Using free space optics research to teach optics and optoelectronics

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ABSTRACT

Free space optics research encompasses a variety of optics and optoelectronics concepts making it an ideal educational venue. The research and development of a free space optics wireless link was used to teach optics and optoelectronics to undergraduate students. Essential to the educational component in the experiment was an actively mode locked ultrashort pulse laser system, designed for telecom research, which offered a clear visual correlation between the optically modulated data signal, displayed on a digital communication analyzer, and the received electrical signal, obtained by an Indium Gallium Arsenide detector, displayed on an oscilloscope. Data patterns generated by a bit error rate tester were modulated onto the laser using a Mach Zehnder Modulator. Optical taps on the laser allowed the students to view the mode locking of the laser and the output signal from the modulator. Both taps were crucial for teaching the students how changes made to the laser cavity, effect the performance of the laser and the modulated output. At the receive end of the link, students learn how the optical signal is transmitted, detected and converted from an optical signal to an electrical signal via the detector. The students can view the received data pattern on an oscilloscope and compare it to the transmitted data pattern. Using the error detector on a bit error rate tester, the students can also determine the bit error rate. This free space optics research project supports course instruction for optics courses, optoelectronics courses and undergraduate research.

Keywords: free space optics, bit error rate, ultrashort pulse lasers, optoelectronics, Mach Zehnder Modulator, wireless communication

1. INTRODUCTION

Free space optics (FSO) is a line of sight technology that uses light to transmit data through the atmosphere. FSO has been viewed as a possible alternative to conventional radio frequency (RF) and microwave links[1,2,3]. It operates at speeds comparable to fiber optics without the disruptive construction and cost necessary to deploy fiber. FSO has the potential to transform many applications in the wireless world including last mile customer access, connectivity bottlenecks, ground to space and space to space communications to name a few[4,5,6]. Developments in semiconductors and optoelectronic components has enabled the successful development of commercial FSO systems. These developments, along with the potential commercial communication applications, make FSO a unique and engaging field to teach optics and optoelectronics to undergraduates.

The paper presents the research and development of a free space optics wireless link and discusses how it was used to teach optics and optoelectronics to undergraduate students. Students participated in the projects for independent study, capstone, summer research, and as part of the optics and optoelectronics courses. The setup of the paper is as follows. Section 2 provides an overview of the project and includes sections dedicated to specifics components of the experiment that are vital to its optics and optoelectronics educational value. Section 3 is the conclusion offering a brief summary of the FSO research and its contribution to teaching students about optics and optoelectronics.

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2. FSO RESEARCH USING AND ULTRASHORT PULSE LASER

2.1 Experiment

Students participated in the research and development of a free space optics communication link using an actively mode locked ultrashort pulse laser. The laser has a wavelength of 1550 nanometers (nm), pulse width of 150 femtoseconds (fs) and a repetition rate of 1.25 gigahertz (Ghz). The maximum power is 0.25 watts. The laser connects directly to a Mach Zehnder Modulator (MZM) and then to an Erbium Doped Fiber Amplifier (EDFA). The connection type for the final modulated, amplified laser output is a one-meter long polarization maintaining fiber pigtail. Because the laser is actively mode locked, it requires an external clock to set the repetition rate. The radio frequency (RF) clock source is an Agilent 83712B Signal Generator operating at 1.25 Ghz.

A digital pattern of ones and zeros, generated by an Agilent 86130A Bit Error Rate Tester (BERT), is modulated onto the laser using the MZM. The BERT is synchronized with the RF clock of the laser. Thus the repetition rate of the laser is equivalent to the transmitted data rate, 1.25 gigabit per second (GBPS). A partial schematic of the FSO transmitter setup is shown in figure 1.

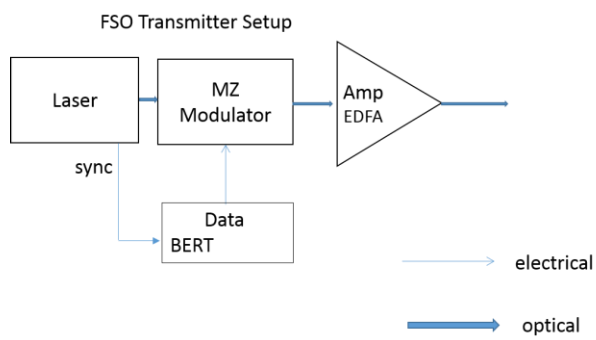

Figure 1. The schematic diagram of the setup used to transmit data in the FSO project. The laser wavelength is 1550nm, the pulse width is 150 fs, the maximum power is 0.25 watts and the repetition rate which is also the data rate is 1.25 Ghz.

