OCSim Modules (Modulation Schemes: QPSK – Nyquist Optical Transmitter IQ MZM)

MODULE 12: MODULATION SCHEMES: QPSK – NYQUIST OPTICAL TRANSMITTER IQ MZM

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Module 12: Modulation Schemes: QPSK – Nyquist Optical Transmitter IQ MZM

Scientific Manual

Background Theory and Formulation of the Module

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Optical Modulation Schemes

Background Theory and Formulation of the Module

Dual Drive Mach-Zehnder Modulators

Mach-Zehnder modulator (MZM) consists of two arms, as shown in Fig. 1. Voltages V_1 and V_2 are applied to the upper and lower arms, respectively. Let the electric field of the

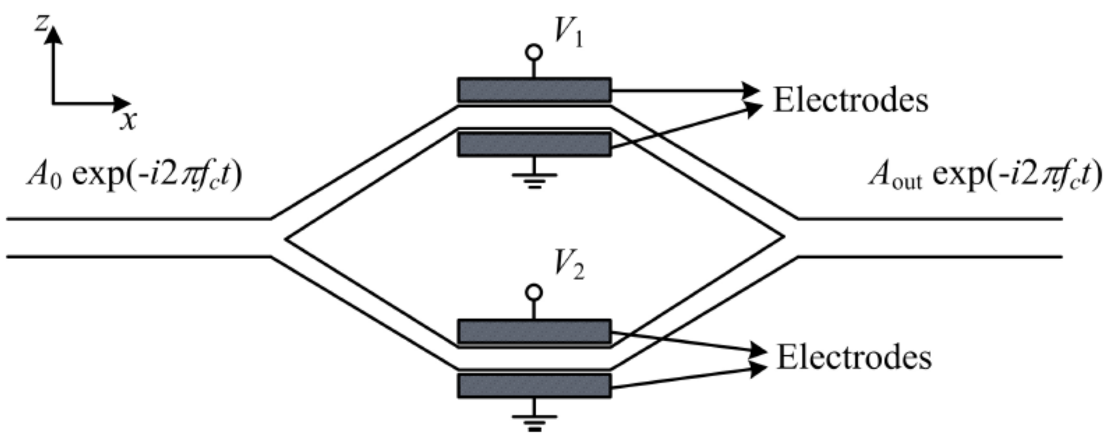


Figure 1. A dual drive mach-zehnder modulator.

input optical beam be,

$$\psi_{int} = A_0 exp(-i2\pi f_c t) \quad (1)$$

where f_c is the frequency of the optical carrier and A_0 is the input amplitude. The output amplitude of the modulator is,

$$A_{out} = A_0 cos\left\{\left[m(t) - \frac{V_{bias}}{2}\right]\frac{\pi}{V_\pi}\right\} \tag{2}$$

where $m(t)$ is the message signal, V_{bias} is the constant bias voltage and V_π is the switching voltage. The power output is,

$$P_{out} = P_0 cos^2\left\{\left[m(t) - \frac{V_{bias}}{2}\right]\frac{\pi}{V_\pi}\right\} \tag{3}$$

where $P_0 = A_0^2$.

Optical Realization of Modulation Schemes

The optical ASK signal can be generated using a Mach-Zehnder modulator (MZM), as shown in Fig. 2. The optical power of the MZM output may be written as (Eq. (3)),

