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DPSK RZ Modulation Formats Generated From Dual Drive Electro-photonic Modulators

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DPSK RZ MODULATION FORMATS GENERATED FROM DUAL DRIVE INTERFEROMETRIC OPTICAL MODULATORS

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Abstract

This article reports the generation of the phase modulation formats, in particular the differential phas shift keying with return-to-zero and non-return-to-zero and with and without suppression of the lightwave carrier.

The operational principles and characteristics of the modulators are described. The model developed under SIMULINK MATLAB is described in details. The optical spectra are confirmed with experimental results. The effectiveness of the bandwidth spectra of the modulation formats are compared and confirmed with experimental transmission performance.

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Abbreviation

ASK	Amplitude shift keying
BER	Bit error rate
CSRZ	Carrier Suppressed Return to Zero
DFB	Distributive Feedback
DPSK	Differential phase shift keying
DWDM	dense wavelength division multiplexing
GVD	Group Velocity Dispersion

$LiNbO_3$	Lithium Niobate
MZIM	Mach Zehnder Interferometric Modulator
NRZ	Non Return to Zero
OOK	On Off Keying
OSNR	Optical Signal to Noise Ratio
RF	Radio Frequency
RZ	Return to Zero
SPM	self phase modulation
XPM	Cross phase modulation
WDM	wavelength division multiplexing

3 Introductory Remarks

3.1 Background

Owing to tremendous growing demand on high capacity transmission over Internet, high data rate of 40 Gb/s per channel has appeared to be an attractive feature in the next generation of light wave communications system. Under the current 10Gb/s DWDM optical system, overlaying 40 Gb/s on the existing network can be considered to be the most cost effective method for upgrading purpose. However, there are a number of technical difficulties confronted by communications engineers involving interoperability that requires 40 Gb/s line system to have signal optical bandwidth, tolerance to chromatic dispersion, resistance to non linear crosstalk, susceptibility to accumulated noise over multi-span of optical amplifier to be similar to 10 Gb/s system.

In view of this, advanced modulation formats have been demonstrated as an effective scheme to overcome 40 Gb/s system impairments. Differential Phase Shift Keying (DPSK) modulation format has attracted extensive studies due to its benefit over conventional On-Off Keying (OOK) signaling format, including 3-dB lower optical signal-to-noise ratio (OSNR) [1] at a given bit-error-rate (BER), more robust to narrow band optical filtering, more resilient to some non linear effects such as cross phase modulation and self phase modulation. Moreover, spectral efficiencies can be improved by using multi-level signaling. On top of that, coherent detection is not critical as DPSK detection requires comparison of two consecutive pulses, hence the source coherence is required only over one bit period.

Nevertheless, DPSK format involves rapid phase change causing intensity ripples due to chromatic dispersion that induce pattern dependent SPM-GVD (group velocity dispersion) effect.[2] Therefore, return-to-zero (RZ) pulse can be employed in conjunction with DPSK to generate more tolerance to the data pattern dependent SPM-GVD effect. In addition, RZ improves dispersion tolerance and non linear effects particularly in long haul network at high data rate. Specific RZ format like carrier-suppressed RZ (CSRZ) helps to reduce the inherent larger spectral bandwidth.

At 40 Gb/s, generation of RZ pulse is not feasible as it is at 10 Gb/s due to the large bandwidth requirement. Thus, 40 Gb/s RZ signals are produced optically in “pulse carver” by driving the modulator with 20 GHz RF signal. With the remarkable advancement in external modular, especially Mach-Zehnder interferometic modulator (MZIM), this is easily achieved by utilizing microwave optical transfer characteristic of MZIM.

3.2 Motivation

In 10 Gb/s system, DPSK implementation is basically limited by SPM (for single channel effect) Since information is encoded by optical phase in DPSK system, SPM would introduce Mollenauer effect through non linear interaction causing phase fluctuation from noise-induced intensity modulation. [1] As a result, this imposes penalty in transmission and offers ASK format an advantage to be used primarily in 10 Gb/s.

Due to high demand of data transmission capacity, with the advent of wavelength division multiplexing (WDM) technology, data transmission has maneuvered into a revolutionary stage for increasing higher system capacity. Higher bit rates up to 40Gb/s and growing numbers of WDM channel are increasingly challenging the limit of Amplitude shift keying (ASK) format, such as OOK. Cross phase modulation (XPM) is a multi channel effect that has imposed severe impact on OOK format. [1] On the other hand, XPM effect is greatly impressed with DPSK in WDM systems. In fact, experimental results showed DPSK outperform OOK in 40 Gb/s WDM systems.

Nevertheless, DPSK is vulnerable to SPM-GVD effect. Therefore, RZ with regular data pulse alleviates this penalty. Unfortunately, RZ pulse has larger bandwidth and this is critical particularly in efficient usage of spectrum. Hence, carrier suppressed RZ (CSRZ) is introduced to combat this shortcoming.

In this report, in order to investigate the viability of RZ-DPSK modulation formats for the next generation of lightwave communication system, especially for ultra-high capacity and ultra-long haul link. Simulations have been conducted extensively based on MATLAB^{TM} Simulink platform. The user friendly environment SIMULINK provides rapid design and modeling tools to simulate components and essential devices such as MZIM. System performances for instances, optical signal bandwidth, eye diagram, error probabilities can be evaluated instantaneously by changing design parameters. In high cost and expensive long haul optical transmission system, these simulation results are important for communication engineers to design network configurations prior to experiment and installation.

3.3 Organization of the report

The organization of this report is as follows

- In the next section, the operational principle and characteristics of interferometric modulators operating in the optical frequency domain are outlined for single and dual drive operations.
- In section 3, the generations of the modulation formats RZ, CSRZ and DPSK are described.

- In section 4, the design of different modulation format of photonics transmitters including lightwave source, and optical modulators are described. Their implementation in SIMULINK is described.
- The optical spectrum of simulation result and eye diagram is illustrated to prove the working of the models. The analyses of optical spectra indicate the interferometric behavior of the lightwave under different modulation format.
- Finally, the future schedule of the rest of the thesis project is outlined.

4 External Modulator- Mach Zehnder Interferometric Modulator

For 10 Gb/s and above, laser is difficult to modulate directly. Data rate is greatly limited by the wavelength chirping due to turning laser on and off. Owing to signal degradation in the presence of fiver chromatic dispersion, [3] external modulators are deployed to overcome these shortcomings.

Generally, external modulators consist of electro absorption modulators and electro-optic modulators. In 10 Gb/s or 40 Gb/s DWDM applications, electro optic modulators are the technology of choice due to better performance in terms of chirp and modulation speed compared to electro absorption devices. Electro-optic modulators work on the principle of electro-optic effect (change of refractive index in material is proportional to the applied electric field). Over the years, lithium niobate ($LiNbO_3$) has been the material of choice for electro-optic modulators owing to its properties of enabling low loss waveguides and high electro optic effect. [4]

The most popular $LiNbO_3$ electro optic modulators nowadays employed particularly in high performance long haul optical transmission system are based on Mach Zehnder interferometric optical waveguide structure. [5] In this report, we are considering only $LiNbO_3$ MZIM modulator.

4.1 Single drive MZIM

In a Mach Zehnder modulator, the incoming light is split equally into two paths at Y branch (3 dB splitter) and traveled along upper and lower traveling wave electrode. An electric field is applied across the optical waveguide by electrode that generates change of refractive index of electro optic waveguide material via electro-optic effect. The change in the refractive index profile causes speed of light wave in the waveguide to change according to c/n_r [4], thus phase shift occurs. When the lights from upper and lower waveguide recombine in the output Y branch, either a constructive or a destructive interference is result depending on the relative phase shift of two branches. If the light waves from two arms are in phase, “ON” state of logic 1 is inferred due to constructive interference. The output is interpreted as “OFF” state or logic 0 if the light waves are π (or 180^o) out of phase derived from destructive interference.

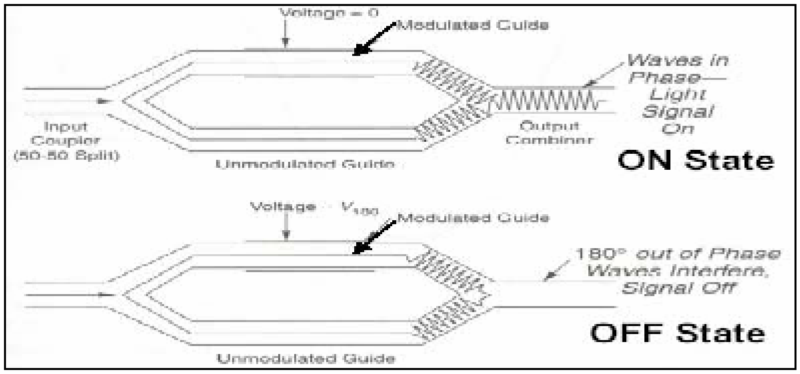


Figure 1 Illustration of constructive and destructive interference at single drive MZ modulator output.[5]

Combined optical wave at output of Y branch is described as [4]

$$E_o = \frac{E_i}{2}\left[1 + e^{j\pi \frac{V(t)}{V_\pi}}\right] = E_i \cos\left(\frac{\pi}{2}\frac{V(t)}{V_\pi}\right) e^{j\pi \frac{V(t)}{V_\pi}} \tag{1}$$

To express in term of optical intensity to derive input-output transfer characteristic of MZIM [4]

$$E_o^2 = E_i^2 \cos^2\left(\frac{\pi}{2}\frac{V(t)}{V_\pi}\right) \tag{2}$$

Where E_o and E_i are the output and input electric field of the Lightwaves, V(t) is the driving voltage or applied voltage at traveling eave electrode, Vπ is the voltage required to cause π phase shift of optical wave