The amplified output is connected via fiber to a collimator and transmitted through free space to a second collimator. The second collimator is coupled to a 50-50 fiber splitter. Half of the signal goes to an optical power meter and the other half to a Thorlabs Indium Gallium Arsenide (InGaAs) biased detector. The detector converts the optical signal to an electrical signal, which is viewed on a 6-Ghz Textronix Digital Phosphor Oscilloscope (DPO). Signal analysis can be performed using the DPO and the BERT.

2.2 Laser Cavity

The laser cavity consists of an EDFA gain medium, output coupler, electro-optic modulator, filter, delay line and fiber that connects all of the components[7]. Students must learn how each component in the cavity operates and the effect it has on the performance of the laser. Unique to the laser system, are two optical taps, one inside the laser cavity to observe the mode locking of the laser and a second outside the laser cavity at the output of the Mach Zehnder Modulator. To view the signals, the taps are connected to an optical module on an Agilent 86100A Digital Communications Analyzer (DCA). The mode lock tap offers a real time view of the laser pulses, allowing students to see how changes made to the laser cavity effect the shape of the pulse displayed on the DCA.

There are four component controls within the laser cavity available to the user. The front panel of the laser has knobs to adjust each component. The component controls include the laser diode pump current, bias voltage to the electro-optic modulator, cavity adjuster for the length and phase shifter for the RF clock input. The schematic diagram of the laser cavity from the Calmar Eureka Laser manual is shown in figure 2. The laser diode is responsible for maintaining the population inversion in the EDFA gain medium. Thus adjustments to the pump current also change the output power.

The Electro-Optic Modulator (EOM) actively mode locks the different modes oscillating in the laser cavity. Adjusting the EOM bias voltage changes the index of refraction in the two arms of the modulator which results in constructive or destructive interference at the output. In order to mode lock the laser the EOM bias voltage must be adjusted properly to control the losses in the cavity.

The cavity adjuster fine tunes the cavity length using a piezoelectric ceramic material. For stable mode locking the round trip frequency in the cavity must be an integer multiple of the repetition rate of the laser. The cavity control allows for adjustments to the cavity length corresponding to frequency adjustments of several kilohertz[7]. The laser manual offers recommended values for the cavity adjust but the user is often left to find the ideal value in the mode locking process, since the repetition rate depends directly on the setting of the signal generator providing the RF clock. The final control is the phase shifter which controls the phase of the RF into the phase lock loop.

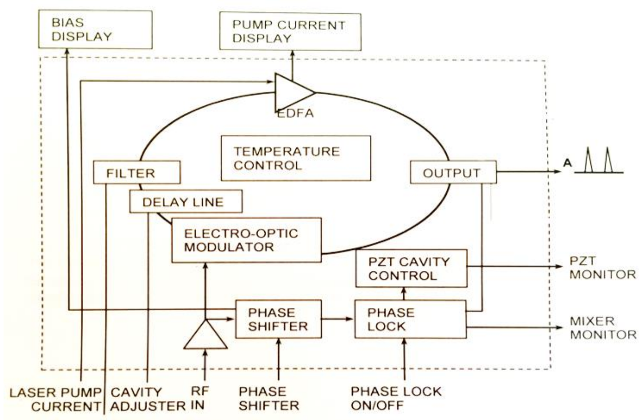

Figure 2. The schematic diagram of the laser cavity from the Calmar Eureka Laser user manual[7]. The front panel of the laser provides knobs to control the laser diode pump current, bias voltage to the electro-optic modulator, cavity adjuster and phase shifter for the RF clock input. The components must be optimized to mode lock the laser.

2.3 Mode locking

Before students begin the mode locking process, they must learn how the fiber laser and its components operate. Without this knowledge, students aimlessly turn knobs. Understanding how the system works, makes the mode locking process more efficient and educational for the students, instead of a task in frustration and knob turning. To assist the students, the instructor offers a basic overview of generic laser cavity then provides the students with the laser manual. The students extent their basic knowledge of the laser cavity to the fiber laser operation. This is a very valuable educational practice for the students. Students learn about fiber optics and electro-optic components such as the EDFA and the electro-optical modulator. Once the students have a basic understanding of the fiber laser, they begin the mode locking process by adjusting the component controls, for the laser cavity, while monitoring the mode lock optical tap signal on the DCA. The laser manual provides additional instruction to assist the students. With the knobs on the front panel of the laser, students control the pump current of the laser diode for the EDFA, the bias voltage to the electro-optic modulator, the cavity length and the phase of the RF clock input. Each of these has a unique effect on the performance of the laser as discussed in detail in section 2.2. Each component must be set properly to mode lock the laser. When the laser is mode locked the optical tap displays a stable pulse on the DCA as shown in figure 3.