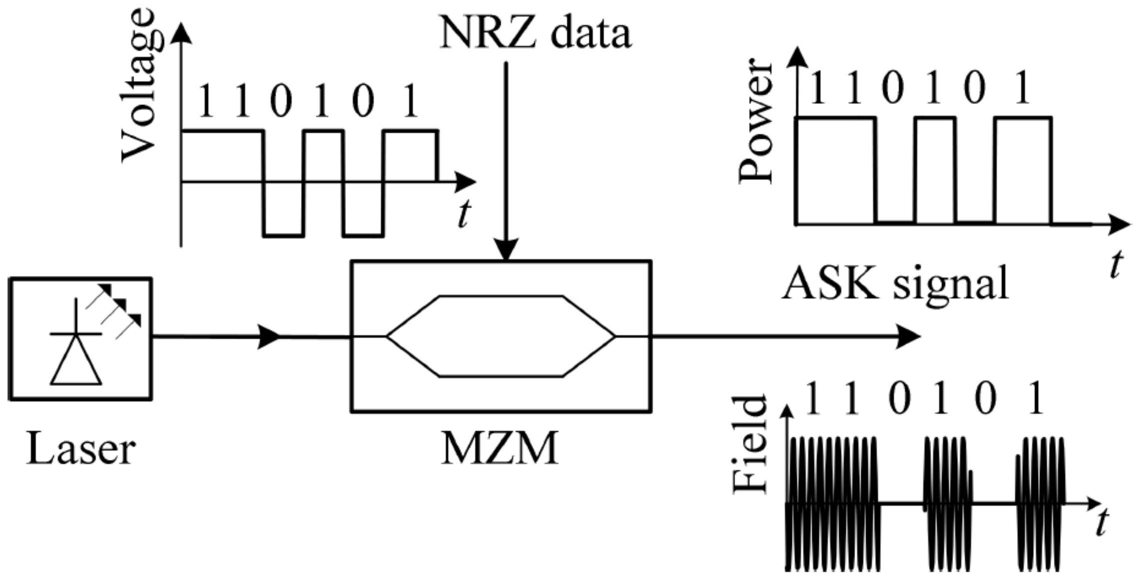


Figure 2. Generation of ASK signal using a MZM.

$$P_{out} = P_0 cos^2 \left[\frac{m(t)\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi}\right]. \tag{4}$$

Let the message signal be a polar NRZ,

$$m(t) = \begin{cases} +V \text{ for bit } '1' \\ -V \text{ for bit } '0' \end{cases} \tag{5}$$

The desired Mach-Zehnder output power is,

$$P_{out} = \begin{cases} P_{out} \text{ for bit } '1' \\ 0 \quad \text{ for bit } '0' \end{cases} \tag{6}$$

For bit $'1'$, substituting Eq. (5) in Eq. (4) and using Eq. (6), we obtain,

$$P_0 cos^2 \left[\frac{m(t)\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi}\right] = P_0$$

$$\frac{V\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi} = j\pi, \quad j = 0, \pm 1, \pm 2, \cdots \tag{7}$$

Similarly, for bit $'0'$,

$$P_0 cos^2 \left[\frac{m(t)\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi}\right] = 0$$

$$\frac{-V\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi} = \frac{l\pi}{2}, \quad j = 0, \pm 1, \pm 3, \cdots \tag{8}$$

Subtracting Eq. (8) from Eq. (7), we find,

$$V = \left(j - \frac{l}{2}\right)\frac{V_\pi}{2} \tag{9}$$

Addition of Eqs. (7) and (8) leads to,

$$V_{bias} = -\left(j + \frac{l}{2}\right)V_\pi \tag{10}$$

If we choose j = 0 and $l = -1$, we find,

$$V = \frac{V_\pi}{4} \tag{11}$$

$$V_{bias} = \frac{V_\pi}{2} \tag{12}$$

Thus, polar NRZ in electrical domain becomes unipolar NRZ in optical domain, as shown in Fig. 2. The process of modulation can be visualized using Fig. 3. When $V = V_\pi/4$ corresponding to bit $'1'$, the constructive interference occurs and MZM power transmission is at its peak. When $V = -V_\pi/4$, the destructive interference occurs and MZM power output is zero.