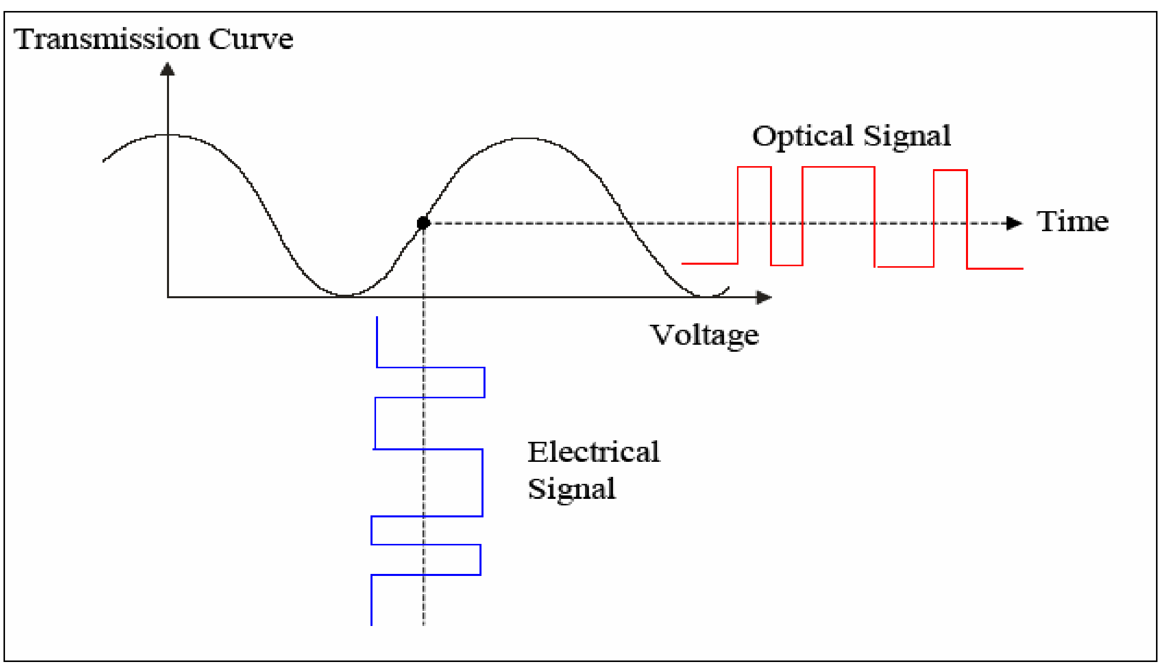


Figure 2 The transmission curve of MZIM derived from equation (2) forms the periodic waveform as a function of applied biasing voltage[1]. [7]

As the transfer characteristic is $\cos^2$-shaped, the modulator will can biased in different region and modulating signal will be superimposed onto the bias voltage. The non linear transfer function has been used to generate non return to zero (NRZ), RZ pulse with various duty cycle, and DPSK signal.

4.2 Dual drive MZIM

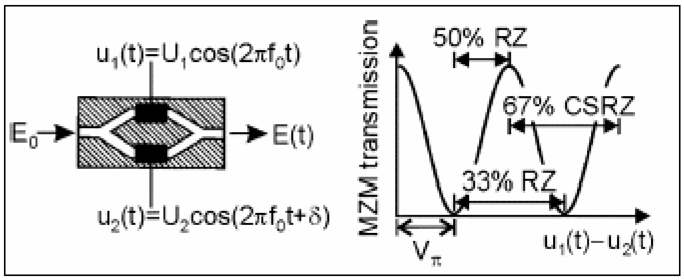


Figure 3 Schematic and intensity transmission curve of a dual drive MZIM.

MZIM can also be driven with dual electrode structure or commonly referred as push pull modulator. In this report, we are considering chirp free driving by using two driving voltages with π phase difference (i.e $u_1(t) = - u_2(t)$, $\delta = \pi$)

The basic principle is similar to single drive MZIM but with both arms applied with voltage to phase modulate optical carrier via electro optic effect. Interference at output of Y branch will produce phase modulation. If the phase modulation is exactly equal in each path but opposite in sign, by combining two optical signals, the phase modulation is converted into intensity modulation. As a consequence, dual drive MZIM has an attractive feature; it can be driven as phase modulator and intensity modulator by changing its driving voltage. [6]

5 Modulation Scheme

5.1 RZ format

There are a number of advanced formats used in WDM transmission link, including NRZ, RZ and duobinary. Most available 10 Gb/s system were developed with NRZ applications due to its simple transmitter design and bandwidth efficient characteristic. However, RZ format has higher robustness to fiber non linearity and polarization mode dispersion (PMD). In this report, RZ pulse is generated by MZIM commonly known as pulse carver. There are a number of variations in RZ format based on the biasing point in transmission curve shown in Table 1.

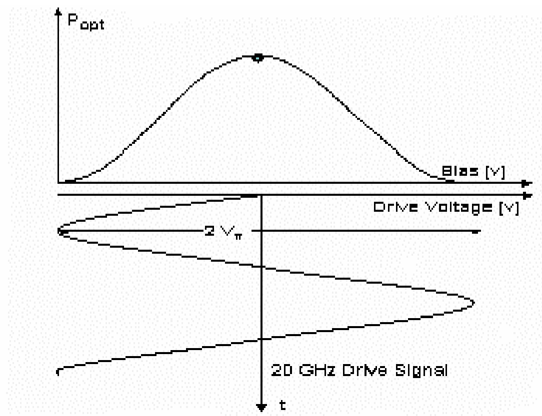
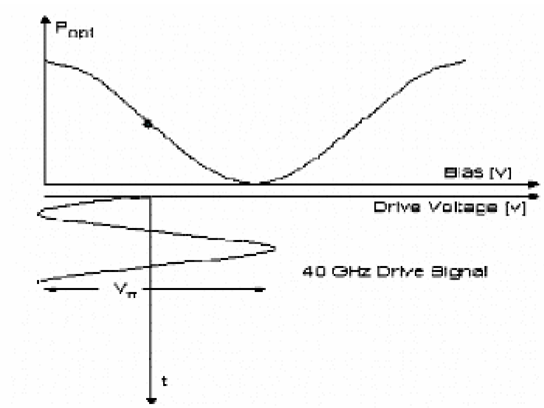
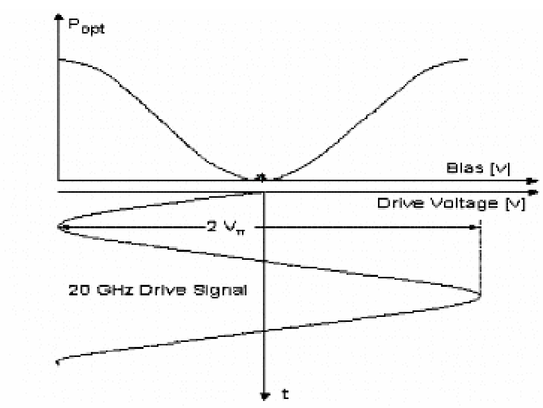
<table>
<tr><td>Biasing point in Transmission Curve</td><td>RZ generation Characteristics</td></tr>
<tr><td>
</td><td>1. Biasing point: Maximum, V2π
2. Drive signal amplitude: 2 Vπ
3. Drive signal frequency: 20 GHz
4. Pulse width: 9 -10 ps
5. RZ pulse frequency: 40 GHz frequency doubling effect.</td></tr>
<tr><td>
</td><td>1. Biasing point: Linear region, Vπ/2
2. Drive signal amplitude: Vπ
3. Drive signal frequency: 20 GHz
4. Pulse width: 9 -10 ps
5. RZ pulse frequency: 20 GHz</td></tr>
<tr><td>
</td><td>1. Biasing point: Minimum, Vπ
2. Drive signal amplitude: 2 Vπ
3. Drive signal frequency: 20 GHz
4. Pulse width: 9 -10 ps
5. RZ pulse frequency: 40 GHz frequency doubling effect. (Carrier suppressed RZ is generated using this scheme)</td></tr>
</table>

***Table 1** Summary of RZ format generation and characteristics of single drive MZIM based on biasing point, drive signal amplitude and frequency*

CSRZ is found to have more attractive attributes in long haul WDM transmissions compared to conventional RZ format. CSRZ pulse has optical phase difference of π in adjacent bits, removing the optical carrier component in optical spectrum and reducing the spectral width. This offers an advantage in compact WDM channel spacing.

5.2 Differential Phase Shift Keying (DPSK)

Information encoded in the phase of an optical carrier is commonly referred to as optical phase shift keying. In early days, PSK requires precise alignment of the transmitter and demodulator center frequencies. [8] Hence, PSK system is not widely deployed. With DPSK scheme introduced, coherent detection is not critical since DPSK detection only requires source coherence over one bit period by comparison of tow consecutive pulses.

A binary 1 is encoded if the present input bit and the past encoded bit are of opposite logic and a binary 0 is encoded if the logic is similar. This operation is equivalent to XOR logic operation. Hence, an XOR gate is usually employed in differential encoder. NOR can also be used to replace XOR operation in differential encoding.

In optical application, electrical data “1” is represented by a π phase change between the consecutive data bits in the optical carrier, while state “0” is encoded with no phase change between the consecutive data bits. Hence, this encoding scheme gives rise to two points located exactly at π phase difference with respect to each other in signal constellation diagram.

