glass); we explained the preparation of the jelly in detail; someone wanted to know more about the laws of refraction; some people with technical backgrounds asked a few deeper questions. All of this was possible because of the relaxed pace of the evening, the fact that some groups were quite small and that there was usually a gap of a few minutes between one group and the next.

This informal demonstration is easy for the experimenter and – we hope – interesting for the audiences. The immediate impression was that the demonstration is able to raise interest. The jelly waveguides can be turned, in a different setting, into a hands-on demonstration where the participants cut their own waveguides and experiment with them. Since the shape of the waveguides that can be cut is rather arbitrary, experimenting should be rich and fun ([5] suggests the following question: we can cut a waveguide that makes the light direction change by 180 degrees – how small can we make this waveguide?). Of course adequate precautions for eye safety need to be taken when distributing laser pointers to participants.

Figure 11: Sending the laser beam through the waveguide.

Photonics explorer

The experiments used at our station were taken from Photonics Explorer; an educational kit (Fig. 12b), developed by the photonics research team B - PHOT at VUB (Vrije Universiteit Brussel), for students of secondary schools to experiment with the different properties of light and photons (Fig. 12a). The concept is a 'lab-in-a-box' that enables students of the 2nd and 3rd grade to do photonics experiments themselves at school with lasers, LEDs, lenses, optical fibers, and other high-tech components.

The kit fits the learning objectives for sciences and pursues two main objectives of STEM (Science Technology Engineering Mathematics). In the first instance Photonics Explorer links applications to real-world situations and to the life of young people. They discover for example how the polarization of light is crucial for LCD screens of smartphones and tablets, or how light can speed up the time to download movies from the Internet. Furthermore, the kit is also built entirely around inquiry-based learning in which all students are involved, observing and reasoning actively. This hands-on approach gives students more confidence and stimulates their curiosity and problem-solving skills.

Since November 2011, EYESTvzw is responsible for the assembly and mass distribution, and for supporting teachers in our endeavour to convey the fascination of science and engineering to pupils (Fig. 12c). To organise the distribution all over Europe, EYESTvzw works together with very motivated partners in several European countries. Local Associated Partners are responsible for the teacher trainings and the distribution of the Photonics Explorer in a particular country or region. For more information visit [9].

a) b) c)

Figure 12: Photonics Explorer: a) the students of secondary schools experimenting with the different properties of light and photons; b) an educational kit; c) workshops for the teachers.

Conclusion

In this paper we have shown that science can be made attractive for people of any age if it is explained and presented in an appropriate way. One of the examples is the Austrian event “The night of science”, that makes science accessible to a wide population. Here we described the activities we proposed visitors at the Research Centre for Microtechnology (FHV) in this occasion. Combining hands-on teaching with having fun while learning about the basic physical concepts was amusing not only for the visitors but also for the demonstrators.

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