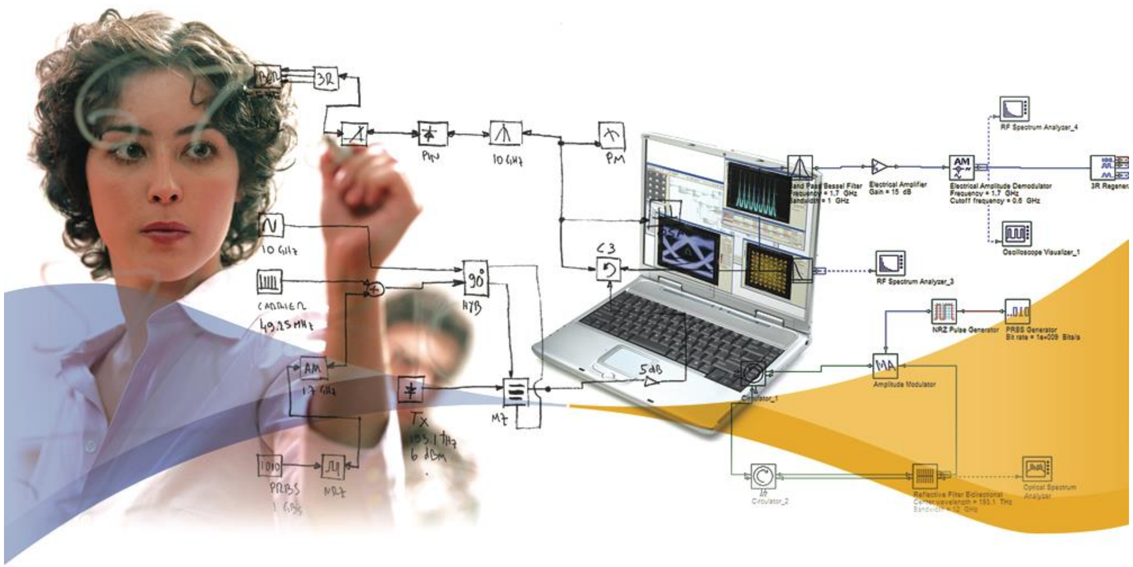

OptiSystem applications:
Optical coherent DSP overview

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Universal DSP (1)

- OptiSystem's **Universal DSP** component performs digital domain impairment compensation to aid in recovering the incoming transmission signal after coherent detection. It supports the following higher order modulation formats:
  - BPSK, QPSK, 8PSK, 16PSK
  - 8QAM, 16QAM, 32QAM, 64QAM, 128QAM, 256QAM

