CHAPTER THREE

METHODOLOGY

3.1 Introduction

In this chapter, the methodology of this research and the approach taken to achieve the goal are described. The study was all carried out using simulation software, OptiSystem (Version 5). The major aspect during methodology stage is simulation process. The main objective of simulation is to find the best configuration of the system that can operate at optimum performance to be implemented it on the application systems, OCDMA. This will not only save time but also can provide a clear picture (based on eye diagram, then can create performance graph) of the designed configurations whether or not the design objectives can be achieved.

The study was carried out with two configurations/models to configure the New OCDMA system. Each model was simulated by varying a set of design parameters. The two models are; parallel and serial configurations of encoder and decoder modules. The performance of each model is characterized by Bit Error Rate (BER). Encoders and decoders can be implemented using any type of optical filtering technology, including thin-film filters, Fiber Bragg Gratings (FBGs), or free-space diffraction gratings, to name a few.

3.2 Optisystem Software (Version 5)

Optisystem software is an innovative optical communication system simulation package that designs, tests, and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks, from analog video broadcasting systems to intercontinental backbones (Optisystem reference guide 2002). Optisystem is a standalone product that does not rely on other simulation frameworks. It is physical layer simulator based on the realistic modeling of fiber-optic communication systems. It possesses a powerful new simulation environment and a truly hierarchical definition of components and systems. Its capabilities can be extended easily with the addition of user components, and can be seamlessly interfaced to a wide range of tools.

The extensive library of active and passive components includes realistic, wavelength-dependent parameters. Parameter sweeps allow the user to investigate the effect of particular device specifications on system performance. Optisystem calculates the signals using the appropriate algorithms related to the required simulation by determining the order of execution of component modules according to the selected data flow model. The main data flow model that addresses the simulation of the transmission layer is the Component Iteration Data Flow (CIDF). The CIDF domain uses run-time scheduling, supporting conditions, data-dependent iteration and true recursion. In order to predict the system performance, Optisystem software calculates parameters such as BER and Q-Factor using numerical analysis or semi-analytical techniques for systems limited by intersymbol and noise.

3.2.1 Simulation Tools

Figures show below are the basic tools and steps used in OptiSystem Software to simulate the encoder and decoder design of parallel and serial configurations.

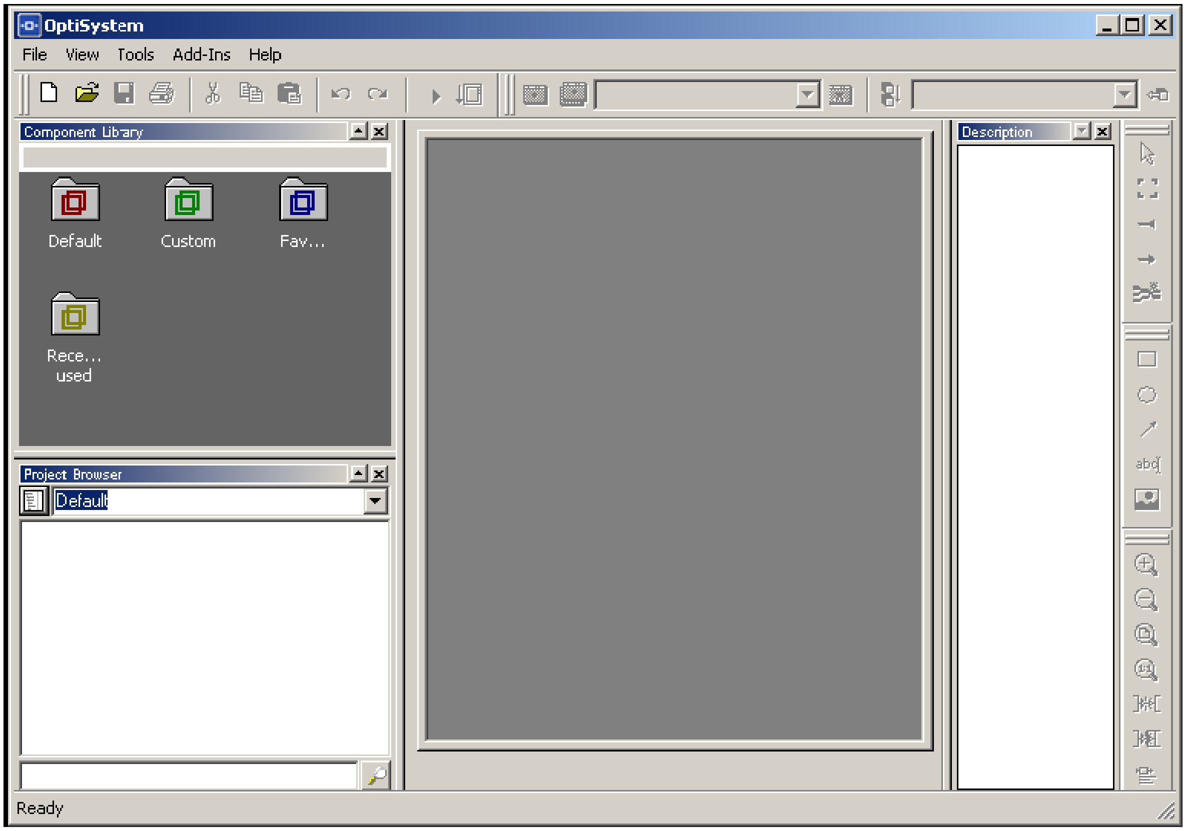


Figure 3.1: Optisystem Graphical User Interface (GUI)

