

## A Novel Noise Free Transmission Technique for Designing 100Gb/s Future Generation Optical Communication System

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### Abstract

Differential Phase Shift Keying (DPSK) techniques are widely used in designing the high-speed communication systems. However, these techniques still need improvement for long haul communication system design. In this paper, high-speed optical signal transmission and reception system is achieved for DPSK system. The system is designed using phase lock loop (PLL) based Non-return-to-Zero (NRZ) modulation scheme. The 100Gb/s DPSK signal is transmitted over single mode fiber (SMF-28) of 300 km distance using PLL based NRZ scheme. The signal is received using direct detection method. It is determined that BER of  $10^{-12+}$ , Q-factor 98 at power penalty of 14 dB is attained using the designed technique for transmitting 100Gb/s at 300 Km. Whereas, existing NRZ technique achieved a BER of  $10^{-6}$ , Q-factor 32 at power penalty of 11 dB for same similar transmission data rate and distance. The designed offers the transmission and reception of data for high-speed long haul communication system without using any amplifier or repeater.

**Keywords:** Bit Error Rate; Demodulation; Direction detection DPSK transmitter; High frequency laser; NRZ modulation; Phase locked loop; Single mode fiber

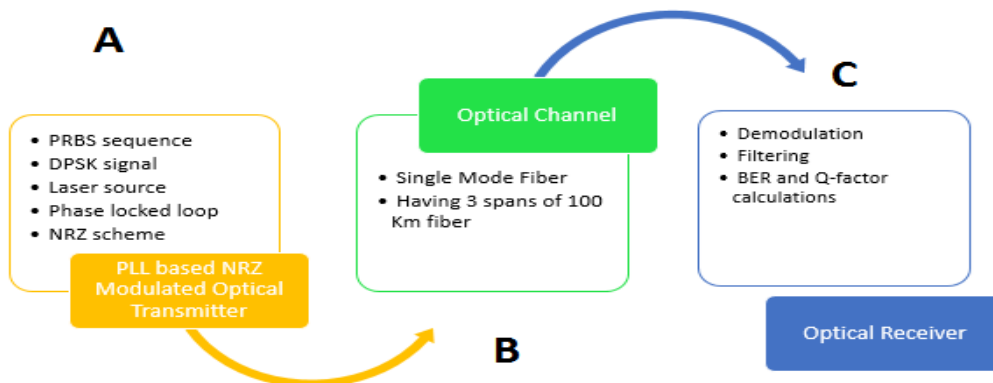
### 1. Introduction

For high-speed communication systems, the system design using simulation is an important tool, which is employed before its practical realization [1-2]. Vaishnavi [3] describes that simulation is an important step in designing the systems for the practical realization. Quelch [4] defines that many telecommunication companies test their model on commercial software packages, which costs them hefty amount. At the same time, for many researchers and students it is not affordable to buy the commercial software package [5]. The optical communication systems has utilized many techniques for designing the long haul communication [6-11]. These techniques include, erbium-doped fiber amplifiers (EDFAs) [7], On-off Keying (OOK) and optical-amplifier repeaters [12]. Warf [13] said that as demand of high-speed transmission over long distance increases. New techniques came in to being such as; Wavelength Division Multiplexing (WDM) [14], modulation schemes [15] and advanced modulation formats. These new techniques have dominantly increased the demand of DPSK systems to be used in advanced optical communication. Since two decades, the DPSK system using modulation schemes are investigated and are in practical use for long haul optical communication systems using amplifier, repeaters, and modulators. In this work, a 100Gb/s optical DPSK transceiver

system for long haul communication system over fiber optic by incorporating the PLL model in NRZ scheme has been designed that provides the high speed signal transmission and reception for long haul communication system without using any amplifier or repeater.