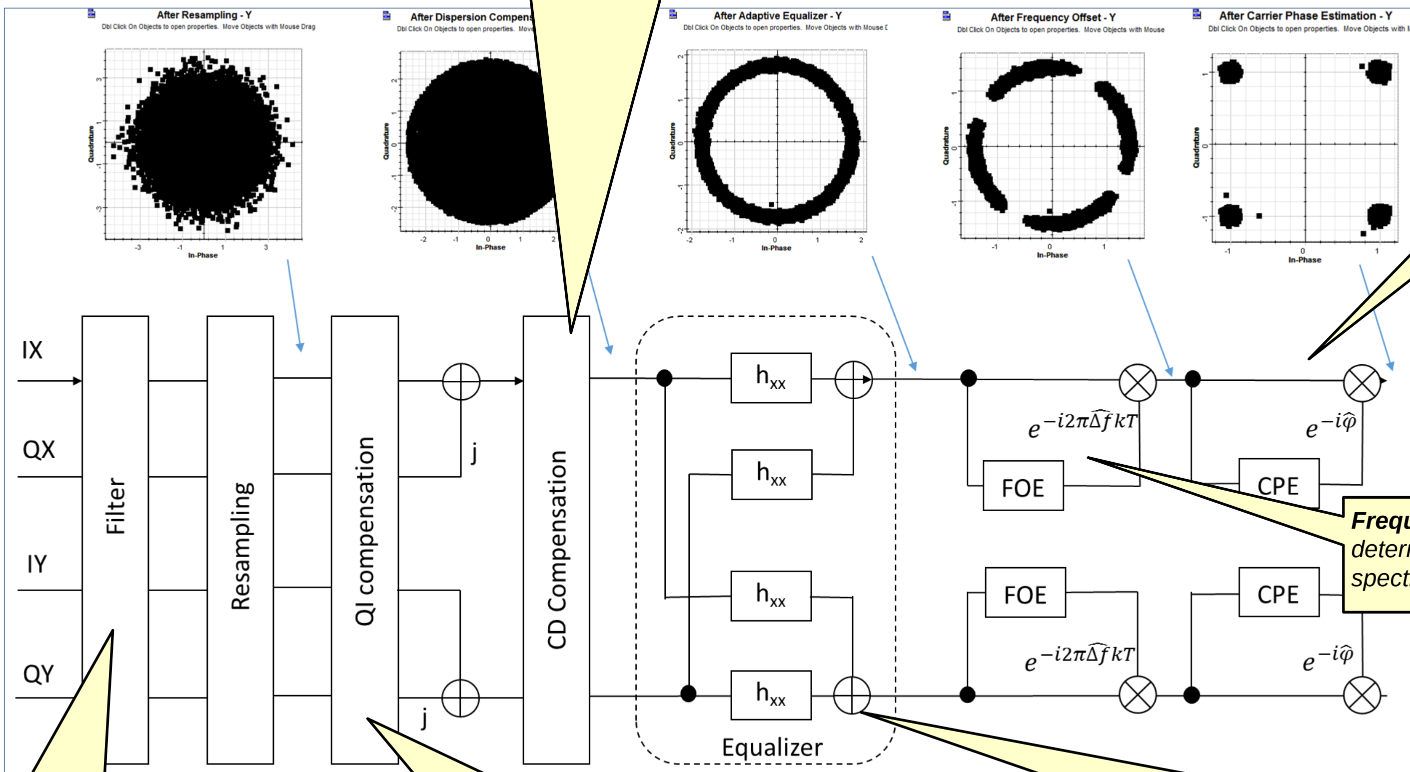
  Note: For QAM modulation formats; square, star, and circular constellation formats are supported.
- The Universal DSP component includes 13 functions and algorithms starting with a preprocessing stage (3 functions) followed by the signal recovery stage (10 functions and algorithms):
  - Preprocessing stage (Samples/Symbol = (4 or 8) x Samples per bit)
    - Add Noise to signal
    - DC Blocking and Normalization
  - Main algorithms stage:
    - Filter (Samples/Symbol = (4 or 8) x Samples per bit)
    - Resampling (Samples/Symbol = 2)
    - Quadrature Imbalance (QI) Compensation (Samples/Symbol = 2)
    - Chromatic Dispersion (CD) Compensation (Samples/Symbol = 2)
    - Nonlinear (NL) Compensation (Samples/Symbol = 2)
    - Timing Recovery (Samples/Symbol = 2)
    - Adaptive Equalizer - AE (Samples/Symbol = 2)
    - Down-sampling (Samples/Symbol = 1)
    - Frequency Offset Estimation - FOE (Samples/Symbol = 1)
    - Carrier Phase Estimation - CPE (Samples/Symbol = 1)

***Note**: Any of these stages can be disabled or enabled (via check box). If desired, a custom algorithm stage can be added between any stage (C++, MATLAB, Python)*

Universal DSP (2)

Digital filtering (time or freq.) can be used to compensate for ***chromatic dispersion***. ***Nonlinear compensation*** *is also performed using a digital back propagation (BP) method*

Carrier phase estimation*: The blind phase search (BPS) algorithm is used to recover and remove the remaining phase mismatch between the local oscillator and the signal.*