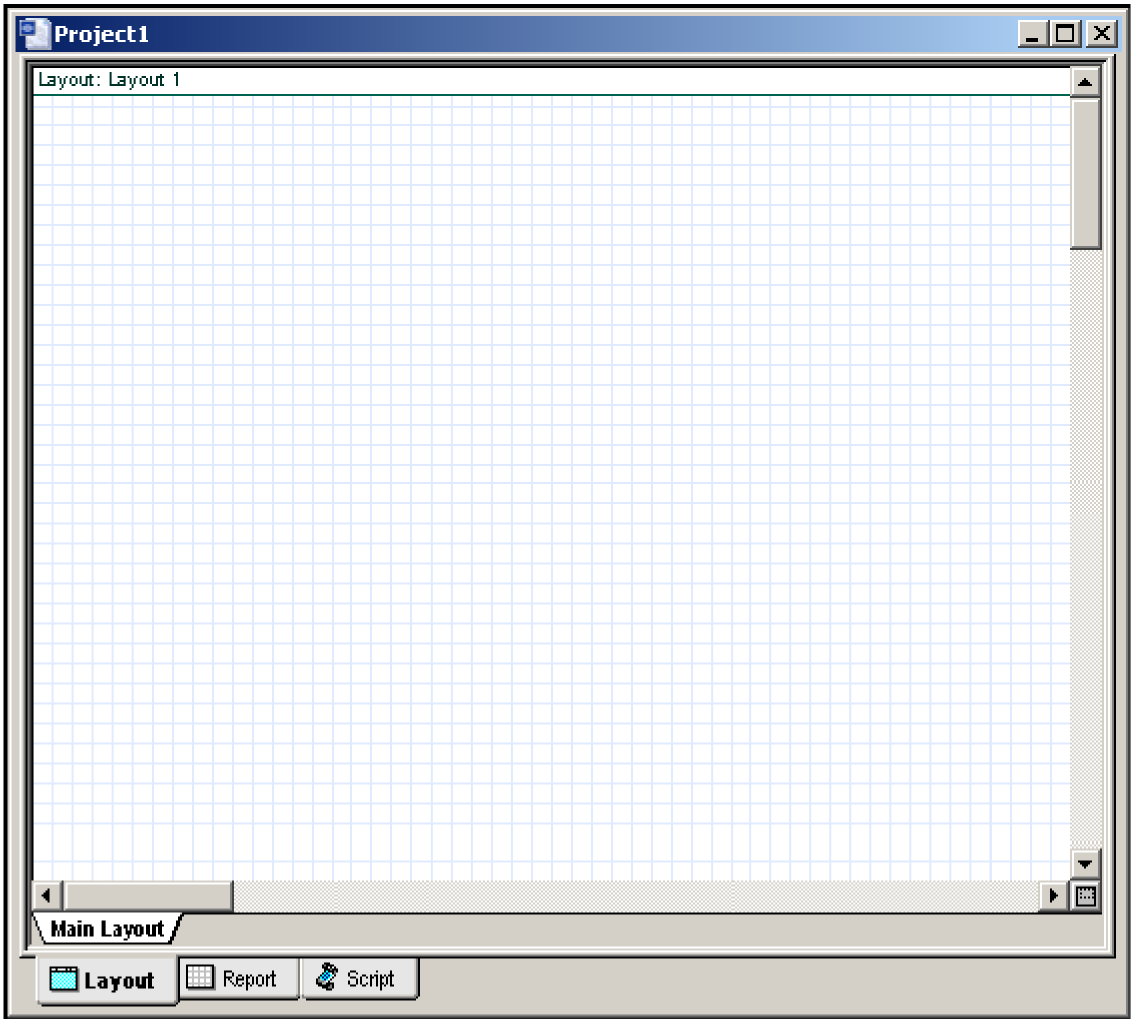


Figure 3.2: Project Layout Window

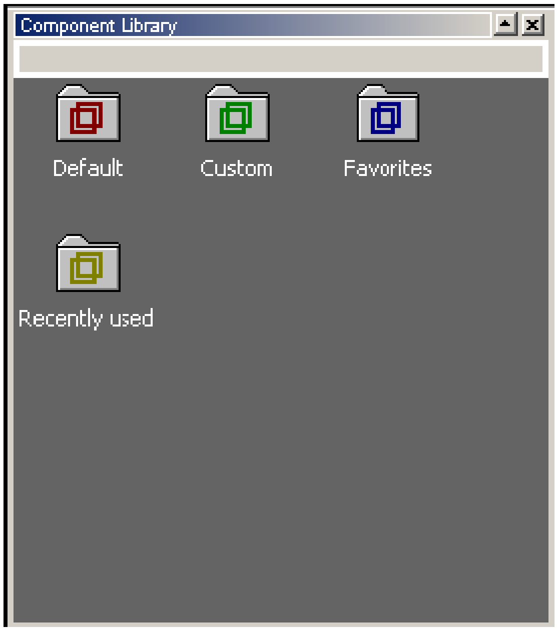
