

## Design and Development of GUI for the Mitigation of Chromatic Dispersion: A New Approach

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### Abstract:

*Chromatic Dispersion (CD) is the important effect that is considering for optical communication system design as it broadens the pulse during the propagation along channel resulting in pulse overlapping and ultimately bit errors raises. The increment in bit error, in result reduce the performance of optical system. Therefore, mitigation CD is necessary in order to improve the performance of optical communication system. There are several techniques of mitigating CD have been proposed and all based on coding based and this will create issues for the communication design engineer that every time the parameters need to be revised. In order to avoid this issue, the ease for the system design engineer has been created in designing the Graphical User Interface (GUI). In this work, GUI is designed and developed that will request the parameters need to be select for the optical system and it will describe the all process for mitigating it from the system. In the first, the communication system designer have to select the Transmission along with modulation and after that transmission at distance is asked in terms of km. The CD is mitigated uses least mean square technique and Fast Fourier Transform method. The further smoothing of signal is improved by Pulse shaping via using the raised cosine filter. In the end, the original signal and the compensated signal are defined. The BER is also calculated to show whether the reduction through DSP is performed. The GUI is developed in MATLAB and every button backhand the strong coding is used in C++ for developing the system. The proposed design of GUI for the reduction in Chromatic Dispersion has successfully attained the reduction of CD as 40%. In addition to that BER of 10<sup>-3</sup> has been attained using the proposed system. The system was designed and developed for the QAM modulation schemes. The designed system has been tested for the 10 Gb/s data rate. The designed and developed system offers the ease of use for the communication engineer, in which on one platform the user can observer well the optical system instead of programming.*

**Keywords:** *Chromatic Dispersion, Digital Signal Processing, Graphical User Interface, MS VISIO.*

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Optical communication is now widely used for high speed communication systems [1]. During the transmission, several transmission impairments effect the performance of systems such as linear and nonlinear parameters. Chromatic dispersion is one of them. Many techniques have already been utilized for the CD reduction [2].

When the signal propagates along fiber optic due to refractive index the pulse broadening effects occur and after some distance signal is lost. The main aim is that to design a platform for CD reduction which should be user friendly even we can execute it without programming [3]. Many researchers has developed the system related chromatic dispersion as discussed in. However, each system has its own advantages and disadvantages [4]. In this research, the CD is reduced in the electrical domain via Graphical User Interface that will help in designing the future communication system in order to solve chromatic issues. In the next section, the problem related to optical system designing for mitigation of chromatic dispersion is discussed and also the proposed work details are described in comparison to the work that have been carried out in the past.

The different researchers have worked on reduction of chromatic dispersion. Each work has its own significant in terms of application and results attained. In this paper, the research paper that are only related to development of GUI or similar software tool are discussed in order to demonstrate the need of efficient GUI design and development for the Chromatic dispersion for the various application of optical communication.

In this work, author Amiri in [5] focused the chromatic dispersion compensation is performed numerically for 250 km fiber and BER achieved was 10<sup>-2</sup> for optical wireless channel. However, the system designed only based on numerical design and simulation was carried out using the ordinary programming no convenient way of demonstrating the simulation was proposed.

The author Neumann in [6] demonstrated the chromatic dispersion using discrete-time filtering strategy the system was designed using the programming no simulator to GUI was designed for the convenient of optical designer was considered. The system was tested on QPSK modulation with some reduction of complexity in existing circuits.

The author Wu in [7] has focused the equalization of Chromatic dispersion equalization for optical communication using PSO algorithm the proposed system was designed using the programming no simulator or GUI was created in order to facilitate the design for future perspective. The system was tested for QAM modulation and reduction of chromatic dispersion with 25% was attained using the proposed system. The filter also discussed the complex design issues.

The author Udayakumar in [8] designed the chromatic dispersion compensation system using FBG fiber Bragg grating. The worked was carried out using the optisystem software. The link is limited to few Gb/s and BER was not so much fascinating as per requirements of optical wireless channel. It is important to note that optisystem is an expansive simulation tool for developing optical related system and it increase the cost of design system using analysis.