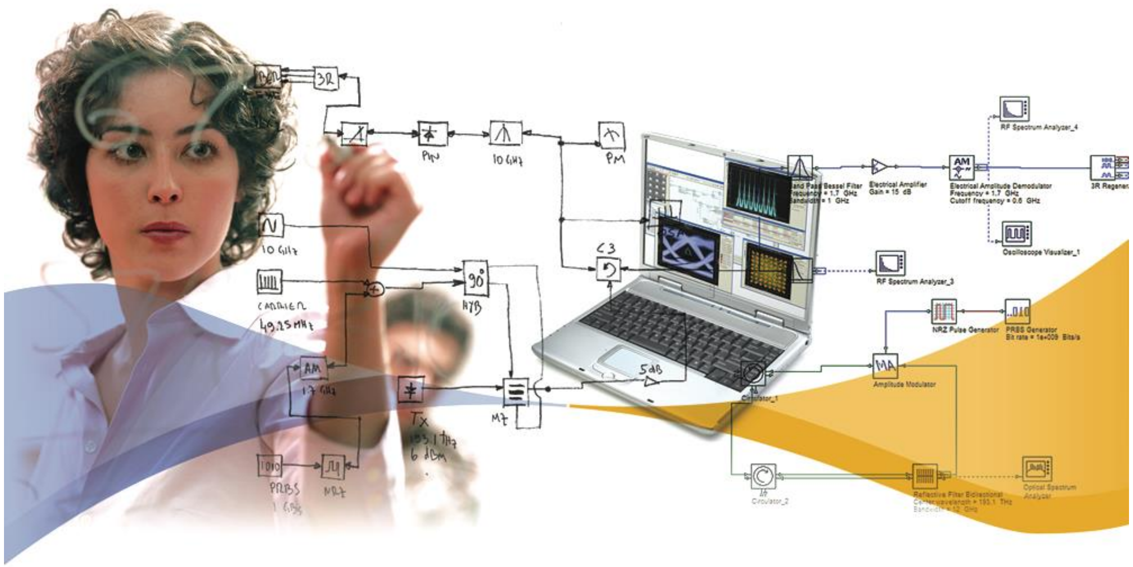


Frequency offset estimation*: Used to determine ∆f based on a feedforward spectral estimation method*

A filter can be applied to help in removing out of band noise

QI compensation *is used to mitigate amplitude and phase imbalances within the in-phase (I) and quadrature (Q) signals.*

The ***adaptive equalizer*** *is used to compensate for residual chromatic dispersion, polarization mode dispersion (PMD) and to reduce inter-symbol interference. For dual-polarization systems, the butterfly structure is used for polarization demultiplexing.*