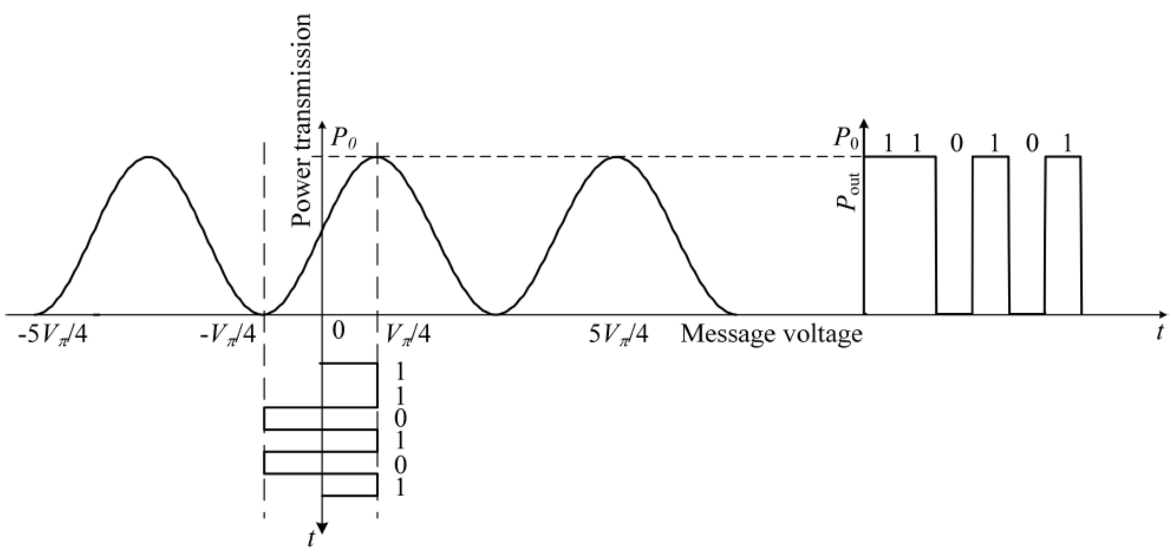


Figure 3. Power transmission function of the MZM. $V_{bias} = V_\pi/2$.

0.0.1 Phase Shift Keying (PSK)

The optical field envelope of the MZM output can be written as (Eq. (2)),

$$A_{out} = A_0 \cos\left[\frac{m(t)\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi}\right] \tag{13}$$

Let the message signal be a polar NRZ given by Eq. (5). The desired field envelope of the Mach-Zehnder output is,

$$A_{out} = \begin{cases} +A_{out} & \text{for bit } '1' \\ -A_{out} & \text{for bit } '0' \end{cases} \tag{14}$$

For bit $'1'$, substituting Eq. (5) in Eq. (13) and using Eq. (14), we obtain,

$$A_0 cos\left[\frac{V\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi}\right] = A_0$$

$$\frac{V\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi} = 2j\pi, \quad j = 0, \pm1, \pm2, \cdots \tag{15}$$

Similarly, for bit $'0'$, we have,

$$A_0 cos\left[\frac{-V\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi}\right] = -A_0$$

$$\frac{-V\pi}{V_\pi} - \frac{V_{bias}\pi}{2V_\pi} = (2l+1)\pi, \quad j = 0, \pm1, \pm2, \cdots \tag{16}$$

Simplifying Eqs. (15) and (16), we obtain,

$$V = \frac{[2(j-1)-1]V_\pi}{2}$$

$$V_{bias} = -[2(j+1)+1]V_\pi \qquad (17)$$

If we choose j = 0 and $l = -1$, $V = V_\pi/2$ and V_{bias}= V_π. Fig. 4 shows the schematic of the PSK signal generation. Fig. 5 shows the MZM field transmission as a function of message signal m(t). When the message signal $m(t) = +V_\pi/2$, the field transmission is maximum and when $m(t) = -V_\pi/2$, it is minimum. Note that the field envelope is negative (π phase) for bit $'0'$ and it is positive (0 phase) for bit $'1'$. However, the power which is the absolute square of the field remains constant for both bit $'0'$ and bit $'1'$.

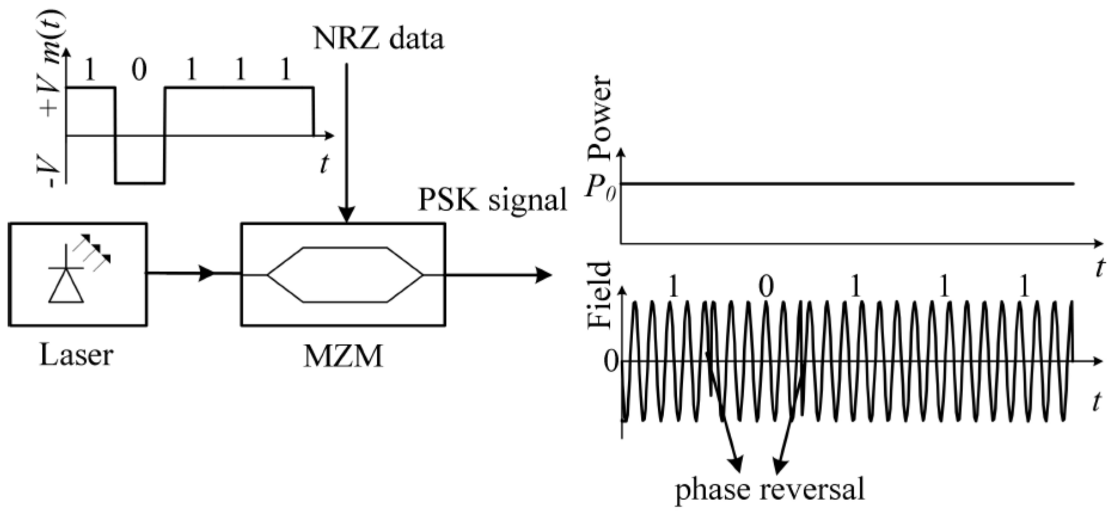


Figure 4. Generation of optical PSK signal.