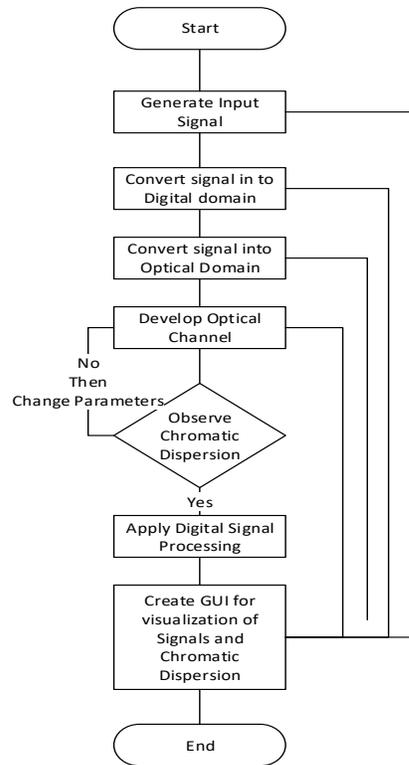
The author Mustafa in [9] worked on compensation of chromatic dispersion in order to maximize transmission bit rate. The work is carried out using soliton transmission technique. It is important to discuss that work was carried using expansive software. Beside that the optical soliton wave technique is utilized and system was designed for the 1.9932.

The author Galvis-Velandia in [10] presented the analysis of dispersion compensation using self-phase modulation using modulator scheme for 50 km fiber link. The system was designed and analyzed for spectral separation of the transmitted channels for 0.2 nm the system has some harmonics alter the spectral density waveform. The system was designed using the programming no simulator or GUI was

designed to help the researcher and optical designer to modify the system characteristics for future design aspects.

Chromatic Dispersion (CD) is key parameter that is considered well when designing the optical communication [11]. The more CD in the signal will increase the Inter Symbol Interference (ISI) that will cause increase in error in transmissions [12]. In result, more bit are corrupted and system performance is highly degraded. Because of that mitigation of CD is important in designing the high performance optical communication [13]. In the past, various CD mitigation have been proposed via signal processing and through programming [14]. There are several issues are encountered when mitigating the CD via programming and signal processing [15]. One is every time, when system designer changes the other parameters the programmer needs to write the all code again and have to check the response of each parameter again and again this will consume lots of time in just checking the system [16]. Furthermore, the signal processing are limited in terms of smoothing the corrupted signal. In comparison to past, the proposed work designed and developed a convenient GUI for the communication system designer that will just ask the programmer to insert values and at back hand the programming for GUI is executing all the variation that is carried out for changing the system. One more advantages of the proposed system is that it will show instant outcome of the developed changes for CD means every time like in the past, the system designed don't need to write and execute the code. The proposed system need all the values of parameters selection. In the next section, the system designing is discussed in detail.

The design and development of GUI for CD mitigation is carried out in different step as shown in Fig. 1. The design steps are shown in flow chart.



**Fig. 1.** Flow chart of Designed and Developed System

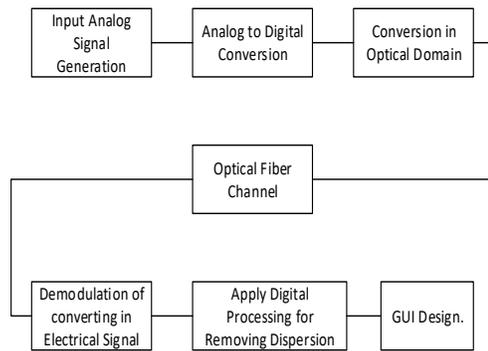
In Fig. 1, the proposed work research flow chart is depicted. It states that in the first design step need to generate an analog signal and its output can be seen in GUI after that this analog signal is converted in digital signal via analog-to-digital conversion. Here, the outcome of digital signal can be viewed at GUI as well as shown in flow chart Fig. 1. After that using modulation, the signal is converted in optical signal as discussed in [17]. The details of the techniques are shown in methodology section.

This optical signal can be seen in GUI. After that this signal propagated at optical channel and where the effect of chromatic dispersion is observed this can be seen on GUI. If the Chromatic dispersion is observed the digital signal processing techniques are applied in order to mitigate the CD. If there is no CD is observed than the parameters of optical fiber channel are varied [18]. Here,

both signal can be observed on GUI. Before Chromatic dispersion and after Chromatic Dispersion as shown in Fig. 1.

In the next section, the detailed methodology of the work is discussed including the analytical work done in order to design and develop the system that mitigates the CD and also the design of GUI and its outcome is discussed in detail.

In this work, the development of chromatic dispersion mitigation is performed analytically and after that system is programmed in MATLAB and in the last design of GUI is executed as shown in Fig. 2.