QPSK back-to-back analysis

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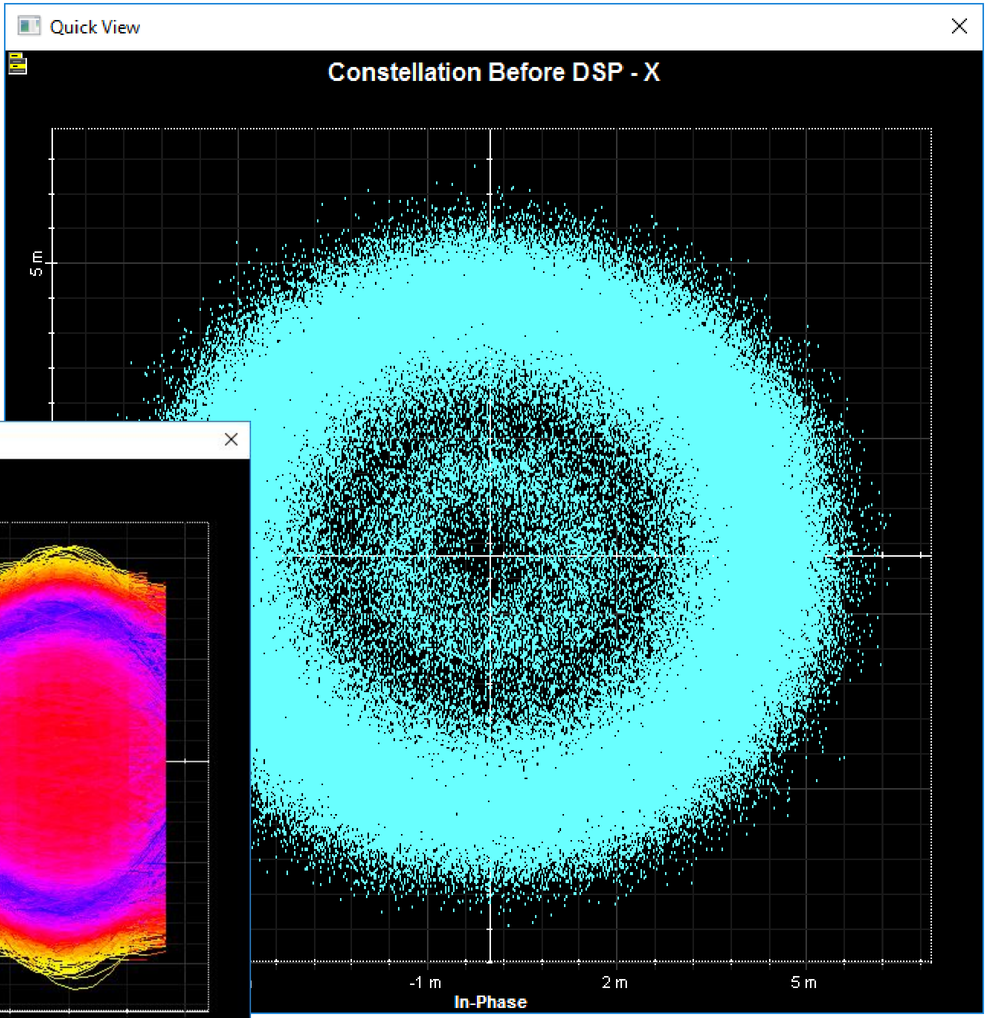
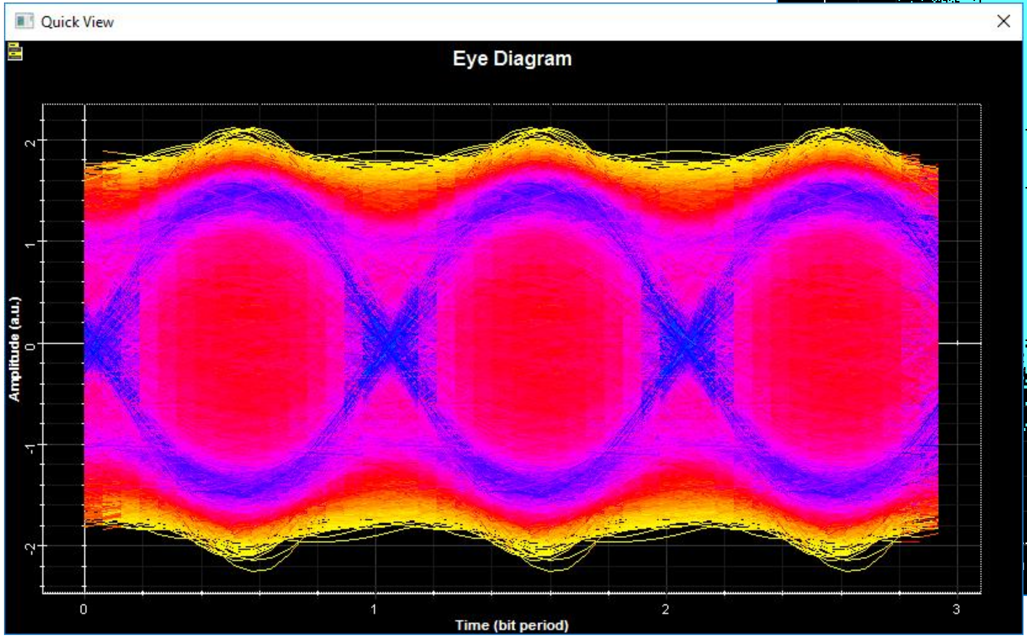
QPSK constellation (before DSP)