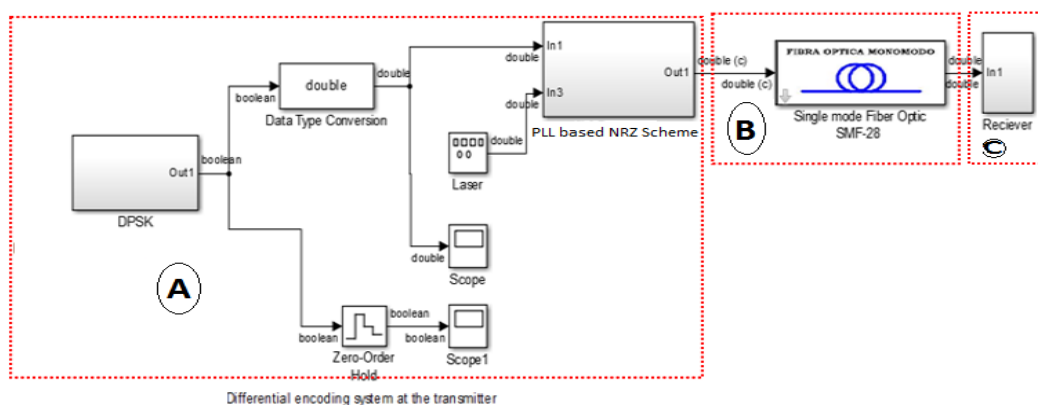
## 2. Methodology

In this work, 100Gb/s DPSK transceiver system is designed by integrating phase locked loop based and NRZ modulation scheme. The designed system consist of 100Gb/s DPSK signal modulated using phase lock loop based NRZ scheme. The designed system is categorized in three main parts A, B and C as shown Figure 1.



**Figure 1. System Block Diagram of Phase Lock Loop Based NRZ Scheme for DPSK Optical Communication System**

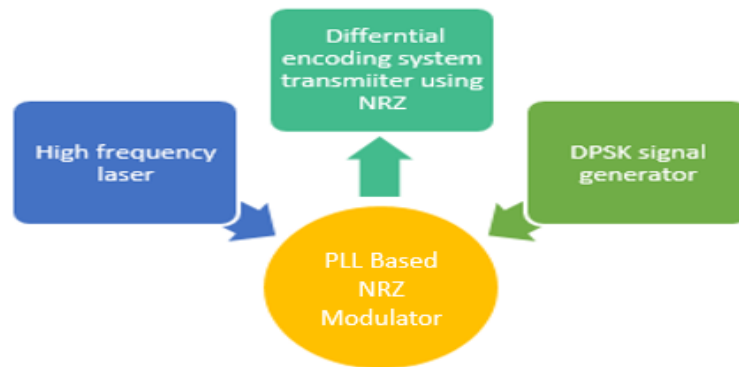
First part entails the development of 100Gb/s DPSK PLL based NRZ modulated signal. Second part entails the transmission of this high-speed modulated signal over signal mode fiber having transmission distance of 300 km. Last part entails about the receiver section, which is used to detect the high-speed modulated signal. Each entailed part of 100Gb/s DPSK transceiver system using PPL based NRZ scheme consists of further subsystems that includes the DPSK transmitter encoding system, single mode fiber design using Split Step Fourier methods (SSFM) and receiver that includes the demodulation and filtration method. The Simulink model of the designed system is demonstrated using Figure 2. It illustrates that model consist of three main sections, *i.e.* DPSK encoding scheme transmitter, single mode fiber channel and receiver.



**Figure 2. Simulink Model of Phase Lock Loop based NRZ Scheme for DPSK Optical Communication System**

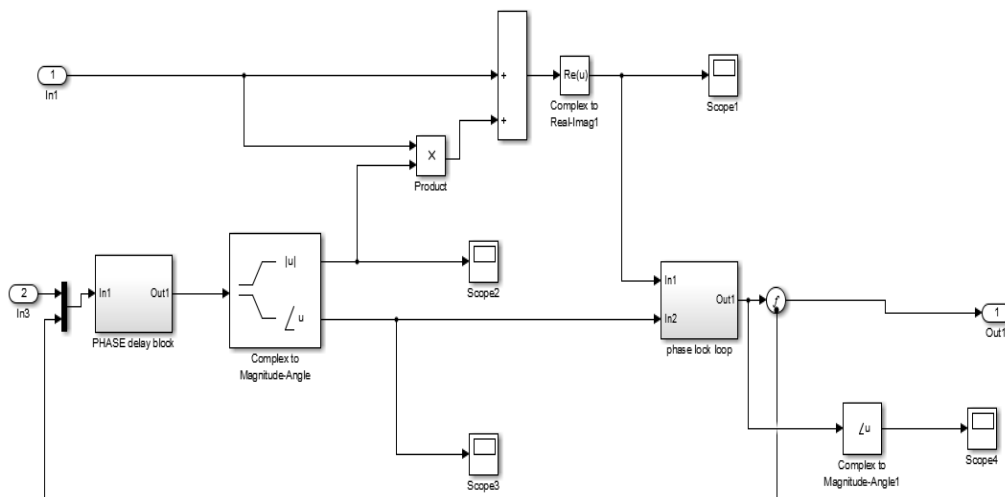
It illustrated in Figure 2 that model consists of three main sections, *i.e.* DPSK encoding scheme transmitter consist of pseudo random binary sequence (PRBS), DPSK signal generator, high frequency laser as a carrier and phase lock loop based NRZ scheme. This produces the 100Gb/s PLL based NRZ-DPSK modulated signal. This high-speed modulated signal is transmitted over fiber (SMF-28) designed using SSFM that uses the nonlinear Schrodinger equation (NLSE). The propagated signal is demodulated and filtered at receiver system.