The PSK with NRZ rectangular pulses is a constant power signal and there is a reversal of phase at the bit boundaries when the data changes from ′0′ to ′1′ and vice versa.

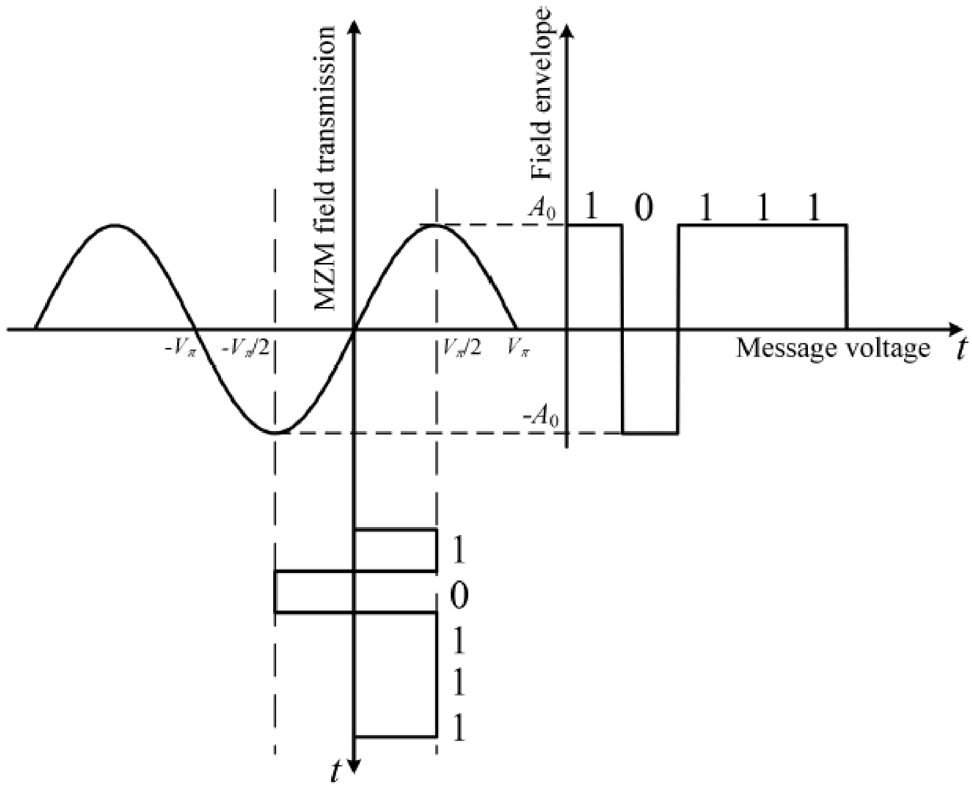


Figure 5. MZM field transmission. $V_{bias} = V_\pi$.

Company Researchers & Developers

Integrate the Modules with your in-house and Commercial Software & Hardware Products

(1) Modify the Source Code Modules / Components to the Next Level for Your Research Papers, Research Projects and Theses.

(2) Integrate Different Source Code Modules / Components in the OCSim Package to Realize Your Own Fiber Optic Communication Systems.

(3) Use the Existing Source Code Modules / Components for Your Research Papers, Research Projects and Theses.

(4) Use the Existing Source Code Modules for Laboratory Simulation Experiments and Exercises.

Simulation of QPSK – Nyquist Optical Transmitter

IQ MZM

Source Code File

Main File : Optical tx_qpsk_nyquist.m

QPSK transmitter that uses raised-cosine pulses in frequency domain is simulated. It is assumed that MZM nonlinearity is compensated by transmitter DSP so that the real part of (imaginary part of) complex optical field envelope is directly proportional to the in-phase (quadrature) component of the driving voltage.

The main file calls the following functions:

power_meter.m: calculates the average optical power in dBm units

raised_cosine freq.m: modulates the output of the laser with raised-cosine pulse in frequency domain

eye_diagram.m: plots the eye diagram of the optical power.