QPSK B2B

- This is the IQ constellation before pre-processing
- The total number of samples is equal to the binary sequence length (65536) x Number of samples per bit (4): 262144
- The receiver eye is shown for the I-X channel (after DSP 1, before resampling)





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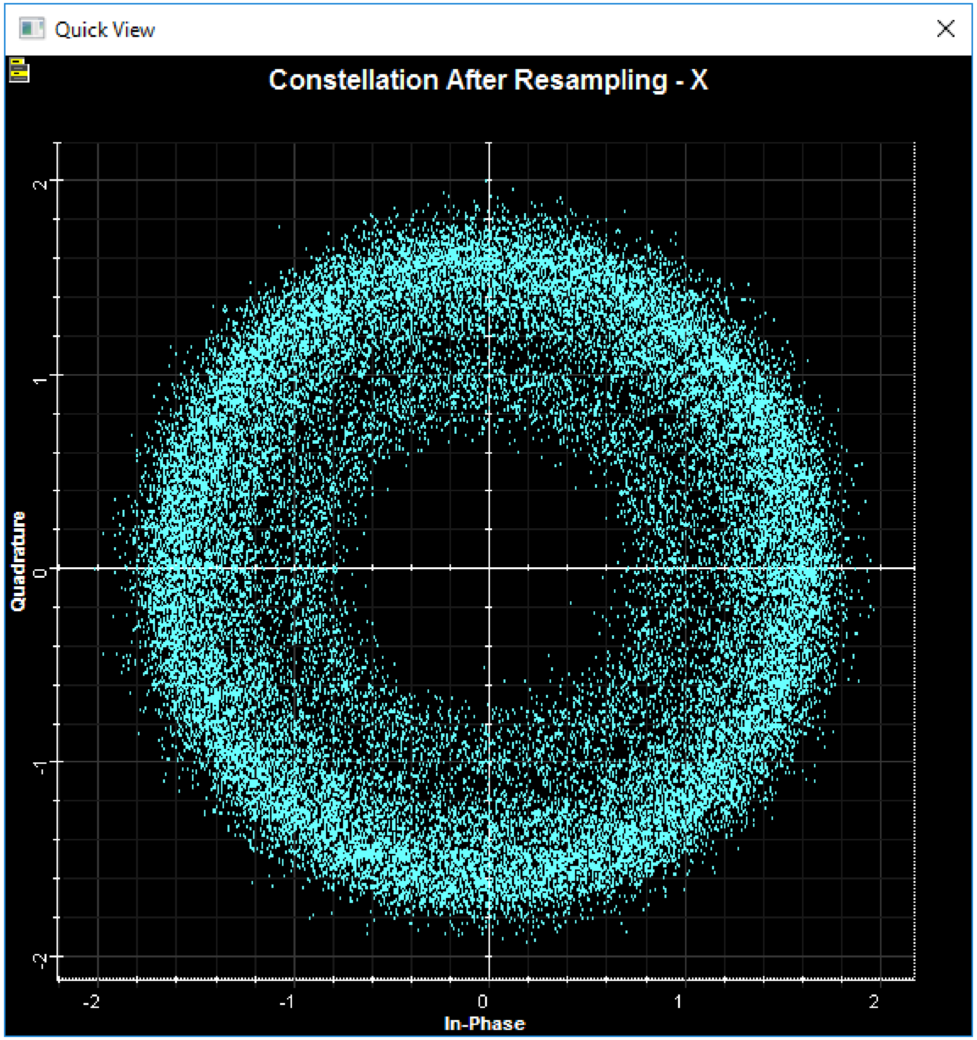
QPSK constellation (after resampling)