**Fig. 2.** Methodology for Development of Chromatic Dispersion and Design of GUI

The methodology of developing the chromatic dispersion reduction is shown in Fig. 2. In the first, the chromatic dispersion reduction is discussed and after that design of GUI is discussed.

#### A. Development of Mitigation of Chromatic dispersion

The input signal is generated using MATLAB, the analog signal is generated of 50 MHz with normalized amplitude values. The signal conditioning of input signal (digitlization) via analog to digital conversion is carried. The generated analog test signal is converted into digital with the frame Size of length 128 bits. The digital signal has 128 number of bits and cyclic prefix that reduce the ISI during the transmission and conversion from digital processing techniques

[19] For converting in digital domain, the 1 to 256 subcarrier having index from [-128 to 128] and [0 to 256] is considered. The following commanded are programmed:

$Channel\_Spacing = [0\ 256];$

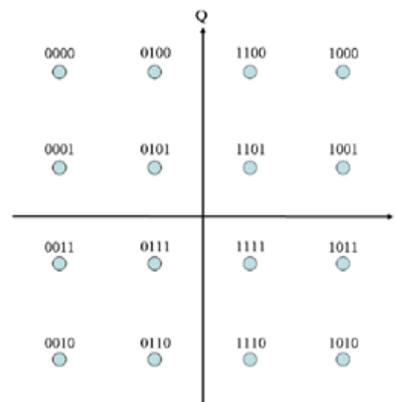
$F = 50MHz;$

$Samples\ space = 10;$

$[y, t] = a2d(channel, F, Samples\ space)$

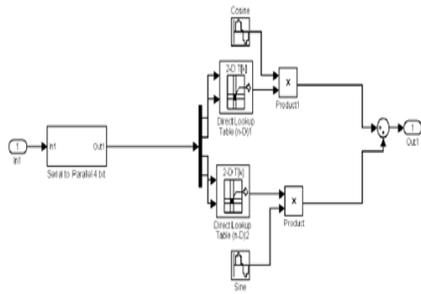
The above code converting the signal in digital domain and after that second stage is modulating the signal in optical domain. This action is performed using the modulation. The modulations are well known process to changing the characteristic of the signal [20]. There are many modulation schemes are there. They characterized based on amplitude, Phase, and Frequency.

In this work, the 256 length of signal taken above is converted in optical signal via QAM modulation the amplitude of carrier is modulated by  $90^\circ$ . The response of QAM signal is shown in Fig. 3.



**Fig. 3.** The constellation diagram

The constellation diagram states that complex digital signal are converted in set in the optical symbols, bits are arranged in unique manner of direct modulation. The QAM modulator is developed in MATLAB Simulink. The model is shown in Fig. 4.



**Fig. 4.** Design of QAM Modulator

From the design of QAM modulator as shown in Fig. 4. The signal is modulated in stream of bits formed by  $\log_2 P$ , where  $P$  defines the no. of symbols. 16-QAM modulations is performed in following way [21]:

$$P = 256;$$

$$I = \log_2(P);$$

$$nSamp = 10;$$

The signal that is modulated in converted above code converting the signal in digital domain and after that signal is converted in optical via direct modulation. This optical signal is ready to launch over optical fiber to be transmitted at different distances [22]. The signal propagation on optical fiber channel is performed using Non-Leaner Schrödinger Equation (NLSE). This NLSE is used to detonate all the basic parameters related to optical fiber transmission. This include losses in optical fiber, Phase and Group Velocity, Single Phase Modulation, nonlinear and linear effects in single mode fiber as shown (1) [21]:

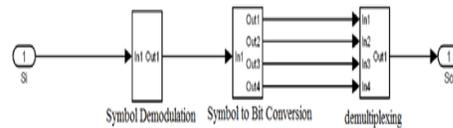
$$\frac{\partial A}{\partial z} + \frac{i}{2}\beta_2 \frac{\partial^2 A}{\partial t^2} = i\gamma|A|^2A - \frac{\alpha}{2}A \quad (1)$$

Equation 1 defines the propagation of signal that is carried out from QAM modulation over optical fiber. The channel is characterized based on Single Mode Fiber (SMF). The parameters that are characterized for designing the optical propagation are defined as  $A$  defines the power of optical field,  $\alpha$  defines the disturbance in the signal, and the  $\beta$  is the one of the crucial parameters over

which all the work is performed is chromatic dispersion. However, in this work, the second derivation of chromatic dispersion is taken in order to analyze the chromatic dispersion well in terms of spectrum.  $\Gamma$  defines the nonlinear effect that defines the phase variation,  $z$  defines the dimension propagation and also the  $t$  defines the interval at which optical signal will prorogate inside the optical fiber [3].