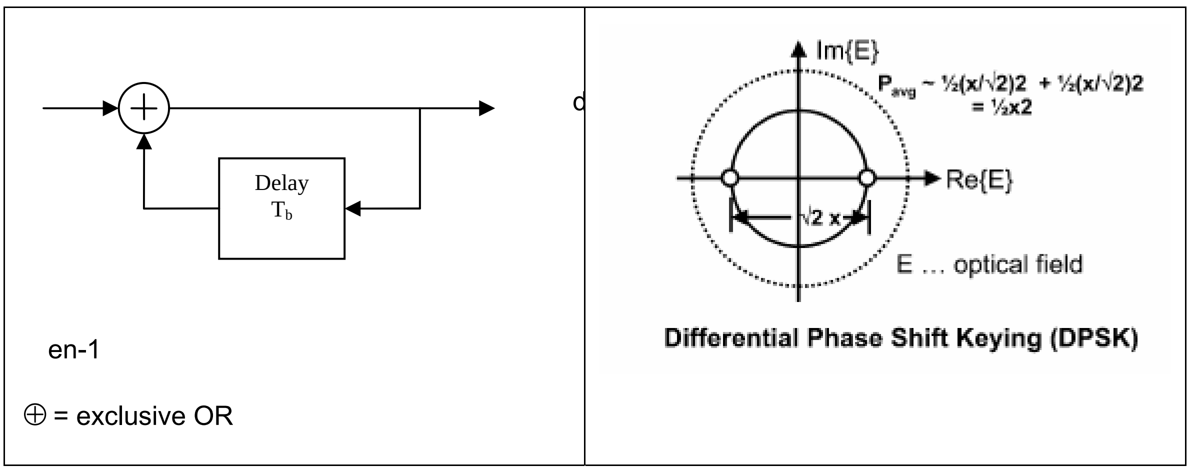


Figure 4(a) The encoded differential data are generated by $e_n = d_n \oplus e_{n-1}$ (b) Signal constellation diagram of DPSK [1]

6 Design and Implementation of 40 Gb/s RZ-DPSK Photonic Transmitter Simulation Model

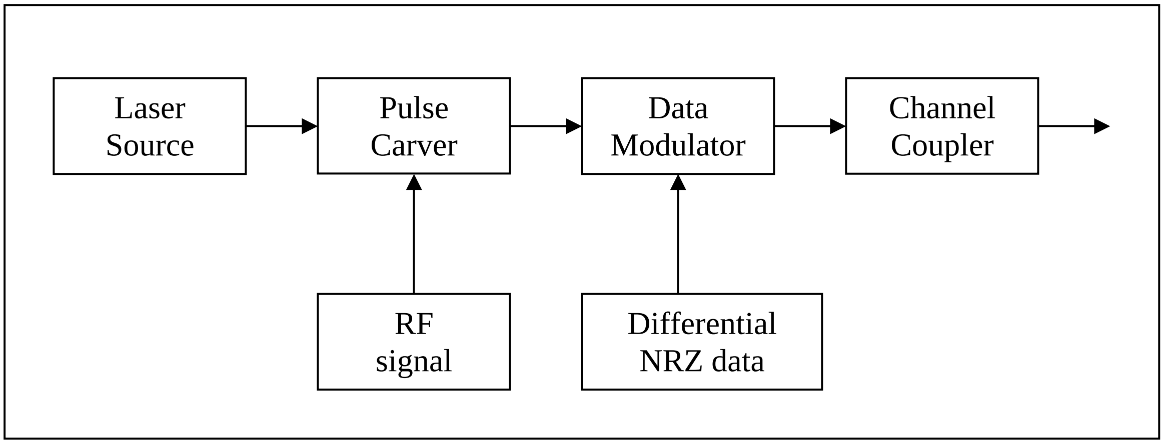


Figure 5 Block diagrams of RZ-DPSK transmitter.

A RZ-DPSK transmitter consists of an optical source, pulse carver, data modulator, differential data encoder and a channel coupler. Channel coupler model is not developed in simulation by assuming no coupling losses when optical RZ-DPSK modulated signal is launched into the optical fiber. This modulation scheme has combined the functionality of dual drive MZIM modulator of pulse carving and phase modulation.

The pulse carver (Mach Zehnder intensity modulator) is driven by sinusoidal RF signal(s) (one electrical RF signal for single drive MZIM; two electrical RF signals for dual drive MZIM) to carve pulses out from optical carrier signal forming RZ pulses. These optical RZ pulses are fed into second Mach Zehnder phase modulator where RZ pulses are modulated by differential NRZ electrical data to generate RZ-DPSK. Data phase modulation can be performed using straight line phase modulator but Mach Zehnder wave guide structure has several advantages over phase modulator described in [1].Electrical data pulses are differentially pre coded in differential pre coder. Without pulse carver and sinusoidal RF signal, the system becomes NRZ-DPSK transmitter.

6.1 Optical Source

Optical source is assumed to be a distributive feedback semiconductor (DFB) laser. In practice, the amount of loss from the light injected by the laser into modulators is approximately 3-5 dB. Assume no insertion loss when light is injected into modulator, optical source can be modeled using a standard Simulink signal generator block. Optical carrier frequency is 193.1 THz normalized amplitude. Initial phase of the carrier can also be adjusted. This model is also employed in modeling RF sinusoidal signal used to drive pulse carver.

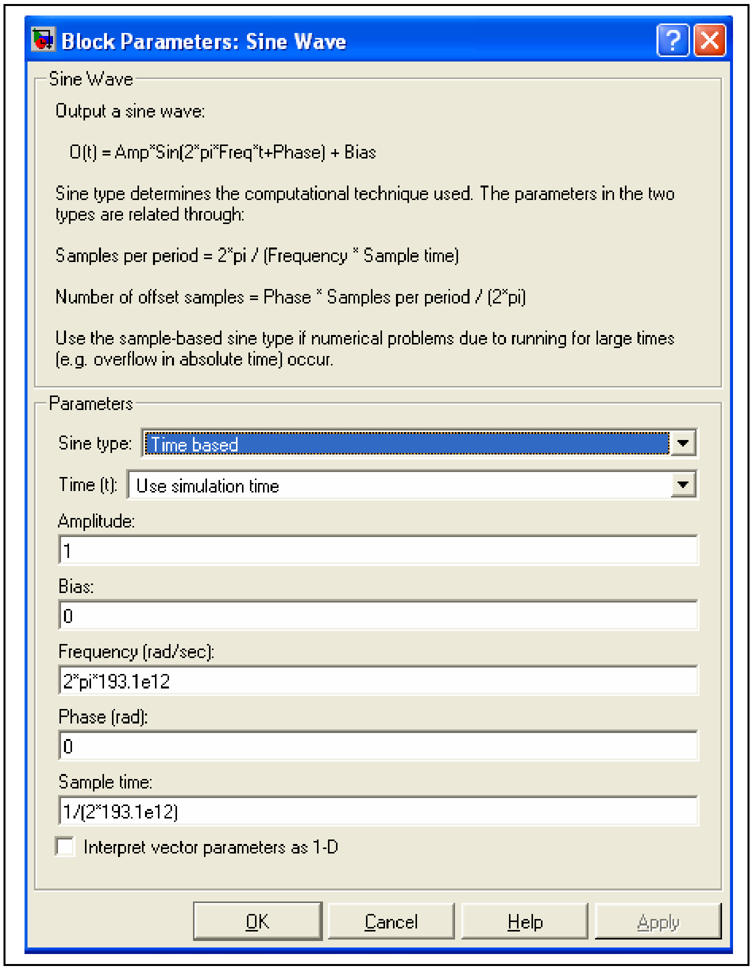


Figure 6 Block parameter and block diagram used in Simulink to generate optical carrier signal and RF modulating signal.

6.2 Pulse Carver

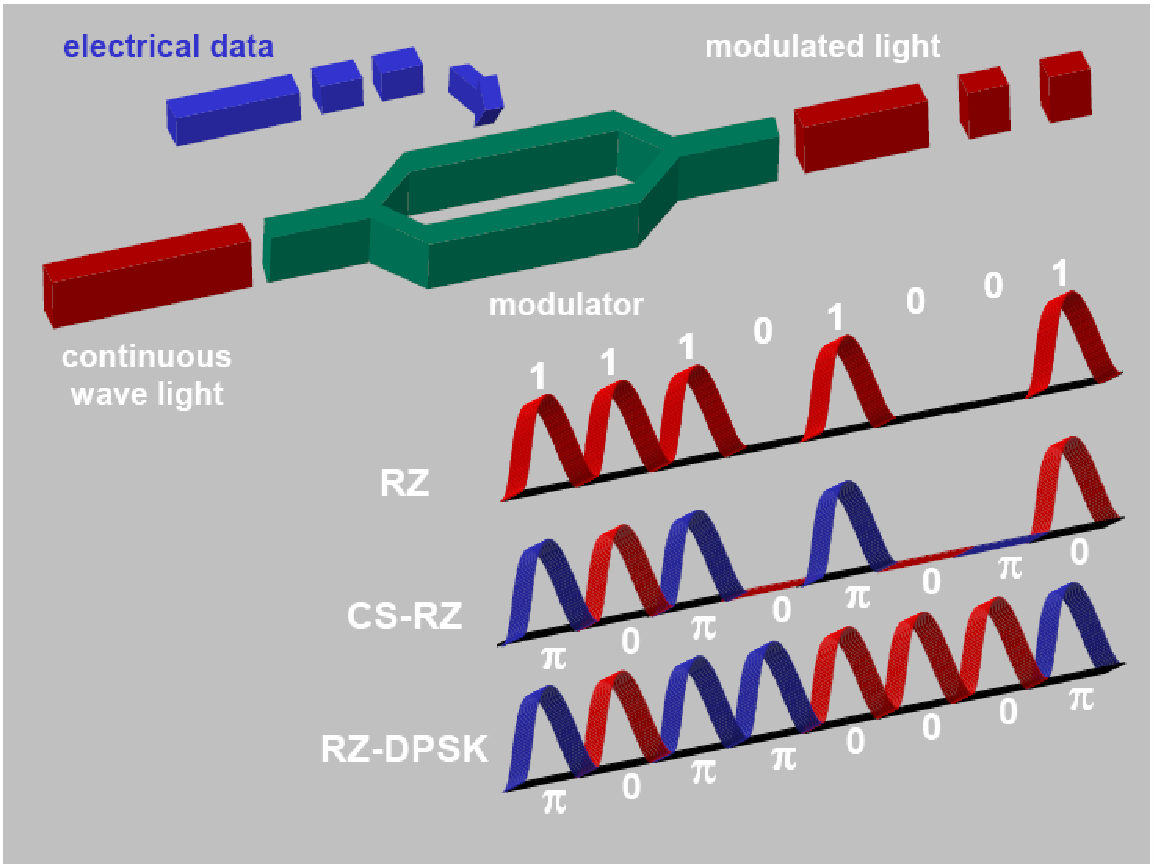


Figure 7 Operation of pulse carver to generate different RZ format. [Adapted from Peucheret]

The pulse carver is used to carve RZ pulses from optical carrier signal. Different biasing point is used to generate various formats of RZ pulses. (as described in **Figure 4**) Since optical phase distortions (such as chirp) will affect DPSK receiver performance, dual drive MZIM pulse carver is required to operate in perfect push-pull operation. In other words, sinusoidal RF signals amplitude has to be similar and of exact opposite phase. This requirement is difficult to achieve in practice but fairly straightforward in simulation environment.