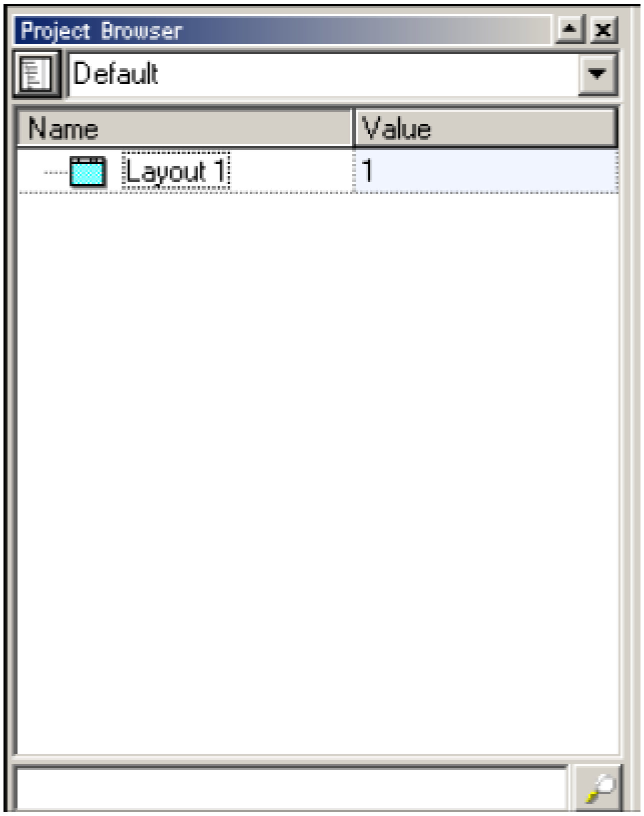
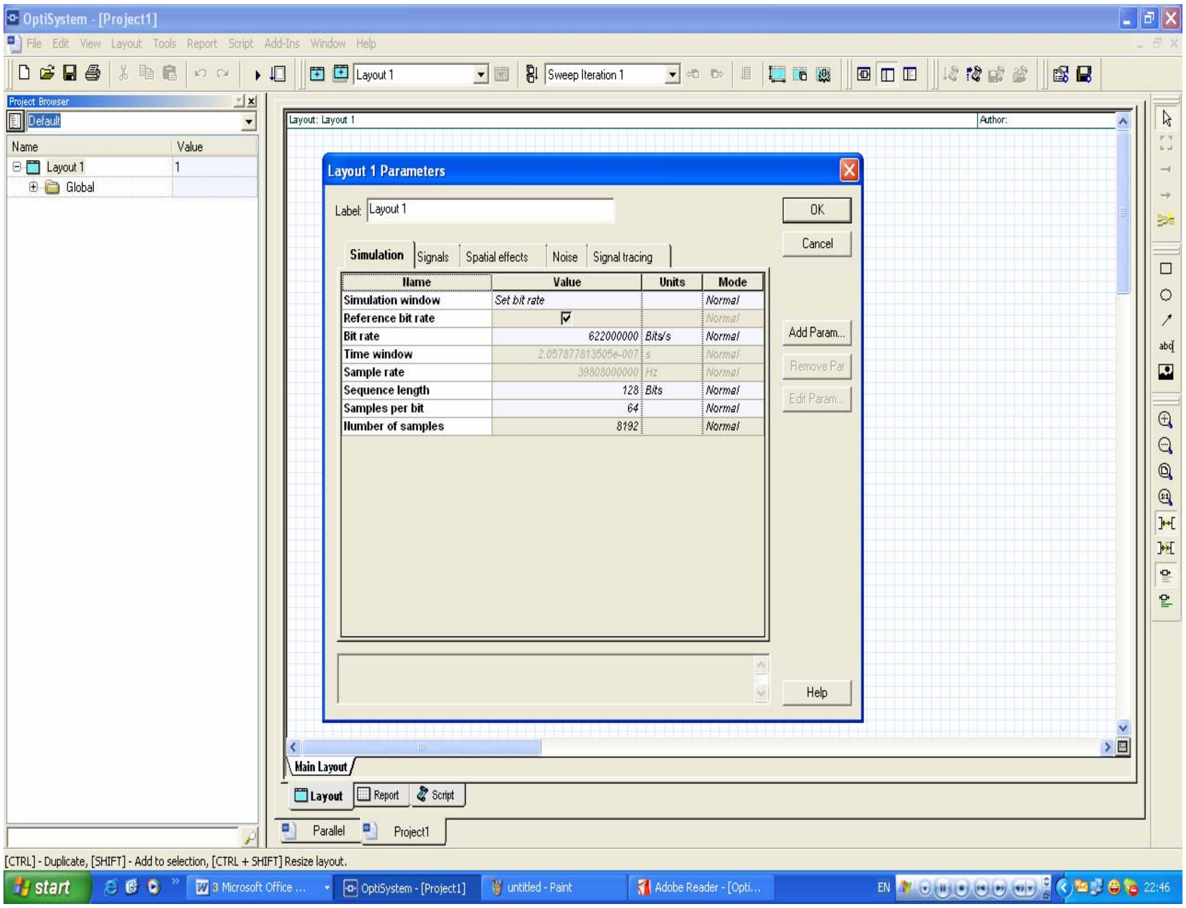