QPSK B2B

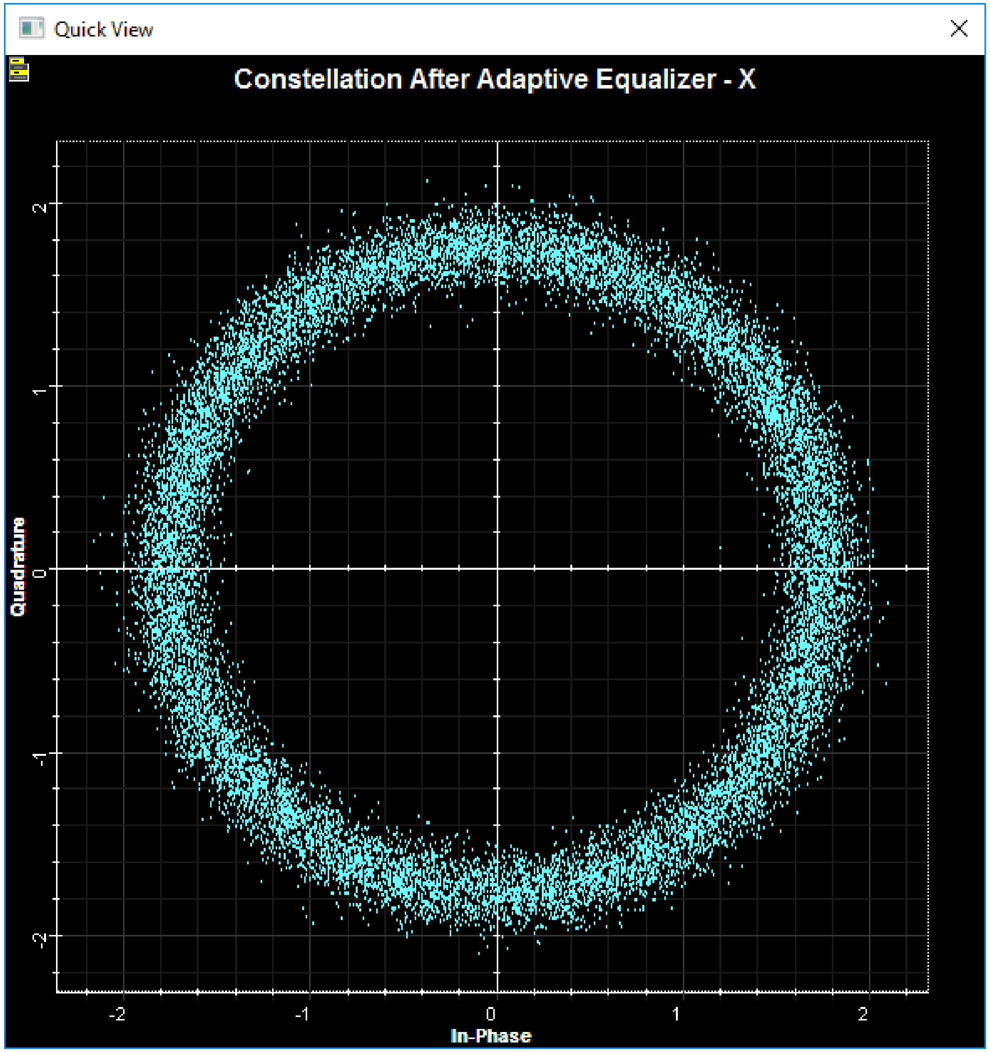
- Prior to re-sampling the following stages are performed:
  - **Add noise to signal**: Any noise source (noise bin) that falls within the bandwidth of the transmission channel will be converted into a signal and added to the optical sampled signal.
  - **DC Blocking**: DC Blocking is applied to offset any imperfectly biased voltages in the modulators.
  - **Normalization**: The received signal is normalized to the appropriate m-QAM or m-PSK grid
  - **Filter stage**: Filtering can be applied to remove out of band noise
- The input sampled signal is re-sampled at a rate of 2 samples/symbol. Interpolation is used to adapt the sampled signal waveform to the new sampling rate (linear, cubic, or step)
- The 1st and N/2+1 sampled signals are used for re-sampling (where N = Samples per symbol).