Assume extinction ratio is large, optical field exiting a dual drive MZIM is described mathematically [1]

$$E(t) = \frac{E_o}{2}\left\{\exp\left[j\pi\frac{u_1(t)}{V_\pi}\right] + \exp\left[j\pi\frac{u_2(t)}{V_\pi}\right]\right\}$$

$$\approx E_o \exp\left[j\pi\frac{u_1(t)+u_2(t)}{2V_\pi}\right]\times\cos\left[\pi\frac{u_1(t)-u_2(t)}{2V_\pi}+\varphi\right] \qquad (3)$$

Where E_0 is magnitude of input optical field, $V\pi$ is the electrical voltage to produce π phase shift in either of modulator's two arms, φ is the relative optical phase between 2 arms without RF drive signals; $u1(t)= U_1\cos(2\pi f_m t)$; $u2(t)= U_1\cos(2\pi f_m t + \theta)$ and fm is the RF signal frequency.

Since chirp free driving condition required $u_1(t)=-u_2(t)$, Equation (3) can be reduced to

$$E(t) \approx E_o \cos\left[\pi \frac{u_1(t) - u_2(t)}{2V_\pi} + \varphi\right] \tag{4}$$

Let

$$\varphi = \frac{\varphi_1 - \varphi_2}{2} \quad \text{with} \quad \varphi_1 = \pi \frac{V_{DC1}}{V_\pi} \quad \text{and} \quad \varphi_2 = \pi \frac{V_{DC2}}{V_\pi} \tag{5}$$

By incorporating optical carrier frequency into Equation (4), optical field exiting dual drive MZIM can be re-expressed as [10]

$$E(t) = E_o \left\{\cos\left[2\pi f_c t + \alpha\pi \cos(2\pi f_m t) + \varphi_1\right] + \cos\left[2\pi f_c t + \alpha\pi \cos(2\pi f_m t + \theta) + \varphi_2\right]\right\} \tag{6}$$

Where fc is the optical carrier frequency, α = $\pi \frac{U_{1,2}}{V_\pi}$ (assigned as the modulation index) In this report, simulation model of dual drive MZIM driven in perfect push-pull configuration is developed using the mathematical model described in (6)

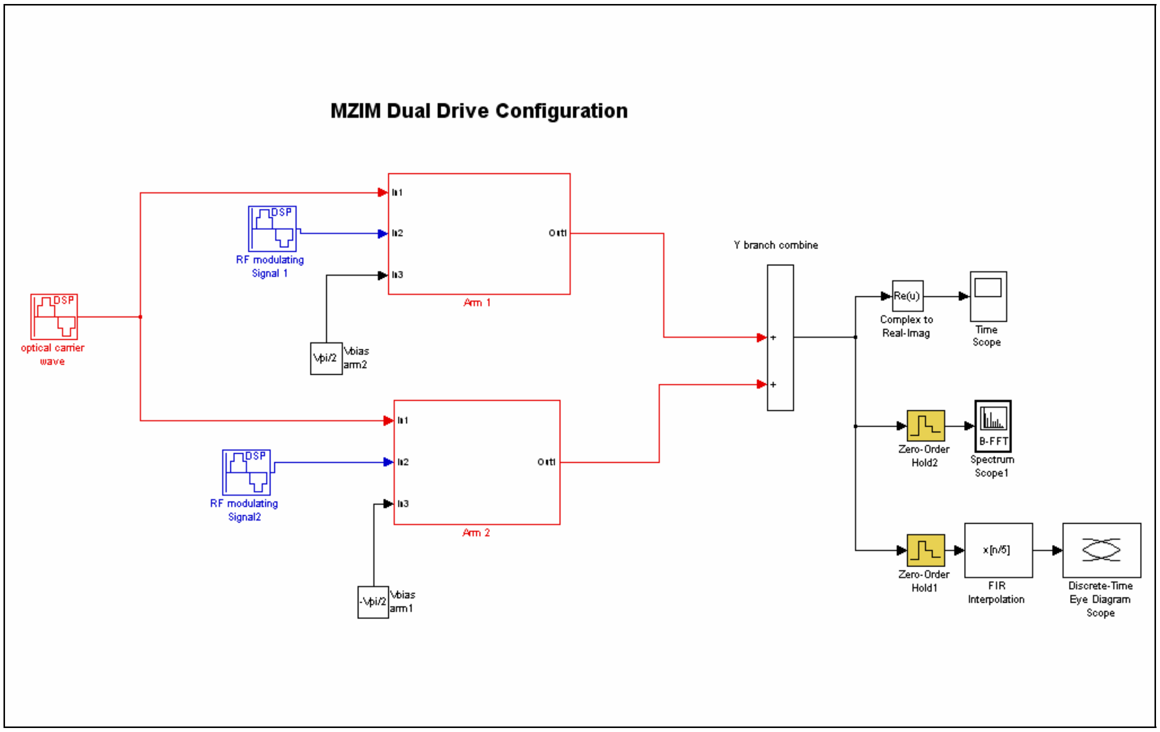


Figure 8 Dual drive MZIM Pulse Carver with optical carrier source, RF driving signal and biasing voltage used to generate various RZ format.

Figure 8 shows the optical carrier is split equally into two paths. Two RF driving signal and two biasing voltages are used to modulate optical carrier frequency and the output from each arm recombines at Y branch (coupler). Spectrum scope and Eye Diagram Scope are used to evaluate RZ formats.

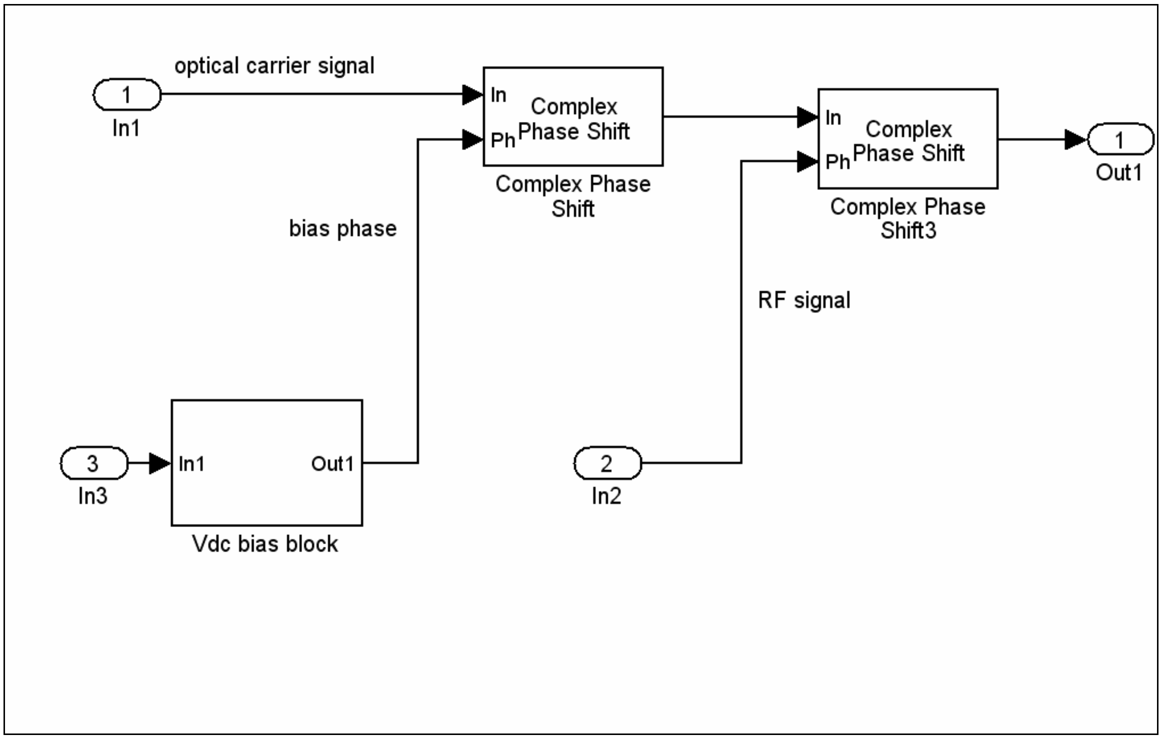


Figure 9 One of the arms in dual drive MZIM illustrating how RF signal is superimposed on biasing voltage to phase modulate optical carrier signal.

Figure 8 shows the equally split optical carrier signal enter one of MZIM path. Biasing voltage is fed to create a relative phase reference (shown in Figure XXXX) for RF signal. RF signal is used to modulate optical carrier signal with phase relative to biasing voltage phase. This model essentially represents one of the two cosine terms in Equation (6). The output of this arm is combined with the output of the other arm by addition to form RZ pulse.