The NLSE is transform in MATLAB via Split Step Fourier Method (SSFM) this model is used as propagation model for transferring the signal over optical fiber [IV]. The simulation is carried for 20 km distance via SSFM. The model developed in MATLAB is used to program input signal, fiber loss db/km, and width of pulse in order to measure the chromatic dispersion. This include different measurement of optical amplitude, and step size for Fourier transform, chirp factor for dispersion [11].

After launching the signal over optical fiber modulation is carried out in converting signal from optical to electrical signal for that demodulation is used as shown in Fig. 5.



**Fig. 5.** Demodulation of the Signal

The reason why the demodulation is performed is because before propagation signal was changes in nature. The demodulation is carried out in terms phase and amplitude of detected signal the signal is converted based on MATLAB model as shown in Fig. 5. After that this transmitted signal over fiber optic is converted signal in electrical and onwards the electrical signal is used for chromatic dispersion mitigation using Digital Signal Processing (DSP) techniques. Chromatic dispersion widen the pulse width during the transmission at optical fiber. This produces losses in the signal and performance is further degraded. In this work,

the chromatic dispersion is mitigated in the electric way, which is far better compare to existing techniques [12] for low dispersion system. The chromatic dispersion is taken in account from (1) and it is defined that chromatic dispersion is calculated as in (2) by abandoning the nonlinear effects from the transmission because no pump signal is used and there was no spikes in the signal recorded [13]:

$$\frac{\partial A}{\partial z} = -\frac{i}{2}\beta_2 \frac{\partial^2 A}{\partial t^2} \quad (2)$$

It was discussed earlier that second order of dispersion is taken for this work. The advantages are coming here because of time delay and different spectrum. The chromatic dispersion is calculated as in (3) [13]:

$$D = -\frac{2\pi c}{\lambda^2} \beta_2 \quad (3)$$

Where in (4)

$$\lambda = -\frac{2\pi c}{\omega} \quad (4)$$

This has the wavelength for dispersion at which pulse is broaden and wavelength interval. It is measured in terms of ps/nm/km. Solving (2) in time domain yields the solution in (5) [15]:

$$\frac{\partial A(z,t)}{\partial z} = j \frac{D\lambda^2}{4\pi c} \frac{\partial^2 A(z,t)}{\partial t^2} \quad (5)$$

The solution of (5) is not possible in time so the signal is converted in frequency domain for measuring the field pattern as in (6) [16]:

$$A(z, \omega) = A(0, \omega) e^{-j \frac{D\lambda^2}{4\pi c} \omega^2 z} \quad (6)$$

$$G(\omega) = \begin{cases} T & \text{for } |\omega| \leq (1 - \alpha) \frac{\omega_s}{2} \\ \frac{T}{2} \left\{ 1 - \sin \left[ \frac{T}{2\alpha} \left( |\omega| - \frac{\omega_s}{2} \right) \right] \right\} & \text{for } (1 + \alpha) \frac{\omega_s}{2} \leq |\omega| \leq (1 + \alpha) \frac{\omega_s}{2} \\ 0 & \text{elsewhere} \end{cases} \quad (10)$$

The signal received from filter is observed in response and it was defined that phase has

By further solving for  $z = 0$  at instantaneous value for frequency will generate the transfer function as in (7):

$$H(z, \omega) = e^{-j \frac{D\lambda^2}{4\pi c} \omega^2 z} \quad (7)$$

After that signal having transfer function of chromatic dispersion in (7), the inverse FFT is taken in order to show the signal in time domain via (8):

$$h(z, t) = \sqrt{\frac{c}{jD\lambda^2 z}} e^{j \frac{\pi c}{D\lambda^2 z} t^2} \quad (8)$$