Explore Further this Module:

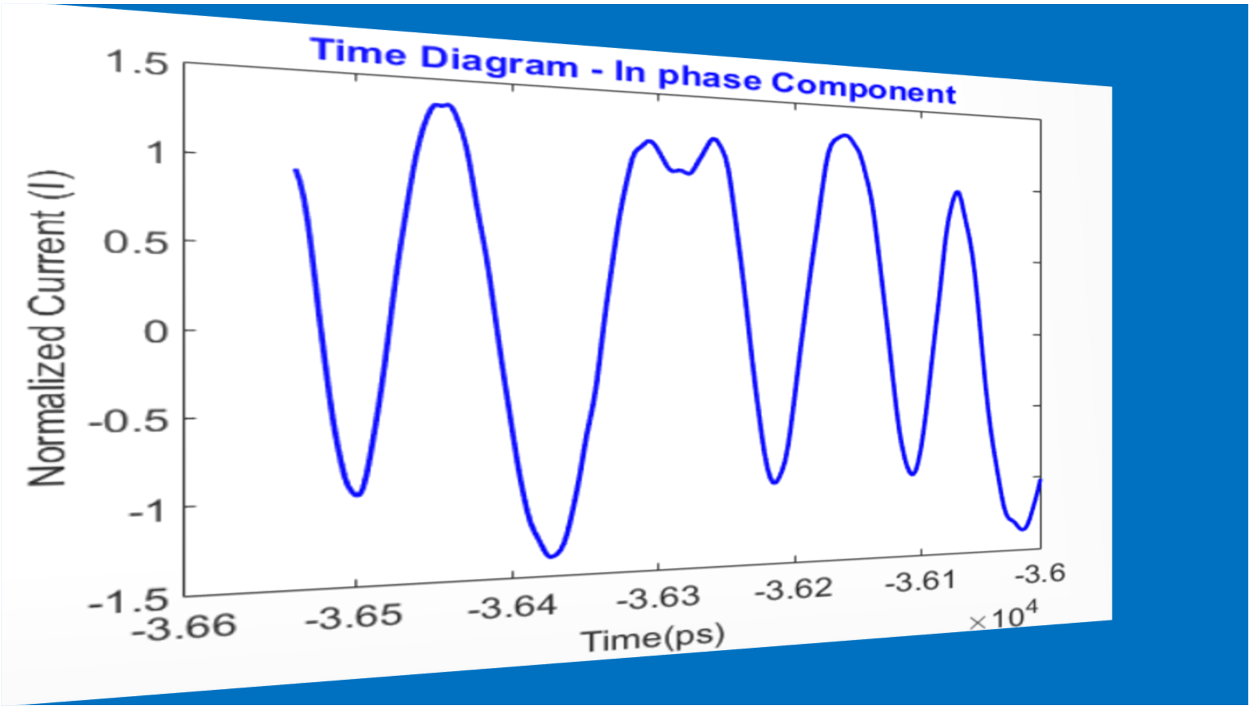
1. **Change** the roll-off factor from 0.3 to 1 and **observe** the spectral width change.

2. **Change** the noise variances of optical and electrical components and **observe** the constellation diagram.

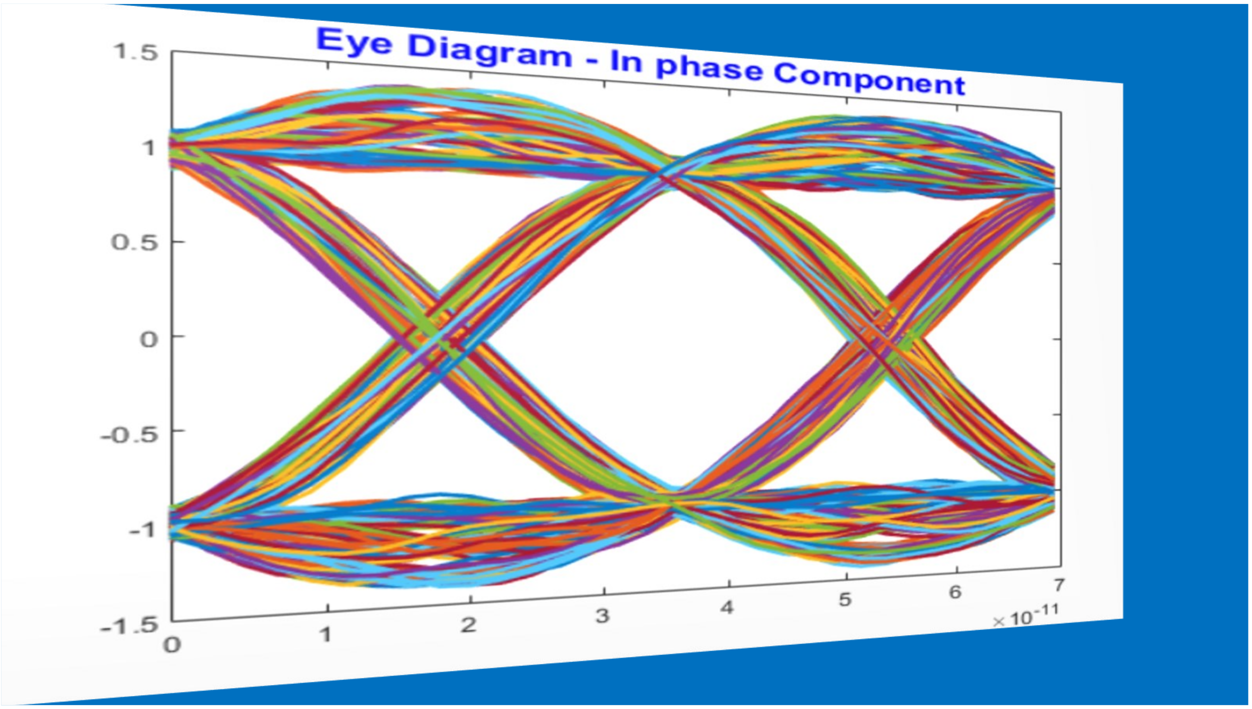
3. **Modify** the code to realize 16-QAM.