The DPSK encoding transmitter system is designed as shown in Figure 3. It consists of DPSK signal generator, high frequency laser and PLL based NRZ modulator. The 100Gb/s DPSK signal is given to PLL based NRZ modulator along with high frequency laser used as a carrier signal. The mixing of these signal produces the 100Gb/s PLL based DPSK modulated signal. The 100 GB/s DPSK signal is given to PLL based NRZ modulator to produce high speed 100 Gb/s DPSK modulated signal. High frequency laser source is designed in Matlab to generate the carrier signal. The carrier signal is generated by designing the semiconductor laser of 1450 nm using laser rate equation [16]. The designed laser has the carrier frequency of 500 GHz.



**Figure 3. Differential Encoding Transmitter System**

The 100Gb/s DPSK PLL based NRZ modulated signal is generated by integrating the phase lock loop circuit in NRZ scheme as shown in Figure 4.

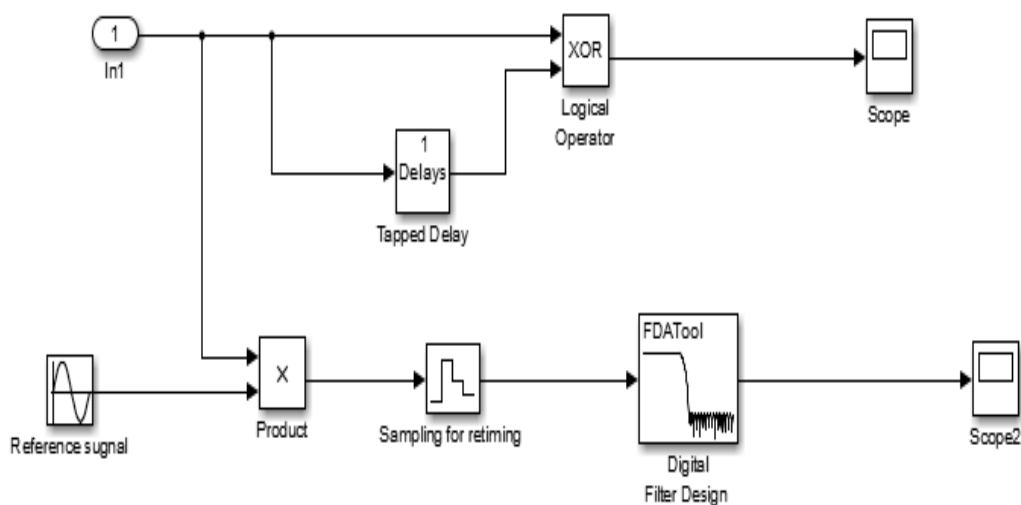


**Figure 4. PLL Based NRZ Modulator**

The PLL based NRZ modulator provides the phase swing between optical carrier and 100Gb/s DPSK signal. This modulated signal is passed to phase lock loop model that produces the constructive interference signal for transmission over fiber. One input of modulator is 100Gb/s DPSK signal and the other is carrier signal. Figure 4 defines the PLL based NRZ modulator design in Matlab for the high-speed DPSK system. In existing NRZ techniques, the phase of the input signal is modulated in conjunction with amplitude and phase of DPSK signal and optical carrier. In the designed PLL based NRZ scheme, the DPSK signal phase is modulated with the amplitude of optical carrier signal and these signals are input to phase lock loop (PLL) model. The DPSK signal is fed to phase swing block that will produce the phase change in DPSK signal. When "1" is transmitted for DPSK signal there will be no change in phase but when "0" is transmitted the  $\pi$  phase shift occurs for DPSK signal.