Figure 3.3: Component Library Window



Name	Value
Layout 1	1

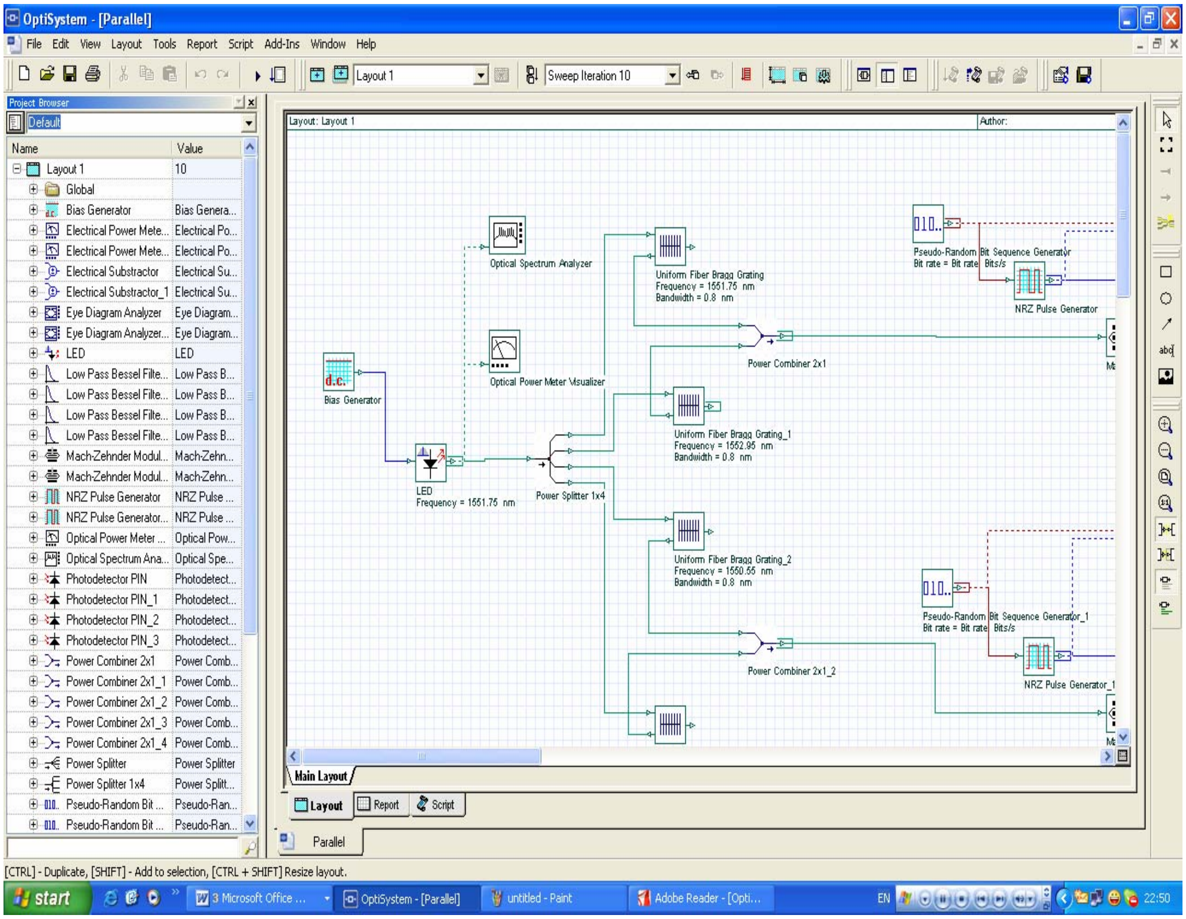
Figure 3.4: Project Browser Window



Label: Layout 1

Name	Value	Units	Mode
Simulation window	Set bit rate		Normal
Reference bit rate	☑		Normal
Bit rate	622000000	Bits/s	Normal
Time window	2.057877813505e-007	s	Normal
Sample rate	39808000000	Hz	Normal
Sequence length	128	Bits	Normal
Samples per bit	64		Normal
Number of samples	8192		Normal