Selected Simulated Results Using this Module

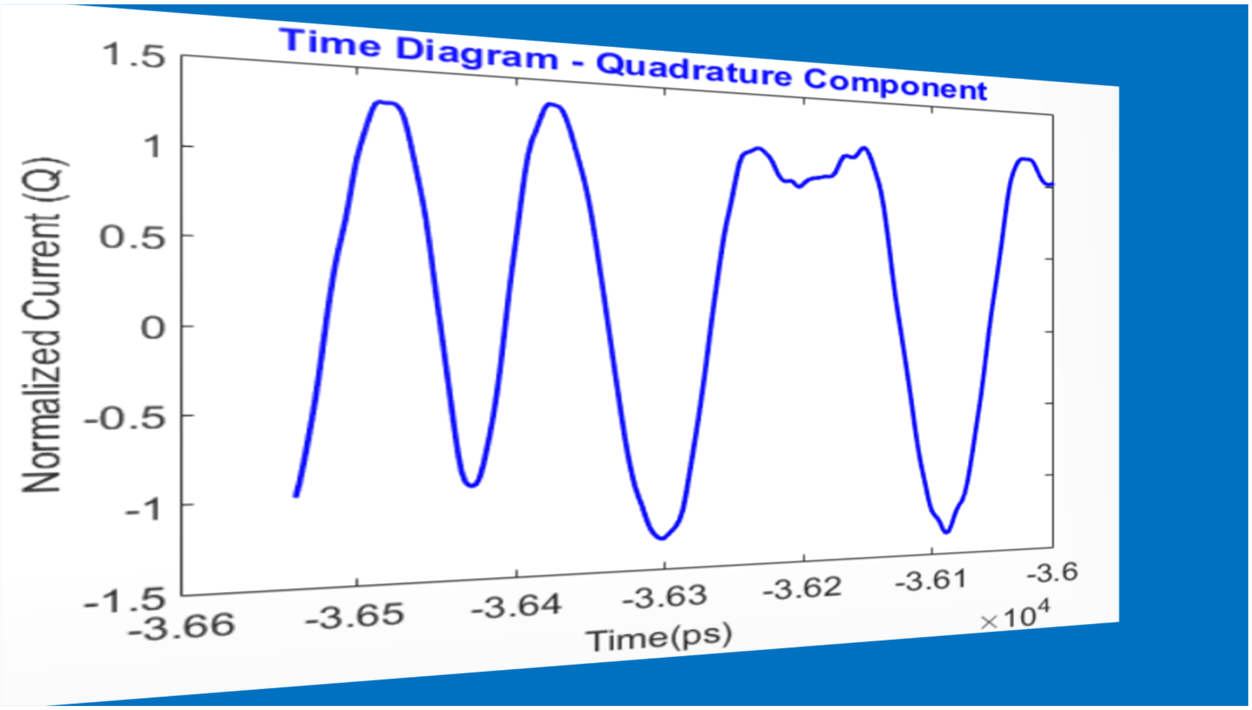
Time Diagram – In phase Component



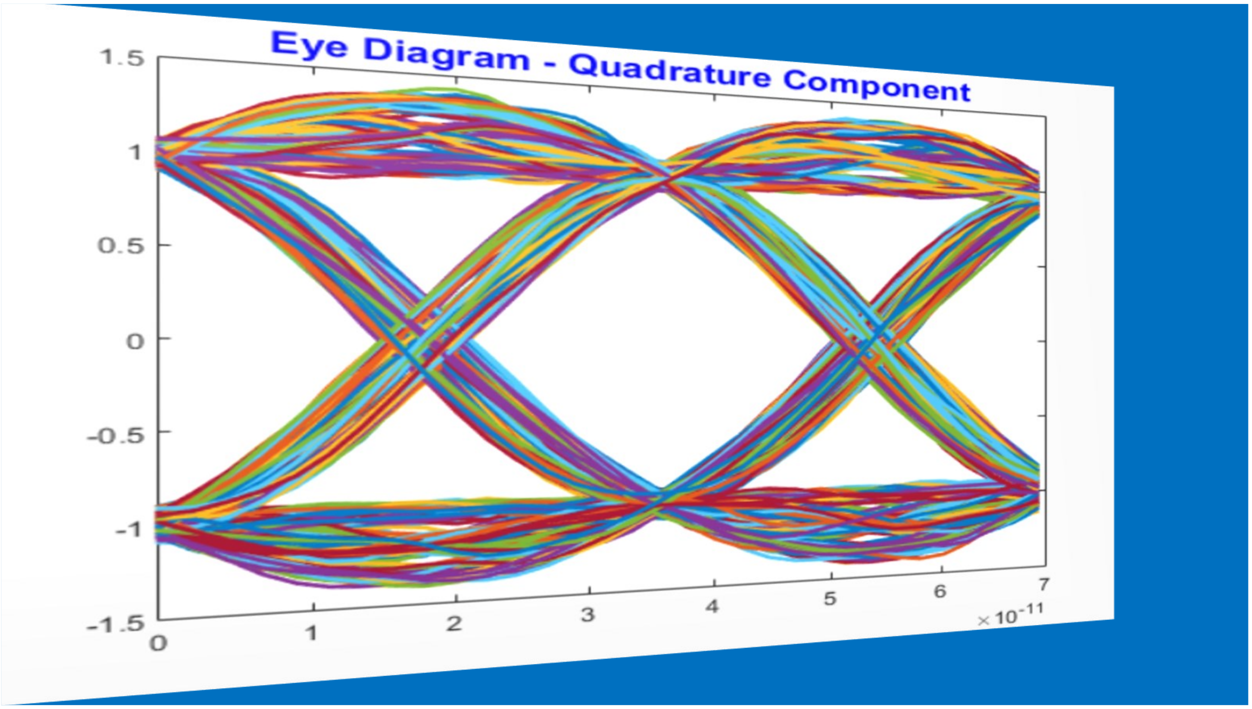