When this signal is mixed with optical carrier in first condition when '1' is transmitted due to in phase of both mixed signal it will produce the 'high NRZ-DPSK' signal by constructive interference. Similarly, in case of '0' transmission due to out of phase for both mixed signal the 'low NRZ-DPSK' signal is generated by destructive interference. This signal is given to phase lock loop model in which constructive interference is checked, if the signal possesses the constructive interference it must be passed to fiber. If the signal doesn't have constructive interference the signal is feedback to the phase swing block. This process is repeated until the constructive interference is achieved. The main advantage of using this technique over existing techniques is that signal analysis for removing the noise from signal is taken care of before passing the signal to the fiber optic. If this PLL model is not used here, the signal having noise will also travel along with signal over fiber optic. The signal is immune to noise and capable to travel at transmission distance of 300 Km.

Single mode fiber (SMF-28) defined by ITU-T is a commercial fiber optical cable, which is used for network applications. SMF fiber is designed using split step Fourier method (SSFM) that uses the nonlinear Schrödinger equation (NLSE) in Matlab. DPSK receiver demodulates the 100Gb/s PLL based NRZ-DSPK signal that has travelled for 300 Km over SMF. The signal is demodulated using direct detection scheme in which, PLL based NRZ-DPSK signal is decoded to recover the original signal. Figure 5 describe the function of receiver model in which each tapped delay is simulated by a set of two "angles" blocks depending upon magnitude.

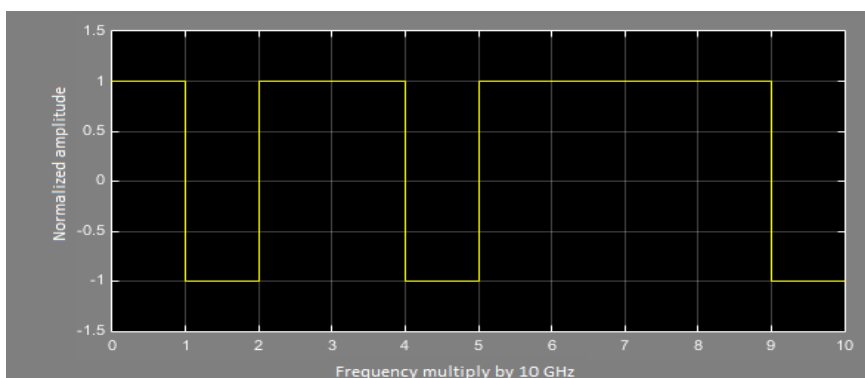


**Figure 5. Receiver Model**

The output from SMF fiber is passed through XOR with carrier signal to extract the carrier and receive the transmit signal. The delay block stores the phase of the previous symbol, the XOR block extracts the phase and amplitude of present and previous symbol. The DPSK receiver is conventional direct detection type, therefore the demodulator and decoder is not necessary. The BER is calculated using bertool in Matlab.

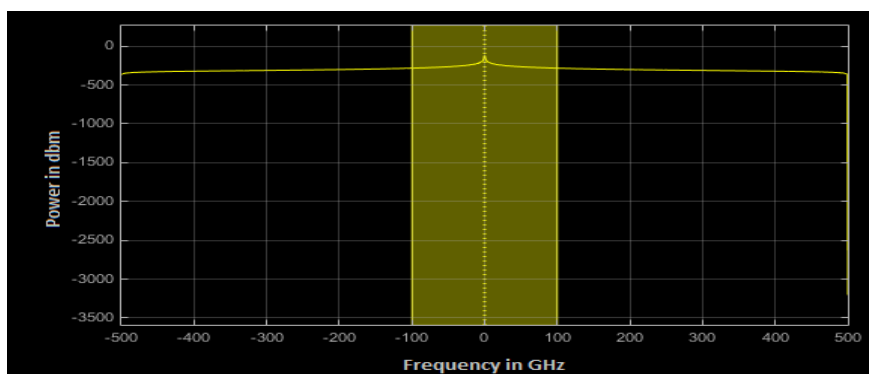
### 3. Results and Discussion

The 100Gb/s PLL based NRZ-DPSK system is demonstrated using MATLAB Simulink model. The output of the designed system is demonstrated using different signal analyzer tools offered by MATLAB. The BER is attained using bertool. The 100Gb/s PRBS sequence is demonstrated in Figure 6. It defines that signal has normalized amplitude.