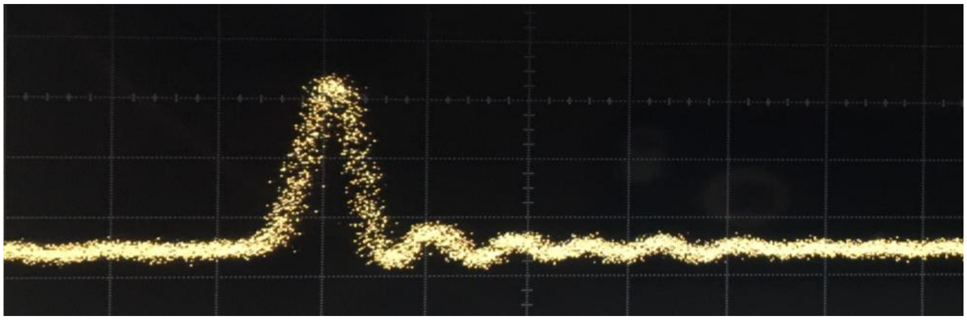

Figure 3. Image from the mode lock optical tap in the laser cavity displayed on the DCA. When the laser is mode locked the pulse is smooth and stable as it is in the figure. Students can monitor the pulse on the DCA as they make adjustments to the components in the laser cavity to mode lock the laser.

The image on the DCA provides the students with a clear view of the pulse during the mode locking process. If the image on the DCA is not a clean and stable pulse then students must adjust the component controls until the mode lock is established. Once mode lock is set, the student can make additional changes to the cavity while monitoring the pulse to further understand how changes the cavity components effect the resulting pulse.

2.4 Mach Zehnder Modulator and Bit Error Rate Tester

The data from the BERT is modulated onto the laser using the MZ modulator. The modulator works on the principle of the Mach Zenhder Interferometer which is ideal for demonstrating a practical application of interferometry to students. Prior to modulating the data onto the laser, students are given an overview of the interferometer and then asked to do the research on the MZ modulator. Once they have an understanding of how the MZ modulator operates, they are given the laser manual and information on the BERT to review before setting up the modulation. If broken into steps for the students, the first step of the modulation process is generating a simple eight bit data pattern using the pattern generator on the BERT. Second the students must synchronize the data with the repetition rate of the laser. There is an SMA connection on the front panel of the laser that provides an output RF that is synchronized with the clock of the laser. By connecting the RF to the Clock In on the pattern generator the students can synchronize the data with the repetition rate of the laser. This process is valuable for teaching students the importance of synchronizing data with the laser to modulate it successfully in a communication link.

Once the pattern is generated and synchronized with the laser, students can perform step three, which is setting the bias and the gain on the modulator using the knobs on the front panel of the laser. The optical output from the MZ modulator tap displayed on the DCA allows the students to observe, in real time, how changes made to the gain and bias effect the modulated data pattern. Figure 4 shows an example on the DCA screen displaying the modulator output for a digital pattern which is 1100110011. The vertical peaks represent the ones and the lack of peaks represent the zeros. The time per division is 1000 nanoseconds. Since the data rate is 1.25 Ghz the time between each digital signal is 800 picoseconds. Therefore a one or zero should fall on every fourth hash mark on the horizontal scale as shown in Figure 4.