Eye Diagram – In phase Component



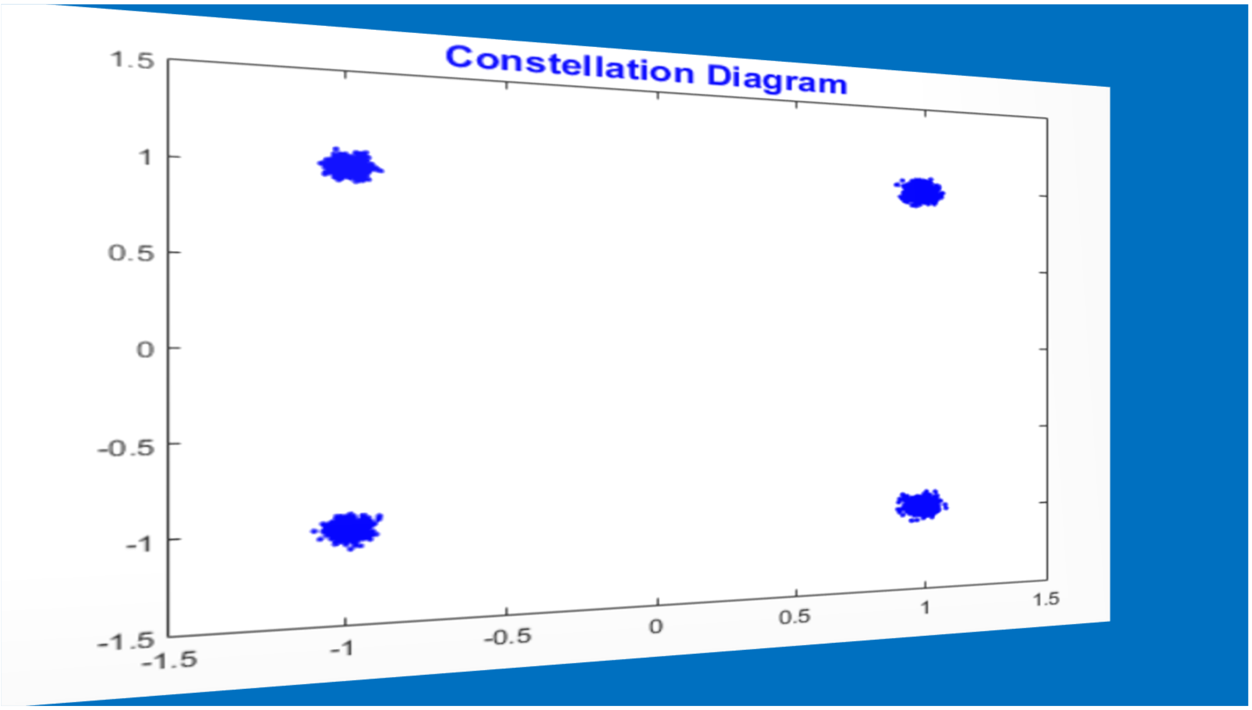
Time Diagram – Quadrature Component



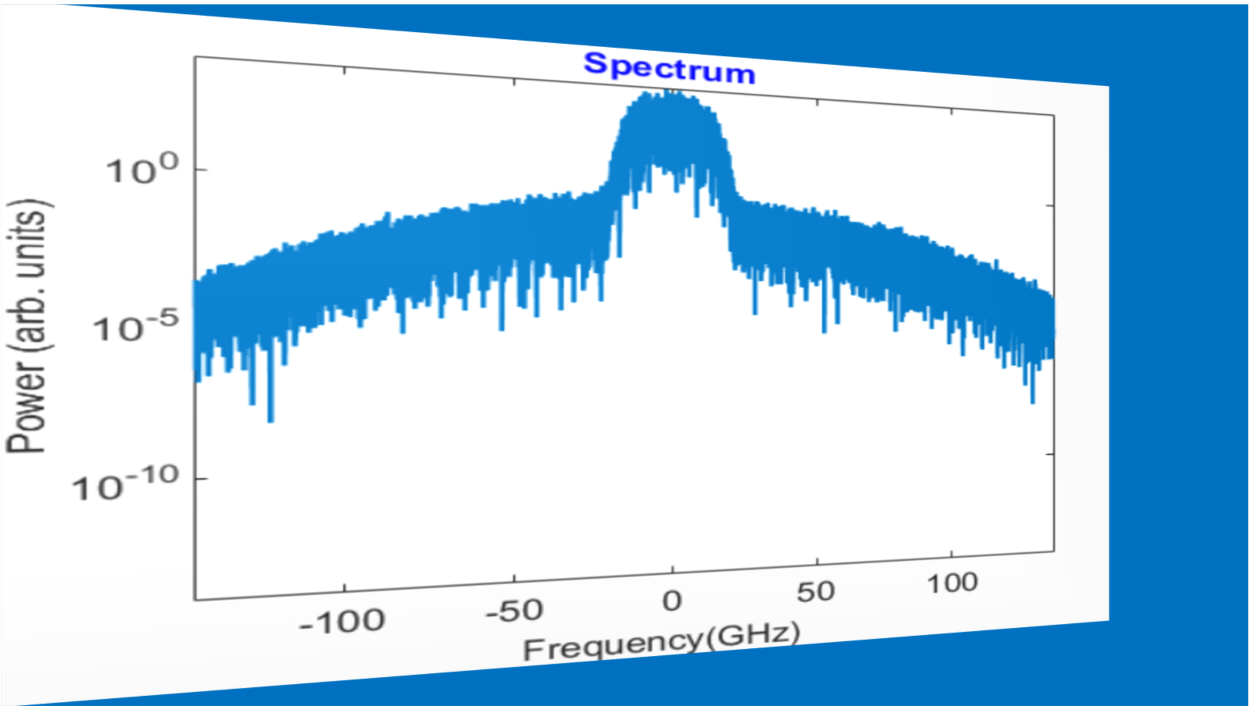
Eye Diagram – Quadrature Component



Constellation Diagram



Spectrum


Spectrum
Power (arb. units)
10^0
10^{-5}
10^{-10}
-100
-50
0
50
100
Frequency(GHz)

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