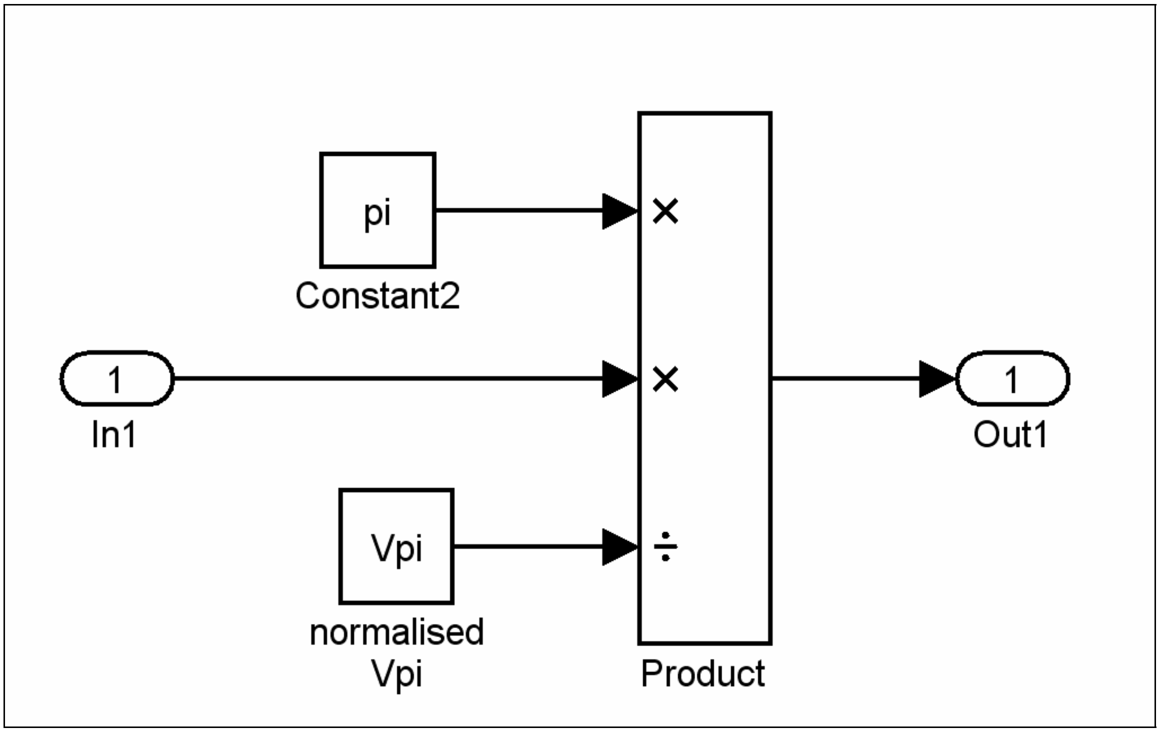


Figure 10 V_{DC} bias block used to create phase reference for RF driving signal.

Biasing Point	Parameters Setting	
	Arm 1	**Arm 2**
Linear region (quadrature point)	1. *RF signal amplitude: Vπ/4* 2. *RF signal frequency: 40 GHz* 3. *Biasing voltage: Vπ/4*	1. *RF signal amplitude: Vπ/4* 2. *RF signal frequency: 40 GHz* 3. *Biasing voltage: -Vπ/4*
Minimum (CSRZ)	1. *RF signal amplitude: Vπ/2* 2. *RF signal frequency: 20 GHz* 3. *Biasing voltage: Vπ/2*	1. *RF signal amplitude: Vπ/2* 2. *RF signal frequency: 20 GHz* 3. *Biasing voltage:-Vπ/2*
Maximum	1. *RF signal amplitude: Vπ* 2. *RF signal frequency: 20 GHz* 3. *Biasing voltage: Vπ*	1. *RF signal amplitude: Vπ* 2. *RF signal frequency: 20 GHz* 3. *Biasing voltage: -Vπ*

Table 2 Parameters setting for three formats of RZ pulses. Details in [6]

The actual RF driving amplitude has to be substituted into Equation (7) and input to amplitude section in RF modulating signal block in Figure (6.2). The mathematical analysis shows that the biasing voltage, V_π is reduced by half with respect to single drive MZIM, thus with driving voltage as well, an advantage using balanced modulator structure [4,6].

6.3 Differential Data Encoder

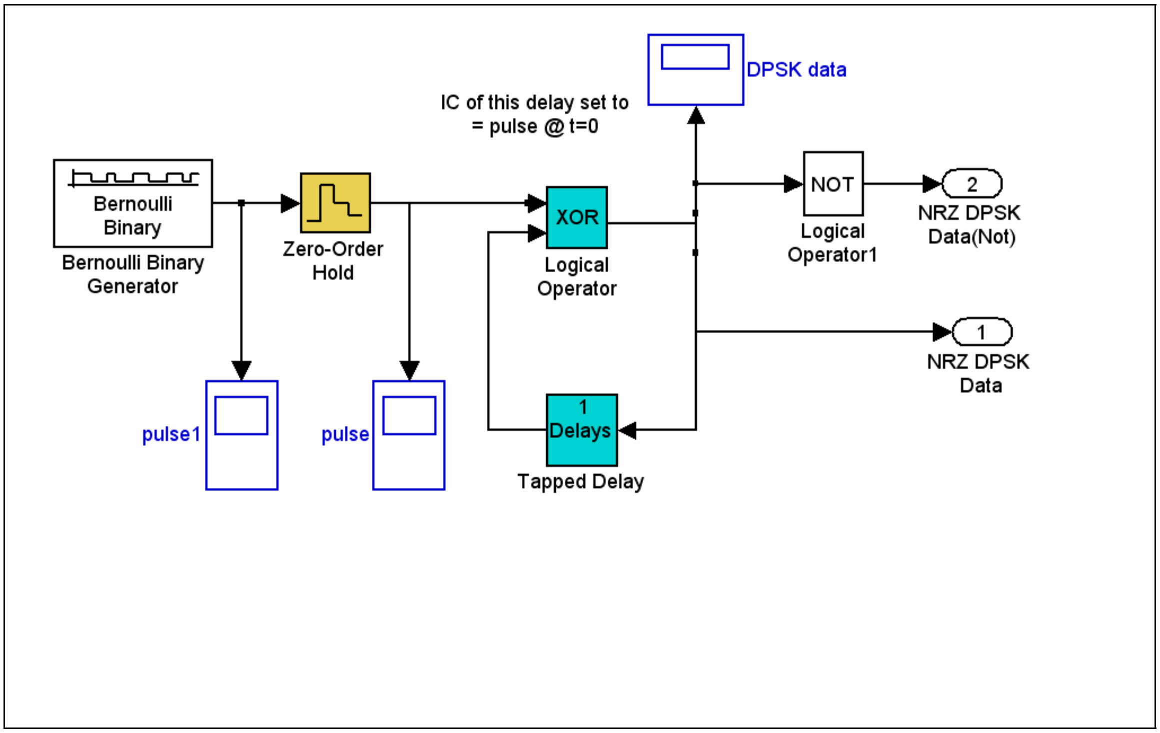


Figure 11 *Differential NRZ data encoder.*

Differential data encoder is implemented using differential encoding logic described in section 4.2. Bernoulli binary generator is driven at 20 Gb/s and sampled at the same frame rate to XOR with the past encoded bit. This model consists of two NRZ DPSK data output complement with each other which are necessary to operate dual drive MZIM modulator at next stage.

6.4 Data Modulator

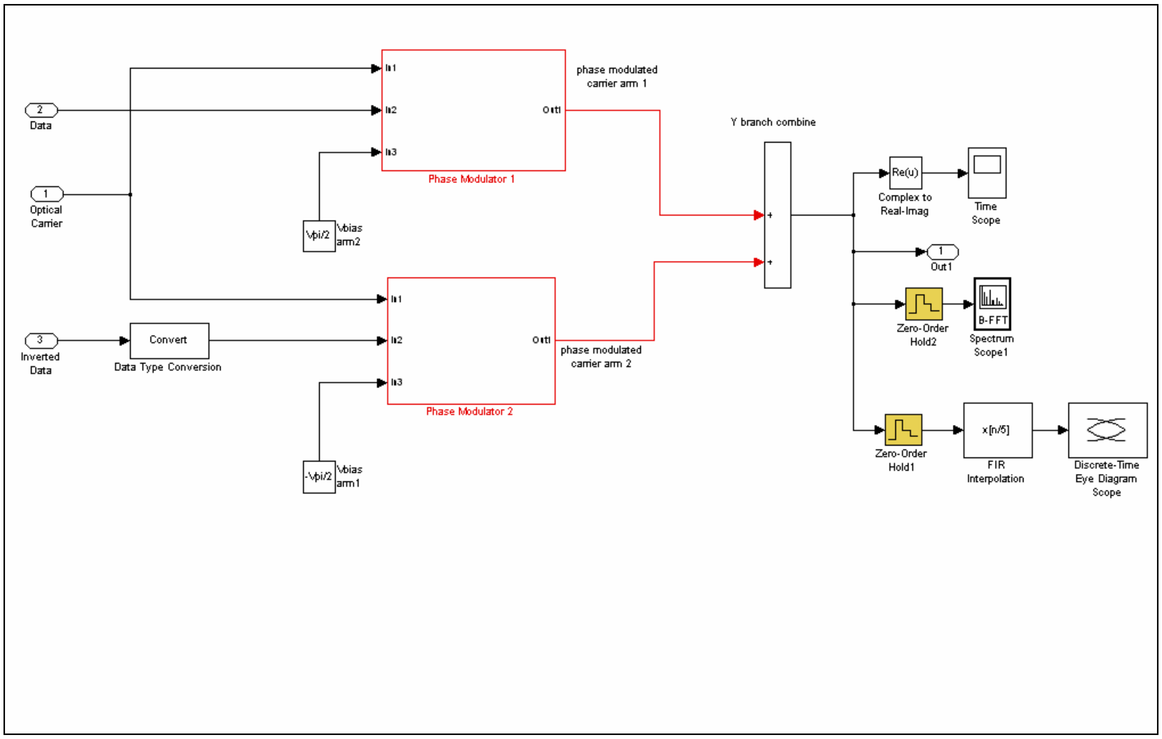


Figure 12 *Data modulator based on dual drive Z cut modulator (modulator structure is similar to that of pulse carver) driven by data and inverted data.*

When a balanced modulator structure is driven by an electrical signal with 2Vπ, there are two important behaviors that can be implicitly utilized to implement PSK encoding scheme. Phase modulation is limited to 0 and π, equivalent to signal constellation diagram in Figure 4.2(b) and double in frequency of driving data.

Logically, the similar structure used for pulse carving can be employed in data modulation scheme. Nevertheless, phase modulator block in data modulator has to be modified to suit the behaviors described above.