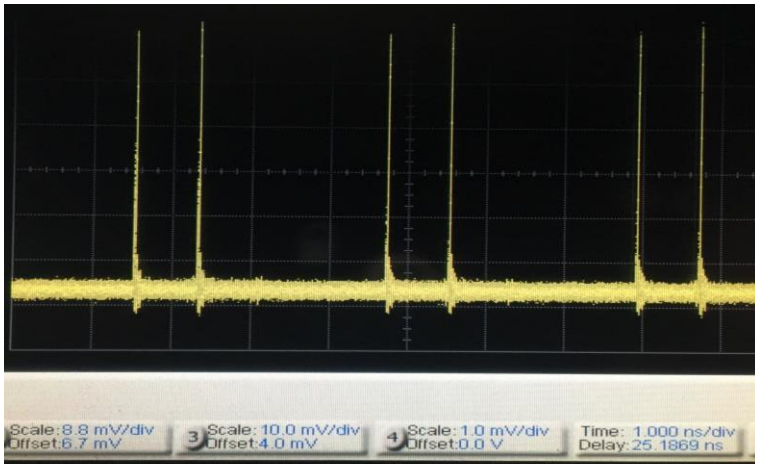

Figure 4. The image shows the modulated data coming from the optical tap at the MZ modulator. The pattern is a 1100110011. The vertical peaks represent the ones and the lack of peaks are zeros. The data rate is 1.25 Ghz so the image shows the digital data separated by 800 picoseconds or every fourth horizontal division. Each major divisions is 1000 nanoseconds as displayed on the DCA time scale.

As the students adjust the bias and the gain on the modulator they can see the change in the heights of the ones on the DCA. For an optimal setting of the modulator a zero should be a flat line with no vertical height. Students can see the zeros creep up from no peak to larger and larger peaks if the gain and bias are not set properly. Once the modulator is optimized, students can change the pattern on the BERT and observe the change in the modulated pattern displayed on the DCA. It is a very visual learning technique.

2.5 Receiver

After the modulator is optimized, the fiber pigtail from the laser system is connected to a collimator and the modulated signal is transmitted through free space to a second collimator located one meter away. Before making the connections the students must learn how to clean and connect fibers to collimators. Once the laser fiber output is connected to the collimator the laser power can be increased by adjusting the pump current to the amplifying EDFA. The second collimator connects to a 50/50 fiber splitter sending half of the signal to an optical power meter and the other half to a Thorlabs high speed InGaAs detector. Students must read and understand how the InGaAs detector works, which is an excellent example of optoelectronics in action. The students align the two collimators by maximizing the reading on the optical power meter. The output of the detector is connected to a Tektronix Digital Phosphor Oscilloscope (DPO). The clock from the BERT is also connected to the DPO to match the received signal with the timing of the laser. Figure 5 shows the signal on the BERT that is sent to the modulator and then transmitted through free space by the laser. It also shows the data rate, 1.25 Ghz in the lower center, as the pattern generator clock rate (PG CLK rate).

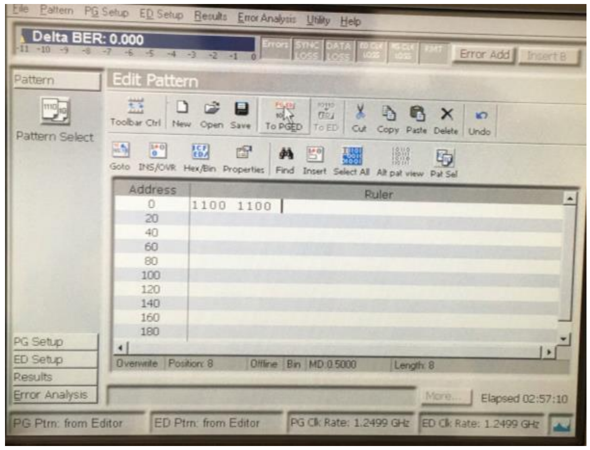

Figure 5. The image shows the digital signal on the BERT that is sent to the modulator. It also shows the data rate, or the pattern generator clock rate (PG CLK Rate), as 1.25 Ghz.

The data is transmitted as a return to zero signal. Figure 6 shows the signal received by the detector, displayed on the DPO (pink small peaks), along with the clock (blue large peaks) from the BERT. For each clock there is a corresponding one (peak) or zero (no peak). The received data in figure 6 successfully matches the 11001100 data pattern transmitted.

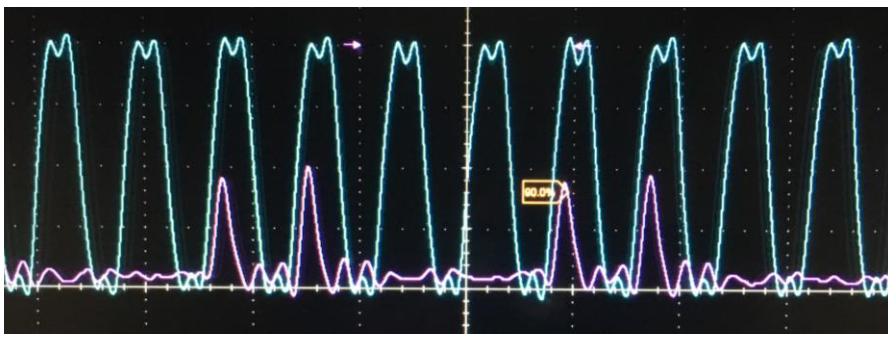

Figure 6. The image shows the signal received by the InGaAs dector (blue smaller peaks) with the clock (blue larger peaks) from the BERT. The signal is return to zero so for each clock there is a peak for a one or no peak for a zero. The data received matches the data transmitted by the BERT, 11001100.