**Figure 6. 100Gb/s Random Sequence Pulses**

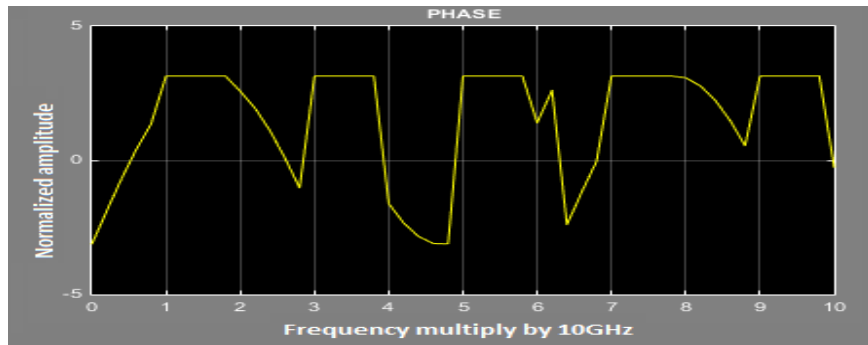
Figure 7 shows the high frequency laser signal, which is used to produce the optical signal. This laser signal has the wavelength of 1550 nm.



**Figure 7. High Frequency Laser Signal**

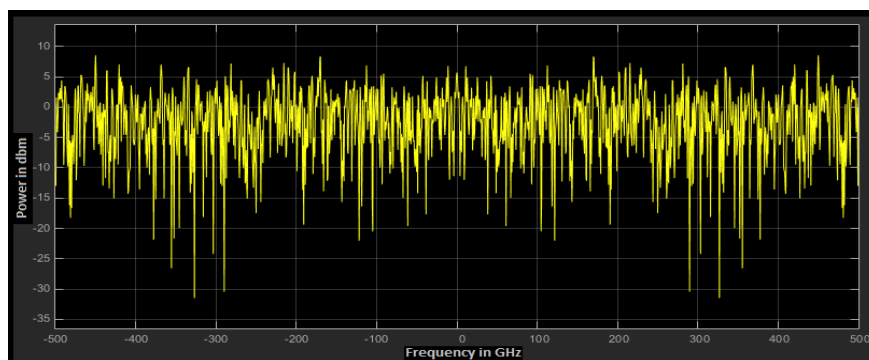
100Gb/s PLL based NRZ DPSK signal is generated by modulating the high frequency laser signal and DPSK signal and both the signals are passed to phase locked loop for producing constructive interference, so that noise free signal is transmitted through fiber. Figure 7 describes the output of phase modulation of laser and 100Gb/s DPSK signal in which constructive and destructive interference is shown. When, “1” is received, the phase shift  $\pi$  is produced in modulated signal, combined with optical signal carrier that produces the out of phase, and will produce “Low” output due to destructive interference. When “0” is received, no phase shift occurs and “High” output is produced due to

constructive interference. If the signal possesses constructive interference than signal is transferred to fiber.



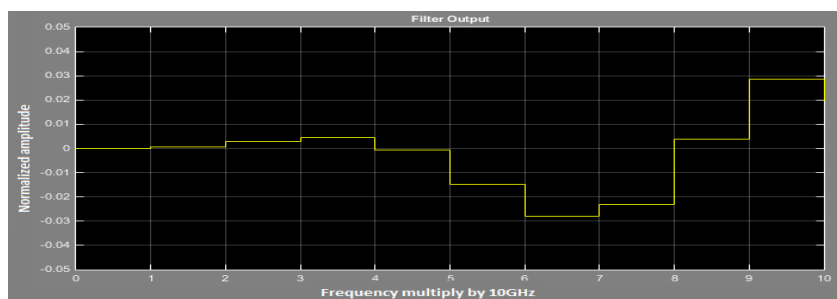
**Figure 7. PLL based NRZ Modulation of 100Gb/s DPSK Signal**

Figure 8 show the signal, which is acquired at the end of fiber. The signal is interacted with different parameters when traveling inside the fiber; such has dispersion, scattering and *etc.*



**Figure 8. Signal Transmission of 100Gb/s PLL Based NRZ Modulated Signal at End of 300 Km SMF Fiber**

Figure 9 shows the direct detection of the 100Gb/s DPSK PLL based NRZ modulated signal, the carrier signal is removed and 100Gb/s DPSK PLL based NRZ signal is differentially decoded.