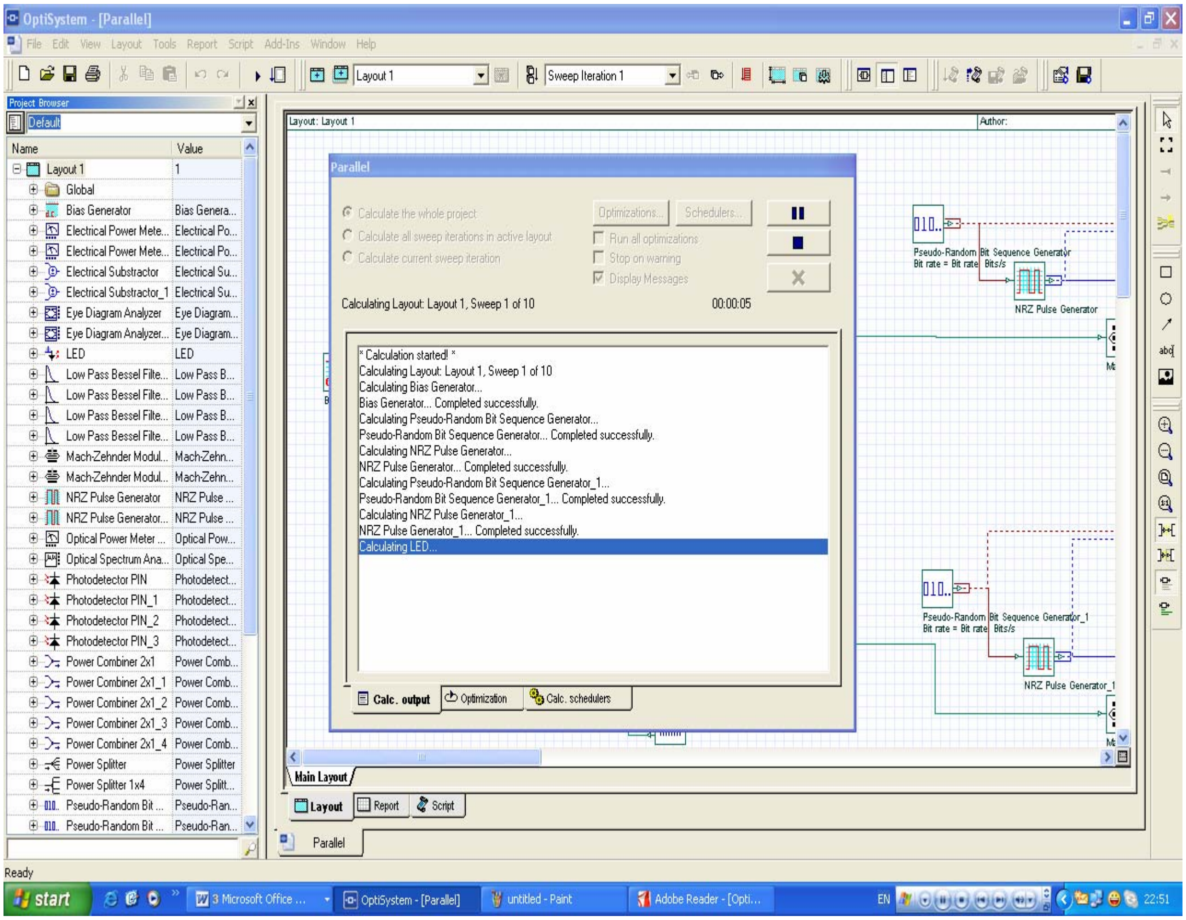
Figure 3.5: Setting the project layout



Name	Value
Layout 1	10
Global	
Bias Generator	Bias Genera...
Electrical Power Mete...	Electrical Po...
Electrical Power Mete...	Electrical Po...
Electrical Substractor	Electrical Su...
Electrical Substractor_1	Electrical Su...
Eye Diagram Analyzer	Eye Diagram...
Eye Diagram Analyzer...	Eye Diagram...
LED	LED
Low Pass Bessel Filte...	Low Pass B...
Low Pass Bessel Filte...	Low Pass B...
Low Pass Bessel Filte...	Low Pass B...
Low Pass Bessel Filte...	Low Pass B...
Mach-Zehnder Modul...	Mach-Zehn...
Mach-Zehnder Modul...	Mach-Zehn...
NRZ Pulse Generator	NRZ Pulse ...
NRZ Pulse Generator...	NRZ Pulse ...
Optical Power Meter ...	Optical Pow...
Optical Spectrum Ana...	Optical Spe...
Photodetector PIN	Photodetect...
Photodetector PIN_1	Photodetect...
Photodetector PIN_2	Photodetect...
Photodetector PIN_3	Photodetect...
Power Combiner 2x1	Power Comb...
Power Combiner 2x1_1	Power Comb...
Power Combiner 2x1_2	Power Comb...
Power Combiner 2x1_3	Power Comb...
Power Combiner 2x1_4	Power Comb...
Power Splitter	Power Splitter
Power Splitter 1x4	Power Split...
Pseudo-Random Bit ...	Pseudo-Ran...
Pseudo-Random Bit ...	Pseudo-Ran...

[CTRL] - Duplicate, [SHIFT] - Add to selection, [CTRL + SHIFT] Resize layout.