In Figure 6 it is evident that the zeros still contain some level of noise. Ideally the zeros would be a flat line but the difference between the peaks of the ones and the zeros makes the signal distinguishable. By adjusting the MZ modulator settings students can observe how changing the modulator at the transmit end effects the received signal displayed on the DPO. Likewise they can observe the changes on the DCA at the transmitter. The visible nature between the transmitted signal on the DCA and received signal on the DPO, make this experiment ideal for teaching students about wireless communication links.

2.6. Bit Error Rate

The same BERT that serves as the pattern generator for the link also serves as an error detector. The signal from the InGaAs detector is connected with an SMA cable to the Data In on the front panel of the BERT. The error detector on the BERT must be synchronized with the clock from the laser since there is no receiver circuit to recover the clock from the signal received by the detector. The clock from the laser is connected to the Clock In on the error detector of the BERT. If all bits are received the students will see a zero bit error rate on the BERT. If the bit error rate is not zero, the students must determine the source of the errors. It can be caused by a variety of issues including low optical power, improper settings on the MZ modulator or improper synchronization. Because the students can view the signal at the transmitter and the receiver and measure the optical power, in all most all cases there is a way to eliminate the error and obtain a zero bit error rate. The DPO also has signal analysis software so students can also learn about eye diagrams and jitter analysis. The knowledge gained by the signal analysis and bit error rate testing is valuable for all students but especially those interested in telecommunications or majoring in electrical engineering.

3. CONCLUSION

Free space optics offers a variety of features for teaching optics and optoelectronics. The equipment used in the FSO laser wireless telecom link for this project offered endless amounts of technology in both optics and optoelectronics to be shared with the students. The actively mode locked ultrashort pulse laser system, custom designed for telecom research, provided a clear visual correlation between the optically modulated data signal, displayed on a digital communication analyzer, and the received electrical signal obtained by an InGaAs detector and displayed on an oscilloscope. The data patterns were generated by a Bit Error Rate Tester (BERT) and modulated onto the laser using a Mach Zehnder Modulator. The optical taps on the laser provide a visual representation of MZ modulator output. The received signal from the InGaAs detector is displayed on a DPO. Students can observe how changes made to the laser cavity and the modulator effect the signal at the receiver by viewing the signal on the DPO. Signal analysis software on the DPO allows the students to produce eye diagrams and look at jitter analysis. In addition the BERT can be used as an error detector to analyze the bit error rate of the transmitted signal. The setup supports course instruction for optics and optoelectronics courses and undergraduate research projects.

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REFERENCES

[1] Malik, A. and Singh, P., “Free Space Optics: Current Applications and Future Challenges,” International Journal of Optics, Volume (2015).
[2] Babanil, S., Abdukmalik, Y. S., Abdul’aziz, A., Loko, A. S., Gajibo, M. M., “Free Space Optical Communication: The Main Challenges and Its Possible Solution,” International Journal of Scientific and Engineering Research, Volume 5, (July 2014).
[3] Henniger, H., and Wilfert, O., “An Introduction to Free-Space Optical Communications,” Journal of Radio Engineering, Volume 19, No.2, (June 2010).
[4] Awan, M. S., Leitgeb, E., Marzuki, and Planck, T., “A Study of Fog Characteristics using Free-Space Optical Wireless Links,” Journal of Radio Engineering, Volume 19, No.2, (June 2010)
[5] Akbulut, A., Ilgin, H. A., Efe, M., “Adaptive Bit Rate Video Streaming Through an RF/Free Space Optical Laser Link,” Journal of Radio Engineering, Volume 19, No.26 (June 2010)
[6] Takayama, Y., Toyoshima, M., Kura, N., “Estimation of Accessible Probability in Low Earth Orbit Satellite to Ground Laser Transmission,” Journal of Optical Networking, Volume 2, No.2, (June 2010).
[7] Calmar, “Eureka Fiber Laser Instruction Manual,” pp. 7, (2017).