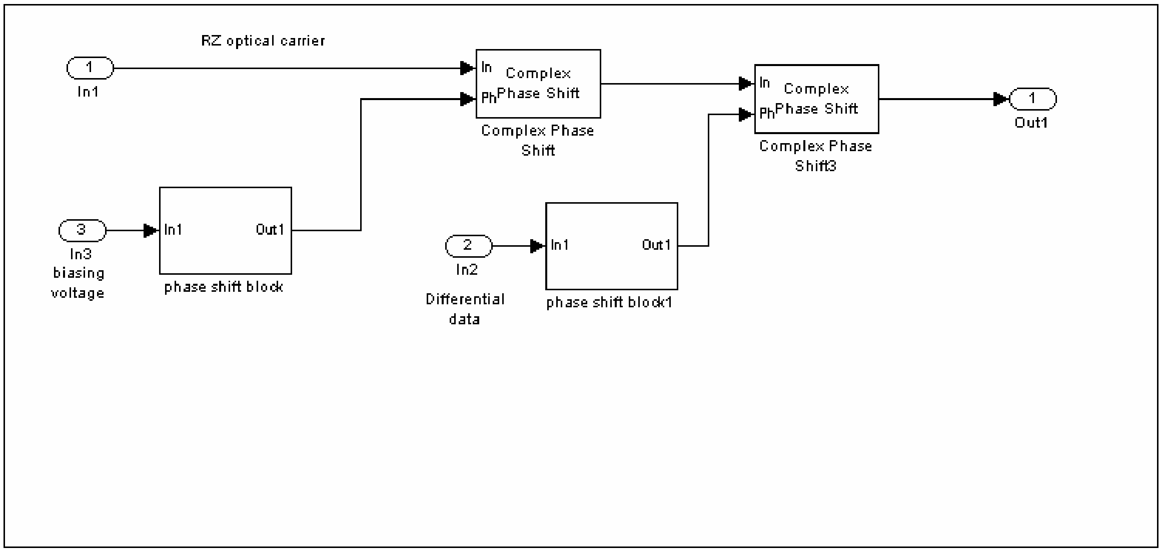


Figure 13 *Phase modulator block in data modulator.*

The phase modulator block is very similar to Figure 12 but with additional phase shift block fed with differential encoded electrical data before phase modulate biased RZ optical signal. This additional phase shift block is similar to Figure 13. It is introduced due to the fact that data modulator model is based on pulse carver structure (it has to be since they are all MZIM) developed implicitly on mathematical model described in Equation (6). The inherent behaviors described previously have to be incorporated into this model via phase shift block.

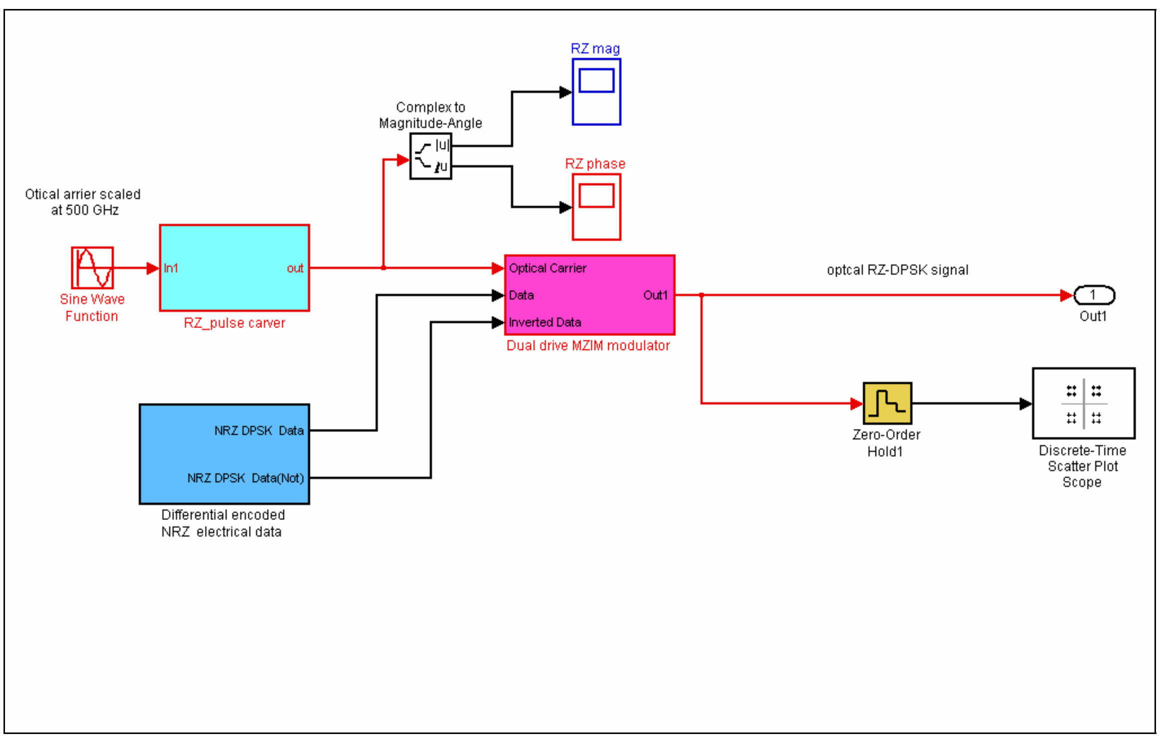


Figure 14 *Simulink model of 40 Gb/s RZ-DPSK transmitter.*

7 Results

7.1 RZ pulse

The following diagrams showed the spectrum scopes obtained for different format RZ pulses based on biasing points. The operating settings were configured according to Table 2.

7.1.1 Biased at Maximum region

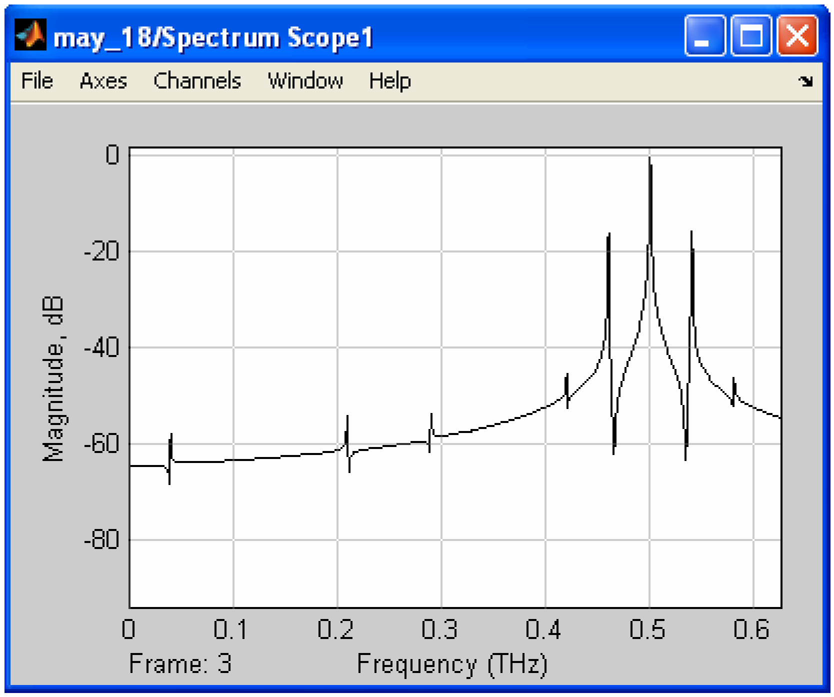


Figure 15 *Spectrum scope of RZ signal generated by biasing MZIM at maximum point.*

The carrier is seen as highest peak at 500 GHz. Two side peaks are RF modulating signal at 80 GHz apart.