Figure 3.6: Designing the project



Name	Value
Layout 1	1
Global	
Bias Generator	Bias Genera...
Electrical Power Mete...	Electrical Po...
Electrical Power Mete...	Electrical Po...
Electrical Substractor	Electrical Su...
Electrical Substractor_1	Electrical Su...
Eye Diagram Analyzer	Eye Diagram...
Eye Diagram Analyzer...	Eye Diagram...
LED	LED
Low Pass Bessel Filte...	Low Pass B...
Low Pass Bessel Filte...	Low Pass B...
Low Pass Bessel Filte...	Low Pass B...
Low Pass Bessel Filte...	Low Pass B...
Mach-Zehnder Modul...	Mach-Zehn...
Mach-Zehnder Modul...	Mach-Zehn...
NRZ Pulse Generator	NRZ Pulse ...
NRZ Pulse Generator...	NRZ Pulse ...
Optical Power Meter ...	Optical Pow...
Optical Spectrum Ana...	Optical Spe...
Photodetector PIN	Photodetect...
Photodetector PIN_1	Photodetect...
Photodetector PIN_2	Photodetect...
Photodetector PIN_3	Photodetect...
Power Combiner 2x1	Power Comb...
Power Combiner 2x1_1	Power Comb...
Power Combiner 2x1_2	Power Comb...
Power Combiner 2x1_3	Power Comb...
Power Combiner 2x1_4	Power Comb...
Power Splitter	Power Splitter
Power Splitter 1x4	Power Splitt...
Pseudo-Random Bit ...	Pseudo-Ran...
Pseudo-Random Bit ...	Pseudo-Ran...

● Calculate the whole project
○ Calculate all sweep iterations in active layout
○ Calculate current sweep iteration

☐ Run all optimizations
☐ Stop on warning
☑ Display Messages

Calculating Layout: Layout 1, Sweep 1 of 10 00:00:05

```
* Calculation started! *
Calculating Layout: Layout 1, Sweep 1 of 10
Calculating Bias Generator...
Bias Generator... Completed successfully.
Calculating Pseudo-Random Bit Sequence Generator...
Pseudo-Random Bit Sequence Generator... Completed successfully.
Calculating NRZ Pulse Generator...
NRZ Pulse Generator... Completed successfully.
Calculating Pseudo-Random Bit Sequence Generator_1...
Pseudo-Random Bit Sequence Generator_1... Completed successfully.
Calculating NRZ Pulse Generator_1...
NRZ Pulse Generator_1... Completed successfully.
Calculating LED...
```

Figure 3.7: Run a simulation design

3.3 Fiber Bragg Gratings (FBGs)

A fiber Bragg grating is a periodic or aperiodic perturbation of the effective refractive index in the core of an optical fiber. Typically, the perturbation is approximately periodic over a certain length of e.g. a few millimeters or centimeters, and the period is of the order of hundreds of nanometers. This leads to the reflection of light (propagating along the fiber) in a narrow range of wavelengths, for which a Bragg condition is satisfied (Bragg mirrors). This basically means that the wave-number of the grating matches the difference of the wave-numbers of the incident and reflected waves. (In other words, the complex amplitudes corresponding to reflected field contributions from different parts of the grating are all in phase so that can add up constructively; this is a kind of phase matching.) Other wavelengths are nearly not affected by the Bragg grating, except for some side lobes which frequently occur in the reflection spectrum (but can be suppressed by apodization). Around the Bragg wavelength, even a weak index modulation (with amplitude of e.g. 10^{-4}) is sufficient to achieve nearly total reflection, if the grating is sufficiently long (e.g. a few millimeters).

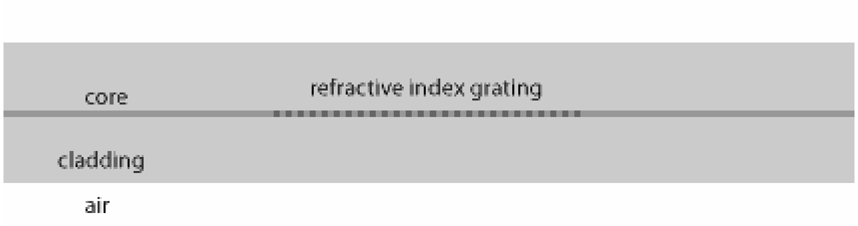


Figure 3.8: Schematic structure of a fiber Bragg grating (FBG).

The fiber core has a periodically varying refractive index over some length. The drawing is not to scale; typical dimensions are 125 µm cladding diameter and 8 µm core diameter; periods of the refractive index gratings vary in the range of hundreds of nanometers or (for long-period gratings) hundreds of micrometers. The length of such a grating is typically a few millimeters.

The reflection bandwidth of a fiber grating, which is typically well below 1 nm, depends on both the length and the strength of the refractive index modulation. The narrowest bandwidth values, as are desirable e.g. for the construction of single-frequency fiber lasers or for certain optical filters, are obtained for long gratings with weak index modulation. Large bandwidths may be achieved with short and strong gratings, but also with aperiodic designs.

As the wavelength of maximum reflectivity depends not only on the Bragg grating period but also on temperature and mechanical strain, Bragg gratings can be used in temperature and strain sensors. Transverse stress, as generated e.g. by squeezing a fiber grating between two flat plates, induces birefringence and thus polarization-dependent Bragg wavelengths.