Further, signal is given to FIR filter to mitigate the chromatic dispersion in time domain as in (9) [18]:

$$z(n) = a_0 w(n) + \underbrace{a_1 w(n-1)}_{\text{-----}} + \text{-----} a_N w(n-N) \quad (9)$$

where in (9) input signal with filter weights are shown for filter length to generate output as in z. In this work, Least Mean Square (LMS) is used to mitigate the chromatic dispersion to maintain the accuracy and relevancy. LMS is used to maintain the filter weight. Tap weights should be initialized except the central one that is set to unity corresponding to no filtering to mitigate chromatic dispersion [22]. The filter signal still have some noises. For that smoothing of signal is required. In this work, the Raised Cosine Filter improves the shape of pulse. The filter is designed and constructed via (10) [12]:

edges and tracking needs to be remove for that phase tracking is used to remove error at

the edges by mitigating the chromatic dispersion. The signal is chunked in smaller window and errors at the edges at specific frequencies are removed via Kaiser Window as shown in (11) [13]:

$$w[n] = \begin{cases} I_0 \left[ \beta \sqrt{1 - \left( \frac{n - M/2}{M/2} \right)^2} \right] & 0 \leq n \leq M \\ 0 & \text{else} \end{cases} \quad (11)$$

This is improving the detected stream from long stream of bits by changing the center lobe width and sided lobe. After that Bit Error Rate is calculated to check that chromatic dispersion is mitigated? BER is number of errors occurring over a time at which signal is received. The error rate depends on signal to noise ratio determined by Q factor. BER was calculated via (12) [13]:

$$BER = \left( \frac{1}{\sqrt{2\pi}} \right) \left( \frac{e^{-\frac{Q^2}{2}}}{Q} \right) \quad (12)$$

As the Q or Quality factor is increased BER decreased and it is defined that by mitigating the chromatic dispersion, the Q-factor is increased and BER Furthermore, the performance is setup via Eye diagram. It gives visual of signal in the shape of an eye to asses maximum transmission rate of a system, it is related to BER as the chromatic dispersion is more the eye will be close and if chromatic dispersion mitigation is archived the eye will be open [27-28].

In the next section, the Design of GUI of carried for finalizing the work step of mitigating the chromatic dispersions.

Graphical User Interface (GUI) is developed in order to mitigate the chromatic dispersion for its better visualization. It was discussed

before that before designing of the system programming was required. GUI helps in recalling the signals and after that their respective output responses are shown in the results section. The GUI setup is shown in Fig. 6, the process involves in reducing the chromatic dispersion are shown. The GUI is characterized in a different section.

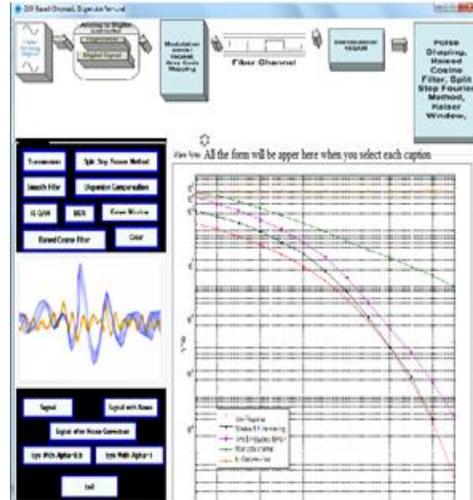
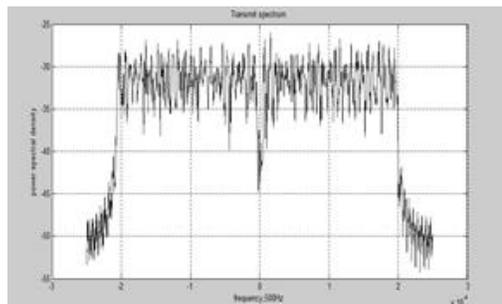


Fig. 6. GUI setup for designing the Mitigation of Chromatic Dispersion

Firstly, the system design via (1) - (12) by using the programming is transformed in GUI. The system designer can insert the value for generating the input signal of any frequency and after that from just signal click the signal will be converted in digital domain [29-30]. The next tag is used for converting optical signal from electrical one via modulation. After that fiber length is choose in order to select the length of fiber. The signal shows the propagation in GUI. The GUI measure the dispersion calculated from (6). After that DPS technique of having raised cosine filter and Kaiser Window is used in order to mitigate the dispersion. This GUI can show the repose of the signal before removing the dispersion and after applying the DSP techniques the response of chromatic dispersion can be shown in GUI as shown in Fig. 6.