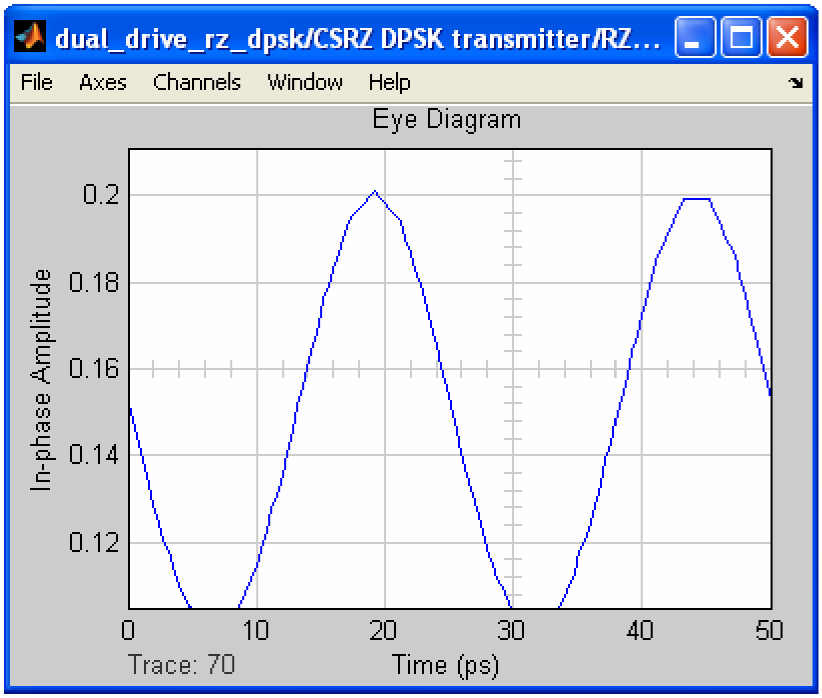


Figure 16 *Eye Diagram of RZ pulse when MZIM biased at maximum point.*

7.1.2 Biased at Minimum

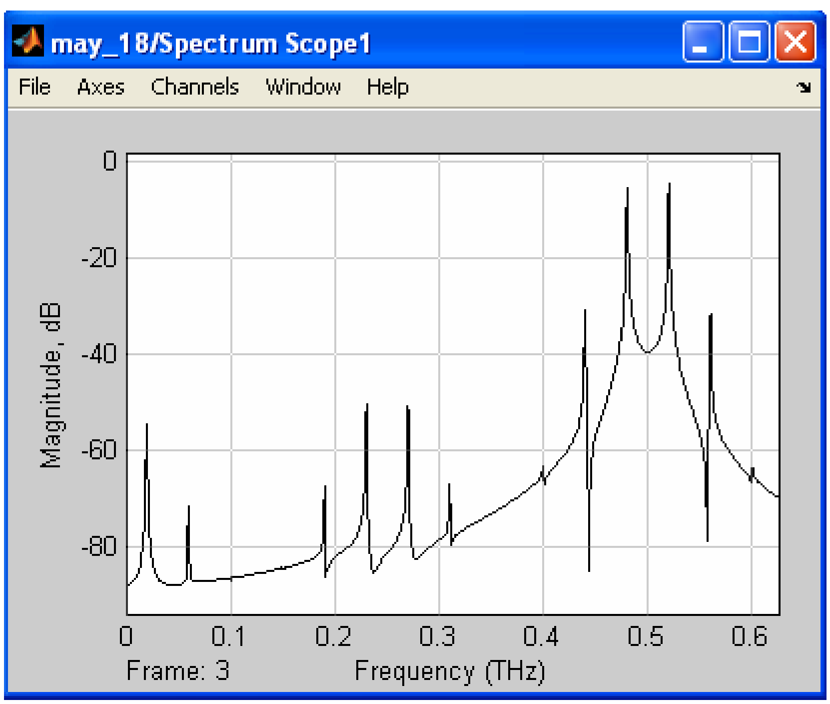


Figure 17 *Spectrum scope of CSRZ with carrier frequency 500 GHz. Two "horns" are 40 GHz apart with carrier being suppressed.*

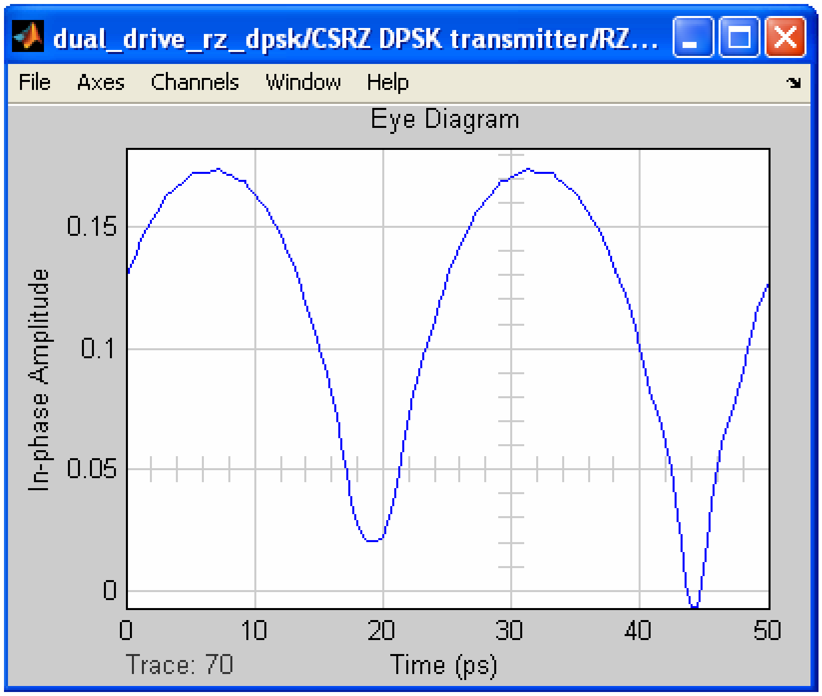


Figure 18 *Eye diagram of CSRZ pulse.*

7.1.3 Biased at Linear

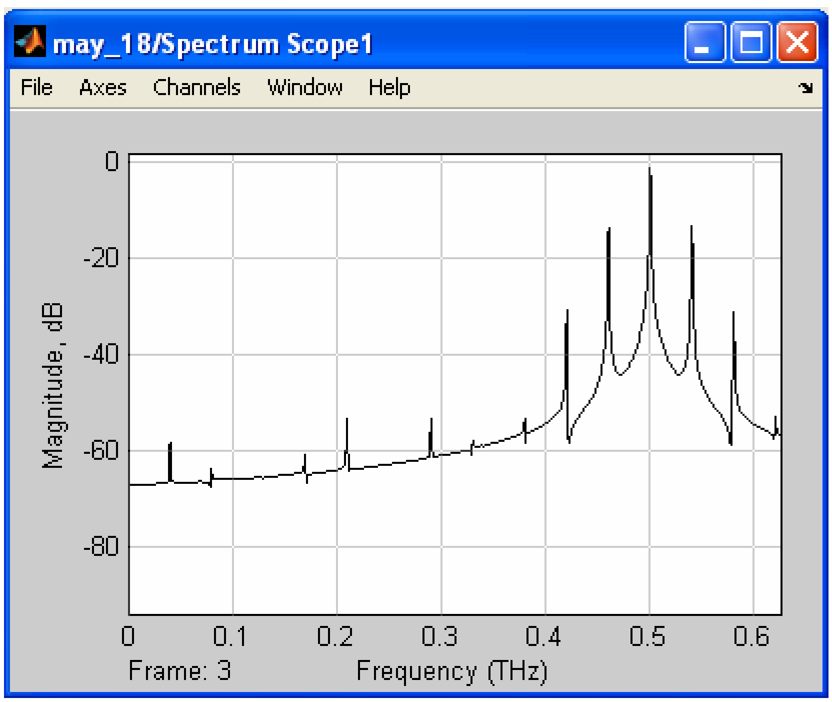


Figure 19 *Spectrum of RZ pulse when MZIM biased at linear region. Highest peak is carrier and side peaks are modulating signal with 80 GHz apart.*

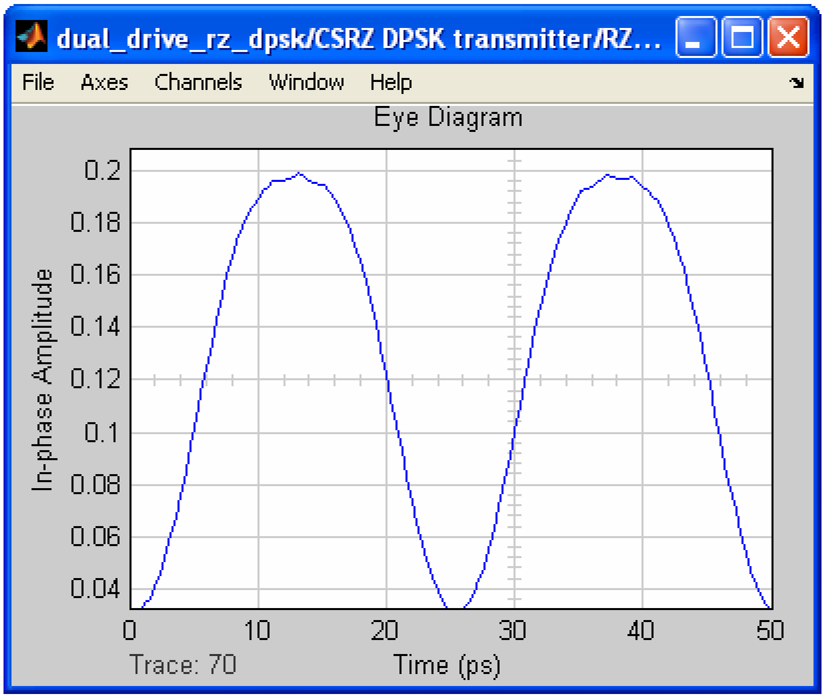


Figure 20 Eye diagram of RZ pulse when MZIM biased at linear region.

7.2 Differential Encoded Electrical Data

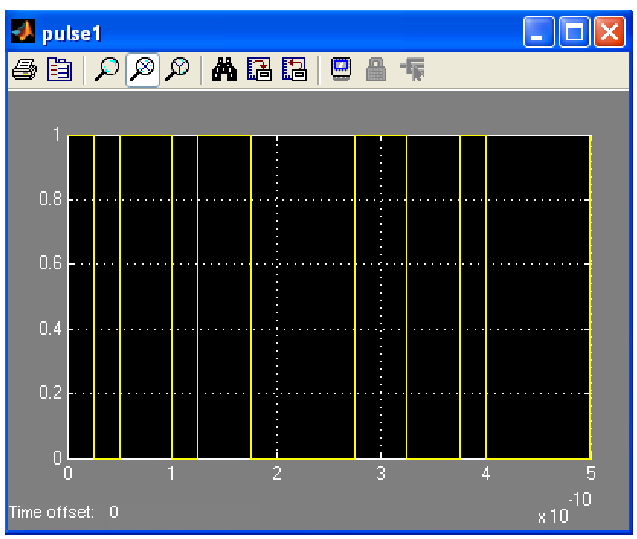


Figure 21 *Binary data generated by Bernoulli binary generator at 20 Gb/s over 10 bit periods.*