3.3.1 Special Types and Application

Fiber gratings with aperiodic index modulations can have interesting properties, such as reflectivity curves without side lobes, multiple tailored reflection bands, or special dispersion profiles. Particularly for dispersion compensation, so called chirped fiber gratings are used, where the Bragg wavelength varies with position. It is possible e.g. to achieve very large group delay dispersion in a short length of fiber, sufficient to compensate the dispersion of a long span of transmission fiber in an optical fiber communications system. Chirped fiber gratings are also interesting for application as fiber-optic sensors with intragrating sensing, i.e., monitoring e.g. the temperature along the length of the device. They are also used for gain equalization.

Apart from dispersion compensation, telecom applications of FBGs often involve wavelength filtering, e.g. for combining or separating multiple wavelength channels in wavelength division multiplexing systems. Extremely narrow-band filters can be realized e.g. with rather long FBGs (having a length of tens of centimeters) or with combinations of such grating. Also, FBGs can be used as end mirrors of fiber lasers (distributed Bragg reflector lasers, DBR fiber lasers), then typically restricting the emission to a very narrow spectral range. Even single-frequency operation can be achieved e.g. by having the whole laser cavity formed by a FBG with a phase shift in the middle (distributed feedback lasers). Outside a laser cavity, an FBG can serve as a wavelength reference e.g. for stabilization of the laser wavelength. The range of interesting phenomena in FBGs is further enriched by the occurrence of optical nonlinearities.

If the polarization of the writing beams is perpendicular to the fiber axis, there can be a significant deviation between the Bragg wavelengths for both polarization directions (i.e., a birefringence). This may be used e.g. for fabricating rocking filters.

Typical FBGs have grating periods of a few hundred nanometers, coupling counter-propagating waves in the core. A second possibility is to use long-period Bragg gratings (LPG, Ref. Vengsarkar 1996) with periods of the order of hundreds of microns (often with tilted grating planes) and a length of a few centimeters. Such gratings can couple modes with the same propagation direction. For example, the fundamental mode of a multimode fiber can be coupled to a certain higher-order mode, or a core mode can be coupled to cladding modes propagating in a similar direction. In the latter case, the coupling effectively introduces propagation losses, because light in cladding modes normally experiences strong losses in the fiber coating. Such gratings are used to generate carefully controlled wavelength-dependent losses, e.g. for gain equalization in erbium-doped fiber amplifiers, but are also used for fiber-optic sensing.

It is also possible to write FBGs in polymer optical fibers. As with silica fibers, one usually uses ultraviolet light, but the physical mechanisms are somewhat different. An advantage of Bragg gratings in polymer fibers is the larger wavelength tunability: polymer fibers can be stretched more strongly, and they react more strongly to temperature changes.

3.4 Optical Sources

The principal sources used for fiber optic communications applications are heterojunction-structured semiconductor *laser diodes* and *light emitting diodes (LEDs).* A heterojunction consists of two adjoining semiconductor materials with different band-gap energies. These devices are suitable for fiber transmission systems because they have adequate output power for a wide range of applications, their optical power output can be directly modulated by varying the input current to the device, they have a high efficiency, and their dimensional characteristics are compatible with those of the optical fiber.

A major different between LEDs and laser diode is that the optical output from an LED is incoherent; whereas that form a laser diode is coherent. In a coherent source, the optical energy is produced in an optical resonant cavity. The optical energy released from this cavity has spatial and temporal coherence, which means it is highly monochromatic and the output beam is very directional. In an incoherent LED source, no optical cavity exists for wavelength selectivity. The output radiation has a broad spectral width, since the emitted photon energies range over the energy distribution of the recombining electrons and holes, which usually lie between 1 and 2 $k_B T$ (k_B is Boltzmann's constant and T is the absolute temperature at the *pn* junction). In addition, the incoherent optical energy is emitted into a hemisphere according to a cosine power distribution and thus has a large divergence.

In choosing an optical source compatible with the optical waveguide, various characteristics of the fiber, such as its geometry, its attenuation as a function of wavelength, its group delay distortion (bandwidth), and its modal characteristics, must be taken into account. The interplay of these factors with the optical source power, spectral width, radiation pattern, and modulation capability needs to be considered. The spatially directed coherent optical output from a laser diode can be coupled into either single-mode or multimode fibers. In general, LEDs are used with multimode fibers, since normally it is only into a multimode fiber that the incoherent optical power from an LED can be coupled in sufficient quantities to be useful. However, LEDs have been employed in high-speed local-area applications in which one wants to transmit several wavelengths on a same fiber.

3.5 Photodetector Types

At the output end of an optical transmission line, there must be a receiving device which interprets the information contained in the optical signal. The first element of this receiver is a photodetector. The photodetector senses the luminescent power falling upon it and converts the variation of this optical power into a correspondingly varying electric current. Since the optical signal is generally weakened and distorted when it emerges from the end of the fiber, the photodetector must meet very high performance requirements. Among the foremost of these requirements are a high response or sensitivity in the emission wavelength range of the optical source being used, a minimum addition of noise to the system, and a fast response speed of sufficient bandwidth to handle the desired data rate. The photodetector should also be insensitive to variations in temperature, be compatible with the physical dimensions of the optical fiber, have a reasonable cost in relation to the other components of the system, and have a long operating life.