Not only this, the GUI also gives the information about BER that was calculated via (12) along with eye diagram. These all measurements defines that signal has the chromatic dispersion during the transmission and via developing the GUI it easily describe the response of all optical communication under one system. The designer don't have to go anywhere else program for displaying the response of developed optical system. Furthermore, the parameters and system can be changed easily without any program efforts. In the next section, results for GUI designed and response of designing the mitigation of chromatic dispersion is show step by step.

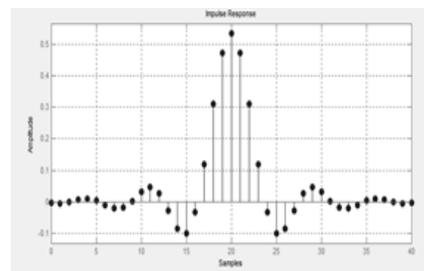
In this work, the mitigation of chromatic dispersion is carried in MATLAB. The chromatic dispersion is removed by using the DSP technique in which raised cosine filter method and Kaiser window method are used. The response are recorded based on Bit Error Rate and Eye Diagram. The chromatic dispersion mitigation is carried out analytically and response are observed on GUI.



**Fig. 7.** The spectrum of the Input signal transmitted at a channel

The GUI generates the response of signal spectrum of input transmitted signal which is converted analog to digital is appeared in Right most box where star is mentioned as shown Fig. 7.

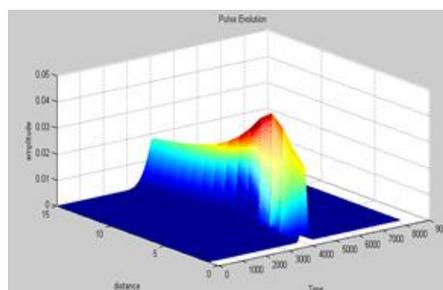
The response of modulation for QAM-16 is display via GUI as shown in Fig. 8.



**Fig. 8.** The response of GUI for modulation (16 QAM)

It can be analyzed from Fig. 8 that the modulation of 16 QAM modulation scheme is used for the GUI. The 16-Qam scheme is widely used scheme for optical communication system due to less effect of noise during the transmission.

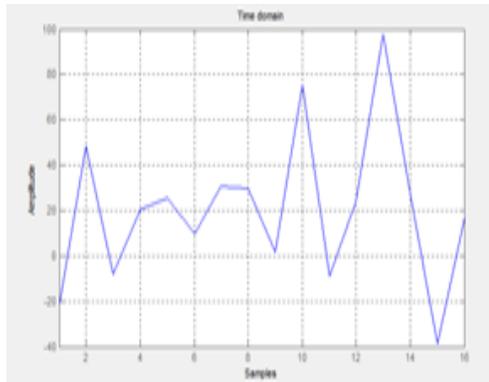
It was discussed that Split Step Fourier Method is used to design the optical fiber model. The response of optical fiber model is shown in Fig. 9 that is generated using the designed GUI.



**Fig. 9.** Response of GUI for Pulse Model fiber Optic

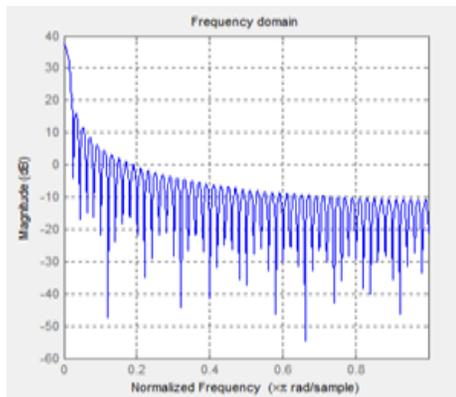
The response of optical fiber model is developed from GUI modeling and depicted in Fig. 9. The optical model is designed using the NLSE equation. The response is characterized using different parameters such as; amplitude of pulse, distance and time for pulse incurred in optical fiber.

The output of chromatic dispersion is performed through raised cosine and Kaiser Window in time domain. The GUI is modeled to generate the response of mitigation of Chromatic Dispersion as shown in Fig. 10.



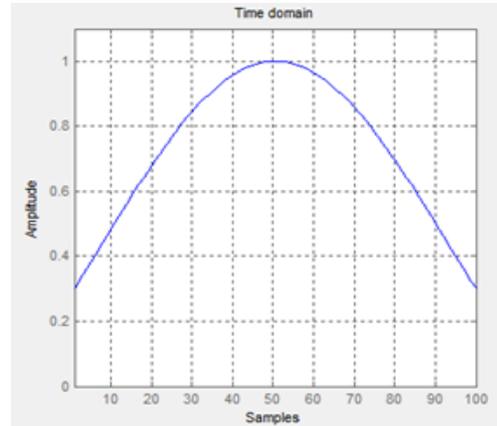
**Fig. 10.** Response of GUI for showing mitigation of Chromatic dispersion in Time domain

It was discussed that mitigation of chromatic dispersion was carried out using raised cosine filter and Kaiser window. The GUI has been created for generating the response of raised cosine filter as shown in Fig. 11.