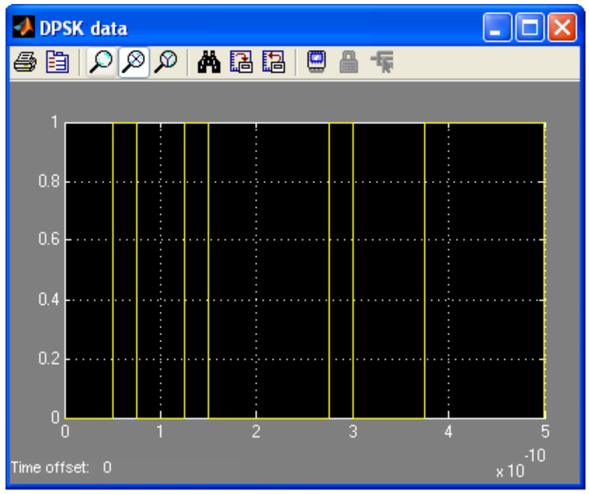


Figure 22 *Differential encoded data.*

7.3 Optical RZ-DPSK spectrum

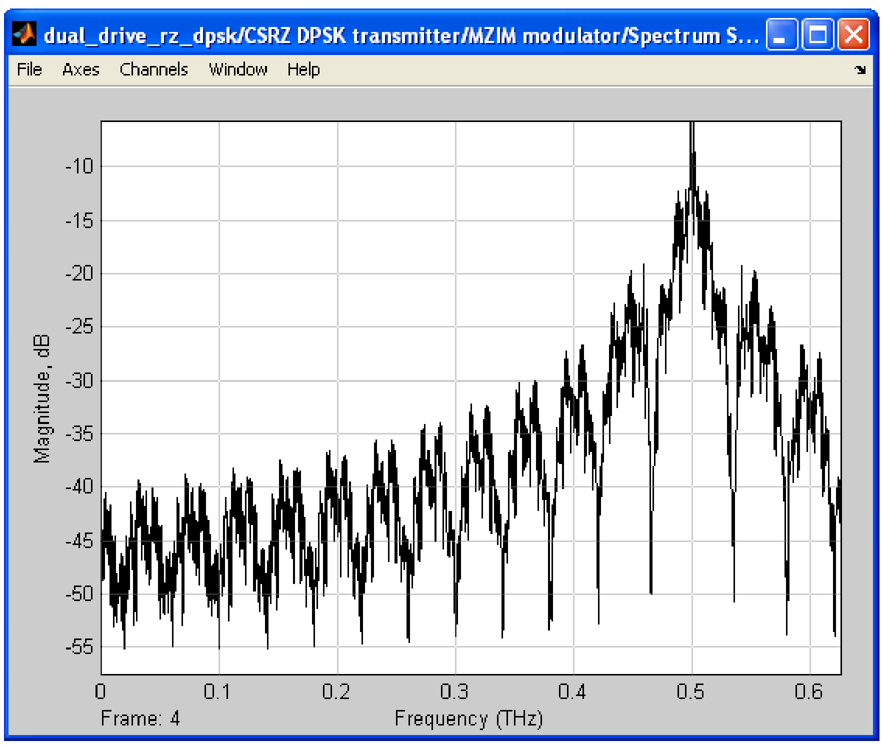


Figure 23 *Optical RZ-DPSK spectrum when MZIM is biased at maximum with 20 GHz RF driving signal and data rate at 20 Gb/s.*

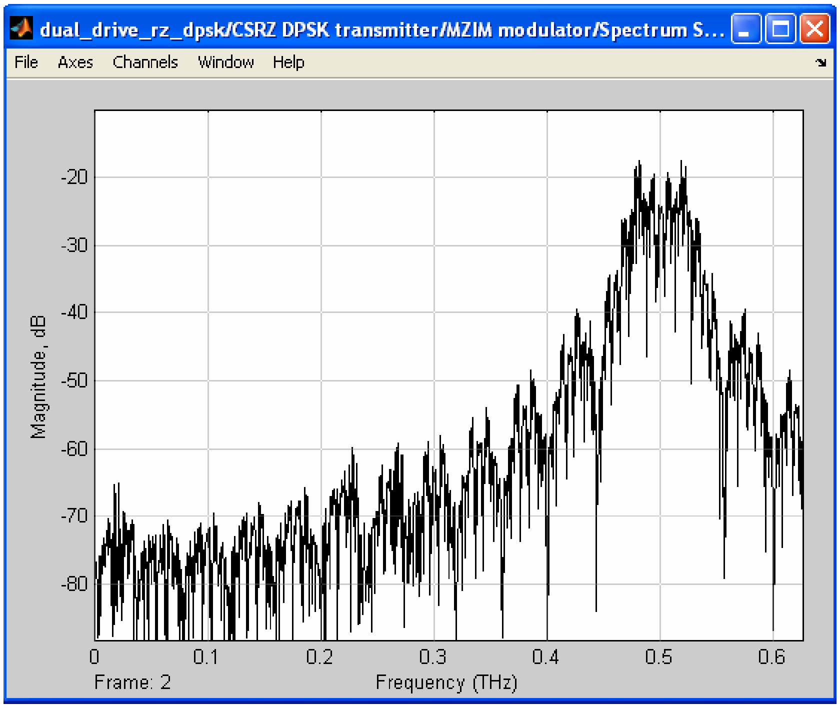


Figure 24 *The CSRZ-DPSK optical spectrum when MZIM biased at minimum point driven by 20 GHz of RF signal and 20 Gb/s of data.*

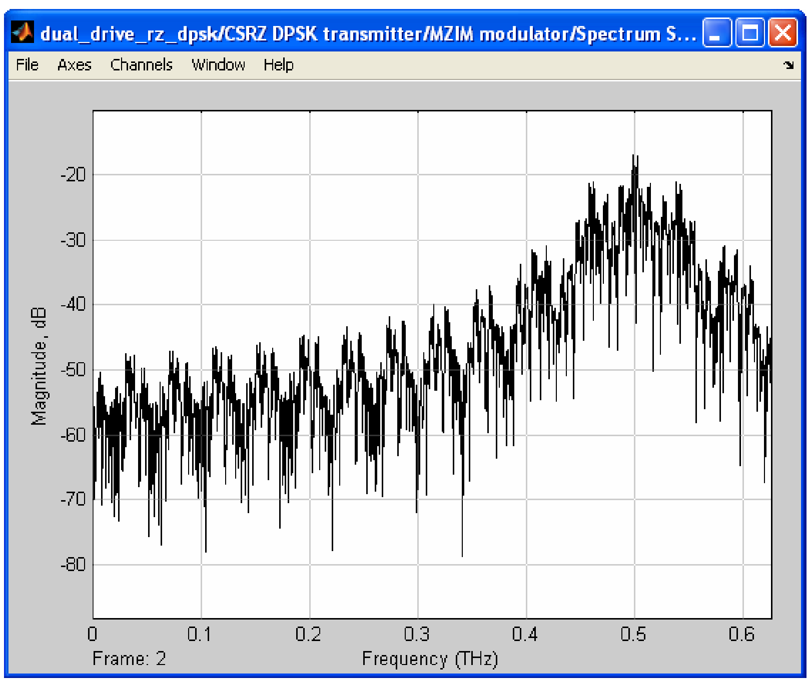


Figure 25 *RZ-DPSK optical spectrum when MZIM biased at linear point driven by 40 GHz of RF signal and 20 Gb/s of data.*

7.4 Discussions

From optical spectra result, it is clear that this model offers an advantage; it can be used to generate three RZ format by simply changing the parameter (Figure 6.8). Convincing evidence showed that when MZIM was biased at minimum, the spectrum scopes (Figure 7.3 and 7.10) illustrated that the carrier power was suppressed and signal bandwidth is 40 GHz. Eye diagram also showed frequency doubling characteristic, in other words, RZ pulse is 40 GHz when RF signal is 20 GHz. Although spectra is more or less identical for the other two RZ format (Figure 7.1 and 7.5), a supportive result that discern both of them from biasing point of view is the RF driving signal frequency. To generate 40 Gb/s RZ pulse, biasing at linear requires 40 GHz of RF frequency while biasing at maximum requires only 20 GHz due to frequency doubling effect. Based on the behaviors displayed by MZIM according to optical transmission curve, the analysis of the result depicted above is convincing enough to prove that the simulation model is working fine. This model was tested against the model developed according to standard phase modulation block set provided in Simulink by setting similar parameters at different biasing region. The results from testing model corresponded to the developed MZIM model.

Nevertheless, due to the fact that modulation index (parameter set in RF signal block) affects overall modulation efficiency, eye diagram of RZ pulse does not correspond well to actual pulse. In other words, duty cycle of RZ pulse does not correspond to the driving voltage signal. The reason is because the model is developed based on mathematical model. RZ pulse duty cycle is largely dependent on α (modulation index- set in amplitude in RF modulating signal block). Hence, pulse width is generally around 9 -15 ps for three RZ pulse formats.

Differential encoder was tested by following procedure. A pulse generator was used to generate 101010…sequence for simplicity. The encoded data sequence was manually calculated by XOR with the last encoded bit. The “manual” result was compared with Simulink result. A simple decoder was developed by delaying a bit period and XOR with the present bit. When the decoded output is similar to original data, it was confirmed that the differential encoder was working fine.

Data modulator block was tested by similar decoding scheme with an additional phase difference block. Original optical carrier was compared with RZ-DPSK signal in phase difference block, the phase difference results was sampled at data rate and fed to decoder described above to retrieve original data. This receiver is not simulating actual receiver mechanism but the principle is exploited to simulate a “temporary” receiver to verify RZ-DPSK signal.

8 Concluding remarks

This report presents the background information and theory of RZ-DPSK transmitter in optical communication system, design ideas and methods to incorporate principles into simulation model as well as tests to verify the results obtained. Simulation results and analysis of results are presented to discuss advantage and improvements required on current model. Future work and schedule is proposed to develop current transmitter model further.

The followings are planned for further works:

- Evaluations of spectrum scope and eye diagram of RZ-DPSK signal consider only a perfect channel, without losses and dispersion. To investigate how RZ-DPSK performs in a non ideal condition, fiber non linearity and fiber dispersion are to be modeled. Since spectrum of RZ-DPSK signal is not confined to band-limited electrical data, a pulse shaper is to be modeled in differential data encoder block to examine how spectrum spread with this constraint. This is particularly important to provide useful simulation result on spectrum spreading in WDM system with band limited electrical data. Bit error rate has to be evaluated in order to inspect the performance of RZ-DPSK transmitter in presence of dispersion, non linearity, and band limited electrical data.

- To increase spectral efficiency, application to transmit higher bit/symbol is proposed using M-ary PSK modulation format. The multilevel signaling poses a great technical challenge in simulation. For example, 8 ary PSK imposes higher limit on relative phase difference between adjacent symbols. As proposed by Ho and Cuei [11], phases of any constellation points can be generated in dual drive MZIM using the mathematical model devised. Hence, significant amount of future work involves in developing M-ary PSK transmitter into Simulink model.

- Eye diagram of current RZ-DPSK transmitter model needs to be improved. The behavior of driving signal amplitude affecting duty cycle of RZ pulse is recommended to be incorporated into the model. Experiment is required to compare with simulation result.

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