Interactive Learning Module
VPI University Program

Introduction to Fiber-Optic Communication Systems I

FOC1
In this module, a simple but complete fiber-optic transmission link will be studied. The setup consists of the three basic elements common to all fiber-optic communication systems:

- An **optical transmitter** converts an electrical signal into optical pulses. In the simulation setup, a single longitudinal mode semiconductor laser is directly modulated with a pseudo random bit sequence (PRBS).
- The optical pulses are transmitted over the **fiber-optic channel**, which in this case consists of one section of optical fiber.
- The transmitted pulse stream is converted back into the electrical domain by the **optical receiver**. In the system under consideration, it consists of a photodetector followed by an electrical filter to enhance the signal quality. Time and frequency domain visualizers are used to evaluate the simulation results.

**Note:**
For details on the handling of VPItransmissionMaker / VPIcomponentMaker please read the *User’s Manual* before starting this unit.
Computer Model of an IMDD

Data

Rise time limiter

NRZ encoder

Laser

Electrical filter

PIN diode

Transmitter

Optical fiber

Receiver

Detectors
Commonly Used Symbols

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Generates a Pseudo Random Bit Sequence (PRBS)

- The output PRBS generator can be modified, for example:
  - fixed mark number (assures a fixed number of ‘1’ s)
  - sequences of ‘0’ s, ‘1’ s, or alternating ‘1’ s and ‘0’ s
  - other features (see Reference Manual for more details)
Computer Model: NRZ Coder

- Generates a NRZ-encoded train of electrical pulses defined by the train of bits at its input
- Pulse waveform at the output of the coder is sampled
- See the *WDM User’s Manual* for more details on TimeWindow and sampling. There is also another unit which discusses numerical modeling in greater depth.
Realistic electrical pulses do not have sharp edges. The edges have a finite *Rise Time*.

*Rise Time* refers to the ratio 10% / 90% of amplitude values.

Typical value: RiseTime = 0.25 / BitRate

Other values may be used where appropriate.
Lasers are usually modeled using laser rate equations.

Time dynamics (like overshoots) and other detailed laser characteristics that can distort the optical pulses and add noise are taken into account.

These characteristics depend on material and geometric parameters of the laser (more on this in another module).
Computer Model: Optical Fiber

- Optical fiber propagation can be modeled using the Nonlinear Schrödinger (NLS) Equation
- The following effects, which distorts optical pulses, are taken into account:
  + fiber loss (or attenuation)
  + first and second order Group Velocity Dispersion (GVD)
  + nonlinear effects (SPM, XPM, FWM, SRS)
Computer Model: PIN Diode

- Converts incident optical field into electrical signal
- Electrical signal is calculated by:

\[ i(t) = i_s(t) + n_{sh}(t) + n_{th}(t) + i_d \]

- Distorted optical pulses
- Electrical pulses + Noise + Dark Current

Amplitude vs. Time graphs are shown for the input and output signals.
• Represents an analog Bessel low pass filter
• Main parameters: CutoffFrequency, FilterOrder
• Typical application: noise suppression after photodiode
• Generally, further processing of the electrical pulses is required to recover the original binary data bit stream
The Transmitter

Once VPltransmissionMaker™ WDM has started and you are in the correct project directory, click and drag the setup FOC1_1 into the work space.

- A schematic of the transmitter section of the fiber-optic transmission link appears. It consists of a PRBS generator, a Non-Return to Zero (NRZ) coder, a rise time adjuster and a laser (see below).
- An optical spectrum analyzer (OSA) is connected to the output of the laser.
The PRBS in the setup is currently set to produce a string of '0's. The laser is biased so that it operates in the linear regime.

- Run the setup as it is. The spectrum of the laser output is generated (see below). Since the PRBS is generating a string of '0's, the laser is unmodulated.
The Transmitter

- Double-click on the icon of the **PRBS**, and modify its parameter **PRBS_Type** from ‘Zero’ to ‘PRBS’, and run the modified setup.
- With the **PRBS** generating a string of random ‘0’s and ‘1’s, the laser is now modulated.
- **Question 1**: What is the difference between this and the unmodulated laser spectrum?