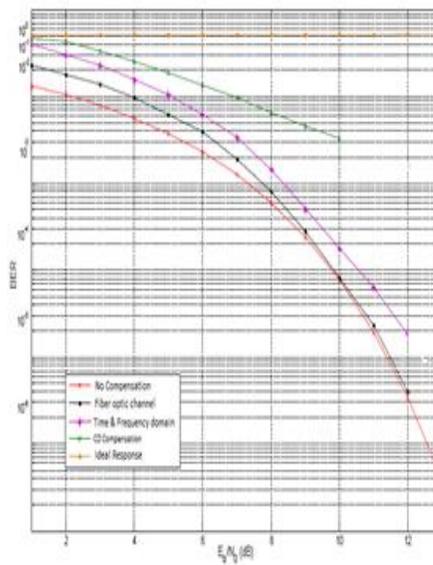


**Fig. 11.** Response of GUI for Raised Cosine Filter Output

After improving the shape of the pulse the phase is improved through the Kaiser window as shown in GUI in Fig.12 at frequency of 1G Hz:



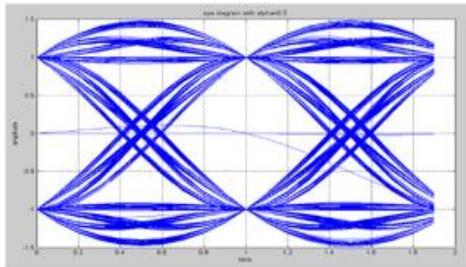
**Fig. 12.** Response of GUI for Time domain Window filtration



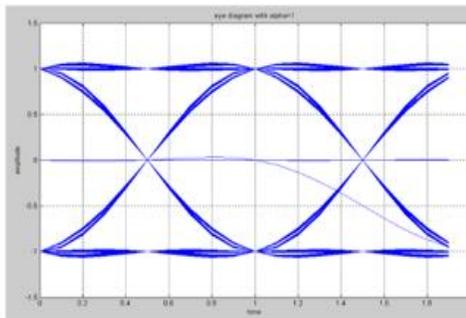
**Fig. 13.** The response of GUI for generating the BER for mitigation of chromatic dispersion

After applying the chromatic dispersion mitigation. It is important to show the performance of the system. It was discussed that chromatic dispersion mitigation is carried out using Bit Error Rate and Eye Diagram. The BER diagram is developed using GUI as shown in Fig. 13

Bit error rate is calculated by the SP tool of MATLAB. The semianalytic type model is selected in which  $E_b/N_0$  range is 0:19 dB, channel is optical fiber, Modulation is 16-QAM and samples per symbols are 256. After that response of chromatic dispersion mitigation is generated via Eye-diagram that is generated via GUI as shown in Fig. 14.



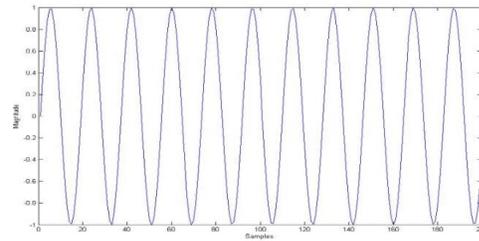
The response of GUI for Eye diagram before CD reduction



The response to GUI for Eye diagram after CD reduction

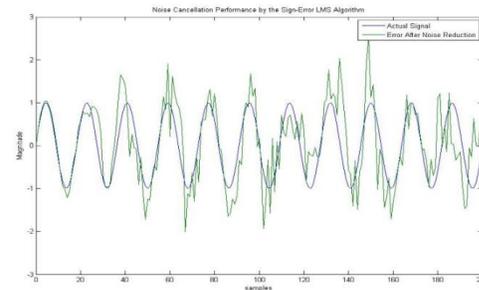
**Fig. 14.** The response of GUI for generating the Eye diagram for performing mitigation of chromatic dispersion

It is really important to show the original signal which is transmitted at optical fiber channel. If the designed system was not developed. Every time have to execute simulation and programming need to be done for that. The response of signal transmitted can be easily developed and displayed via GUI as shown in Fig. 15.