Different system performances can be achieved by changing the photodiode used in the design. PIN and APD (Avalanche Photidiode) are the main types. Different device characteristics, and different material profiles used to construct such devices might affect the system performances significantly. The selection of the photodetector must consider two main aspects; performance and compatibility. There are few factors influencing the performance of photodetector. When purchasing a photodetector to be used in the optical receiver system, these factors must be considered seriously to achieve a good output signal.

Generally, there are many types of photodetectors for light detection and conversion. PIN photodiode is the most common in the optical fiber communication systems. It has wide intrinsic semiconductor layer between the P and N regions. The photodetector is normally designed so that these carries are generated mainly in the depletion region (the depleted intrinsic region) where most of the incident light is absorbed. The high electric field present in the depletion region causes the carries to separate and be collected across the reverse-biased junction. This gives to a current flow in an external circuit, with one electron flowing for every carrier pair generated. Another type of photodiode is the APD (Avalanche Photodiode). It is that is popularly used in the optical telecommunication. Having an internal gain the APDs are much more sensitive than PIN photodiodes; it means that the responsivity of the APD is better than the PIN photodiode due to its internal gain. The effect of this parameter is shown by changing the photodiode types to realize their effect on the system performance. A comparison between the two photodiode sensitivities against the system performance is performed to show their effect.

3.6 Design Parameters

The design parameters are the system parameters that a designer can vary or change in order to study its effect on the system performance. In the simulator, the change can be made by setting at the dialogue box of each component. The design parameters consist of distance, bit rate and bit format for both parallel and serial configurations of encoder and decoder modules.

3.6.1 Distance

The transmission distance is basically represented by the fiber length. The distance of the fiber is characterized by the light propagation time, line attenuation and dispersion. As the light travels through the medium, the energy is absorbed or scattered and the intensity is reduced. After some extend, the light may not be sensed by any detector as it is so low that the level is masked by the noise. This phenomenon is known as attenuation and it is related to the reduction of the pulse amplitude. The reduction of the power from the light is geometric. For an instance, after traveling for 1 km in the fiber; the power of a 1 mW signal may be reduced to half and after another 1 km the power becomes one-fourth.

Lengthening the transmission distance is one of the main objectives of this project. The effect of the length increment is explicated by the amount of dispersion and loss that the signal experiences. Throughout the study, the standard Single Mode Fiber (SMF) is used with the characteristics listed in Table 3.1.

Table 3.1: Parameters for standard Single Mode Fiber (SMF)

No	Parameter	Unit
1	Attenuation constant	0.25 dB/km
2	Chromatic dispersion	16 ps/nm/km
3	All non-linear effects	On
4	Group delay	Wavelength Dependent
5	Polarization mode dispersion coefficient	0.07 ps/√km

The variation of the fiber length can be characterized by the amount of dispersion. Dispersion is a pulse spreading as a function of wavelength and is measured in picoseconds per kilometer per nanometer (*ps / (km x nm)*).

The transmission distance is basically represented by the fiber length. The distance of the fiber is characterized by the light propagation time, line attenuation (loss), and dispersion. The length used in this study is from 1 to 20 km (multiple access).

3.6.2 Bit Rate

The bit rate is the number of bits that passes a given-point in an optical network in a given amount of time, usually a second. Thus, a bit rate is usually measured in some multiple of bits per second - for example, kilobits, or thousands of bits per second (Kbps). The term bit rate is a synonym for data transfer rate. Bit rate seems to be used more often when discussing transmission technology details and data transfer rate (or data rate) when comparing transmission technologies for the end user. The system bandwidth that is required to carry a signal may be more than or equal to the bit rate, depending on the coding scheme. As the data rate increases the detection and regeneration circuit becomes more complex because of high speed requirements. In this study, there are three main bit rates which are 155 Mbps, 622 Mbps and 1 Gbps are used to see the performance of the system.

3.6.3 Bit Format

The format transmitted optical signal is a crucial issue in designing optical fiber link. It is important for the synchronization of timing information between the incoming optical signal and the received optical signal. The three main purposes of timing are; to allow the signal to be sampled by the receiver at the time the Signal Noise Ratio (SNR) is maximum, to maintain the proper pulse spacing and to indicate the start and end of each time interval. This is called signal encoding that uses two-level binary type code that can be used for optical fiber transmission link such as the Non-Return-to-Zero (NRZ), and the Return-to-Zero (RZ) format. The most widely used modulation format has been the Non-Return-to-Zero (NRZ) for optical transmission system.

On of the aims of changing this design parameter is to show which of the coding schemes performs more elasticity to the system, another is to find out which standard coding schemes shows more immunity to the nonlinearity effects and other factors in the system. The study of this design parameter is done by changing the bit format either NRZ, or RZ and detecting the effects on the system performance.

3.7 Performance Parameter

In this report, we consider that only one performance parameter is required to evaluate the system under study. The performance parameter is about Bit Error Rate (BER). BER is the probability of errors in number of bits of data over the total transmitted bits at a certain time interval. The minimum error rate is 10^{-9}, which means that, on the average, one error occurs for every billion pulses sent. Typically the error rate for optical communication systems ranges from 10^{-9} to 10^{-12} depending on the service types. In the simulator, the BER is measured by the eye diagram analyzer in the system layout.