![Graph showing spectrum broadening and peak shifting due to modulation and chirp.](image)
The Transmitter

- The ViOSA is a frequency domain visualizer that is used to examine the frequency content of a signal. The signal may also be examined in the time domain, by using a ViScope.

- Close the current setup. Open the setup FOC1_2. The setup that appears is exactly the same as the previous setup, except that the ViOSA has been replaced by a ViScope.

- Run the setup. A scope trace* in the time domain appears, showing the optical waveform produced by the laser.

  * Note that in real scopes, any optical waveform that is displayed has to be converted into an electrical waveform by a photodetector first.
The Transmitter

- Play around with the various features of the scope (e.g. rescaling the axes, magnifying a portion of the trace, etc).

- **Question 2**: From the scope trace of the laser output, can you estimate the speed of the optical signal? The speed of a signal given by the number of bits per second.
The Complete Fiber-Optic Link

- Close the current setup and open the setup FOC1_3.
- A schematic of the complete fiber-optic link appears.
- The transmitter section of the setup is the same as the previous setups. The output of the laser is now connected to a 10 km length of optical fiber, then a PIN photodetector followed by a electrical low pass (LP) filter. The detected signal is displayed on a scope (ViScope) and a radio-frequency spectrum analyzer (ViRFSA).
The Complete Fiber-Optic Link

- Run the setup FOC1_3 as it is. When the simulation is finished, two visualizer windows open to display the received electrical signal in the frequency domain (shown below) and the time domain (next page).
When analyzing the waveforms of a signal, it is useful to overlap the received pulses. The resultant diagram is known as an Eye diagram.

Click the Eye mode button and the maximize display button (as shown below).
Eye Diagrams

- The Eye diagram is a useful tool for visualizing the performance of communication systems. The maximized Eye diagram of the received pulses is shown below.

- The Eye below is wide open. This shows that the digital ‘1’ and ‘0’ levels of the received bits are easy to distinguish, and implying a very good quality received signal. The other features of the Eye diagram also tell us something about the signal (and thus the system), as we shall see later.
Eye Diagrams

- Double-click on the fiber icon in the schematic, and modify its parameter Length from '10.0e3' (10km) to '150.0e3' (150 km). Run the modified setup, and display the Eye diagram.

- The Eye shown below indicates that the received pulses are severely distorted compared to the previous simulation. The deterioration is caused by higher optical attenuation experienced by the pulses propagating over the longer fiber.
• Note that the received optical power is significantly smaller (by about three orders of magnitude). As a result, the thermal noise in the detector has a more severe effect on the weaker received signal pulses.

• This is reflected by the fuzziness of the Eye diagram in the previous page, as the digital ‘1’ and ‘0’ level are corrupted by receiver noise. Such an Eye diagram is said to be ‘closed’, and indicates a received signal of a poor quality.

• A fiber-optic communication system in this state is said to be ‘loss-limited’.

Eye Diagrams
Bit Error Ratio (BER)

The Eye diagram introduced previously provides an immediate, graphical/visual feel for the performance of the system.

A more objective measure of the performance of a system is the Bit Error Ratio (BER) (also known as Bit Error Rate). This is the number of bits detected incorrectly (i.e. bit errors) over a certain time interval, divided by the total number of bits transmitted during the same time interval.

The scope used to display the received pulses as an eye diagram has a built-in function that can estimate the BER. It works by making certain statistical assumptions about the distribution of the digital ‘1’ and ‘0’ levels of the pulses in the received signal. The theory of BER estimation will be covered in greater detail in another module.

Determine the BER of the signal in the Eye diagram in the previous page.

- Click on the Vertical Markers button on the control panel of the Eye diagram (remember to restore the diagram to its normal size to reveal the panel)
- Click the Create button place a marker, then move it to the middle of one of the eyes
- Click on the check box marked BER.
The estimated BER at the marker position is displayed below the BER check box. It is found to be of the order $10^{-6}$, which is not satisfactory in practical fiber-optic communication systems (should be below $10^{-9}$ for systems without FEC).

**Estimating BER from an Eye Diagram**

![Eye Diagram Image]
Answers

• **Question 1**: The bandwidth is broadened in the modulated laser spectrum and the lasing frequency is shifted because of the chirp in modulated laser output.

• **Question 2**: Yes. Measure the time duration of several bits and the speed of the optical signal is the number of bits over that time duration.