**Fig. 15.** Response of GUI for Input Signal to be transmitted

Similarly, the GUI has the capability to generate the response and difference between the signals transmitted and signal that is corrupted via chromatic dispersion. The response of noisy signal due to chromatic dispersion is shown in Fig. 16. This shows that after propagation at fiber optic at receiver we get this noisy signal due to chromatic dispersion.

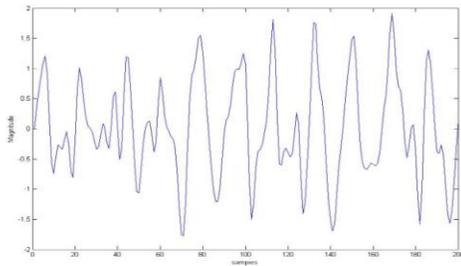


**Fig. 16.** Response of GUI for Noisy signal received at end of Fiber channel

Finally, after applying the proposed technique that mitigates the chromatic dispersion via our method. The final output of the signal in which chromatic dispersion is removed can be depicted as well. This is only possible due to the development of GUI. The response of the output signal that is generated from which chromatic dispersion is mitigated is shown in Fig. 17.

In this work, the development of chromatic dispersion is carried out via digital signal processing technique i.e. raised cosine filter, window and filtration method. The GUI is designed in order to ease the system designer, in terms eliminate the need of re-

programming for each change in parameters and running whole simulation again and again.



**Fig. 17.** The response of GUI for output Signal after mitigation of Chromatic Dispersion.

In the past, the work also carried out related to reducing the chromatic dispersion. Alfiad M.S et al, (2009) [21], worked on digital modulation scheme in an electrical and optical chromatic dispersion compensation for low frequency. Every time when changing the parameters, the re-programming of algorithm was required. Cherbi L et al, (2006) [22], worked on measures CD in optical networks in which compensators is designed for certain wavelength. Phase-shift modulation scheme is adopted for the measurement of CD SMF for 10 km distance only. Li, Xu et al, (2020) [23] worked transmission systems artificial CD and DGD is compensated can be compensated but without simplifying system. Goldfarb Gilad and Li Guifang, (2007) [24] worked on Digital IIR filtering to control CD in system with DSP. There are less number of taps are used in IIR filtering as compared in FIR filtering, complex programming and no re-programming feature was there. Borjesson (2016) [25] worked on design of compensator for CD. Compensator works on lookup table function along with usage of BPSK with low BER. Xu Tianhua, (2012) [26] worked on digital filters for compensation of CD and improved feature recorded.

From above it was concluded that in the past lack of programming, re-programming, visualization, execution of models, complex modeling, low data rate, lack of data analysis

and several issues left unaddressed. Taking the benefits of all that our work proposed the chromatic dispersion is carried out via digital signal processing technique for better BER performance. One of the main novelty of the work is design and development of GUI that is not described yet in the literature. The designed provided various feature to communication system designer that reduces the efforts of programming, not only this the system characterization can be changed easily. The designed system will be helpful for many researcher those who are working on optical system as it is giving the fast and accurate way of analyzing the results.

In this work, the mitigation of chromatic dispersion is carried out along with design of Graphical User Interface (GUI). The designed offers great feature of mitigating chromatic dispersion using the less complex algorithms, better BER and Eye diagram and one of the main novelty and contribution of the work is system changes in parameters and characterization is developed and designed are made ease. The existing system offering the output execution separately and changing of parameters is also challenging.

In developing the GUI there are many features are added such as overserving results in faster development of optical fiber channel in a GUI is not done before. The designed system can be beneficial for the student's and researcher that are working of optical system design via this system they can design, analysis, and output can be observe. The designer can work other aspects such as developing advanced algorithm in the system.

It is concluded that the designed work offer the GUI in order to mitigate the chromatic dispersion from the optical systems. The system has been developed for the 10 Gb/s data rate and the compensation of more than 40 % has been attained during the proposed system and the BER of  $10^{-3}$  is achieved. The system is considered to be the good step as in the past discussed in literature review that no such type of GUI was report. The designed system will be helpful for the optical designer and researchers as it will be great platform to demonstrate the chromatic

dispersion compensation by configuring their system requirements and they can see the output at the same time.

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