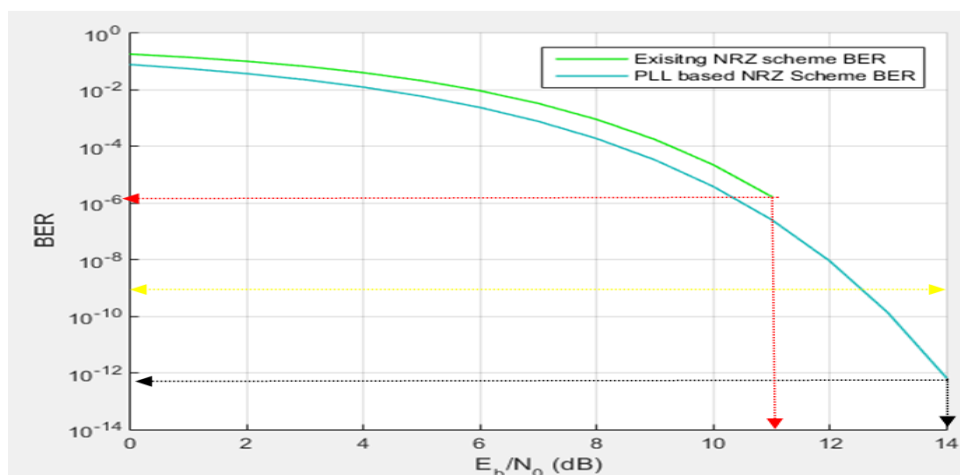


**Figure 9. Signal Recovered after Direct Detection at Removing Carrier Signal**

The signal is received with noise; these noises are reduced using low pass filter. The advantage of using phase lock loop is depicted here; it is actually the PLL circuit in

designed modulated system in which it is controlling the noise. The random distribution of noise facilitates to detect the original signal using ordinary noise low pass filter, otherwise, it is necessary to use the noise cancellation techniques.

Additionally, like in the case of existing NRZ schemes. After that BER is calculated for the designed system and existing NRZ scheme using bertool. BER of PLL based NRZ scheme is compared with existing technique of NRZ scheme by transmitting 100Gb/s signal at a transmission distance of 300 Km, as shown in Figure 10, it defines that approximately  $10^{-12+}$  BER and Q-factor 98, is achieved for PLL based NRZ scheme at power penalty of 14 dB. However, existing techniques are limited up to  $10^{-6}$  BER at power penalty of 11 dB.



**Figure 10. BER Comparison of PLL Based NRZ Scheme and Existing NRZ Scheme**

The yellow line in Figure 10 defines the standard BER of  $10^{-9}$  for optical communication with minimum power penalty depending upon the systems performance. It is observed that PLL based NRZ scheme is producing very low BER with high Q-factor for 100Gb/s data rate transmitted at 300 Km for DPSK system. Whereas, the existing technique failed to reach the minimum requirements of optical systems. This technique will help in designing the high-speed communication systems for long haul communication.

#### 4. Conclusion

NRZ modulation schemes are widely used in designing the high-speed communication. However, these existing techniques are not capable to transmit higher data rate of 100Gb/s at long transmission distance. In this work, the phase lock loop model is used in existing NRZ scheme to transmit the 100Gb/s signal at a transmission distance of 300 Km. It is concluded that using the designed technique BER of  $10^{-12+}$ , Q-factor of 98 is realized, which is not retained by existing techniques. Furthermore, the 50% BER is reduced and 67% Q-factor is improved using the designed technique for high-speed long distance communication system. This technique can be utilized various other formats such as; phase shift keying (PSK), binary PSK (BPSK) and others.

#### Acknowledgments

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