QPSK constellation (after AE)

QPSK B2B

- The adaptive equalizer is used to compensate for residual chromatic dispersion, polarization mode dispersion (PMD) and to reduce inter-symbol interference. For dual-polarization systems, the butterfly structure is used for polarization demultiplexing.
- The two-stage constant modulus-radius directed (CMA-RD) algorithm is used
- Down-sampling to 1 sample/symbol is performed after AE



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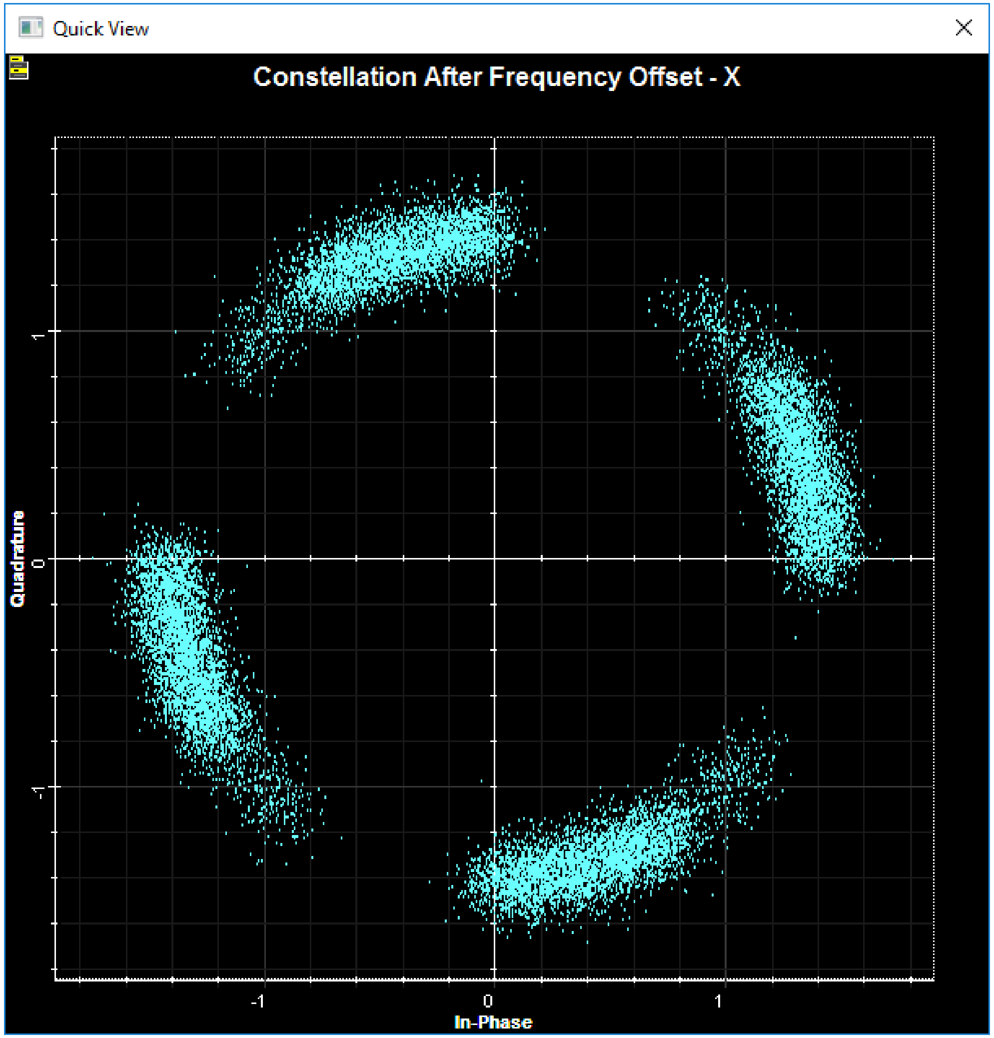
QPSK constellation (after FOE)

QPSK B2B

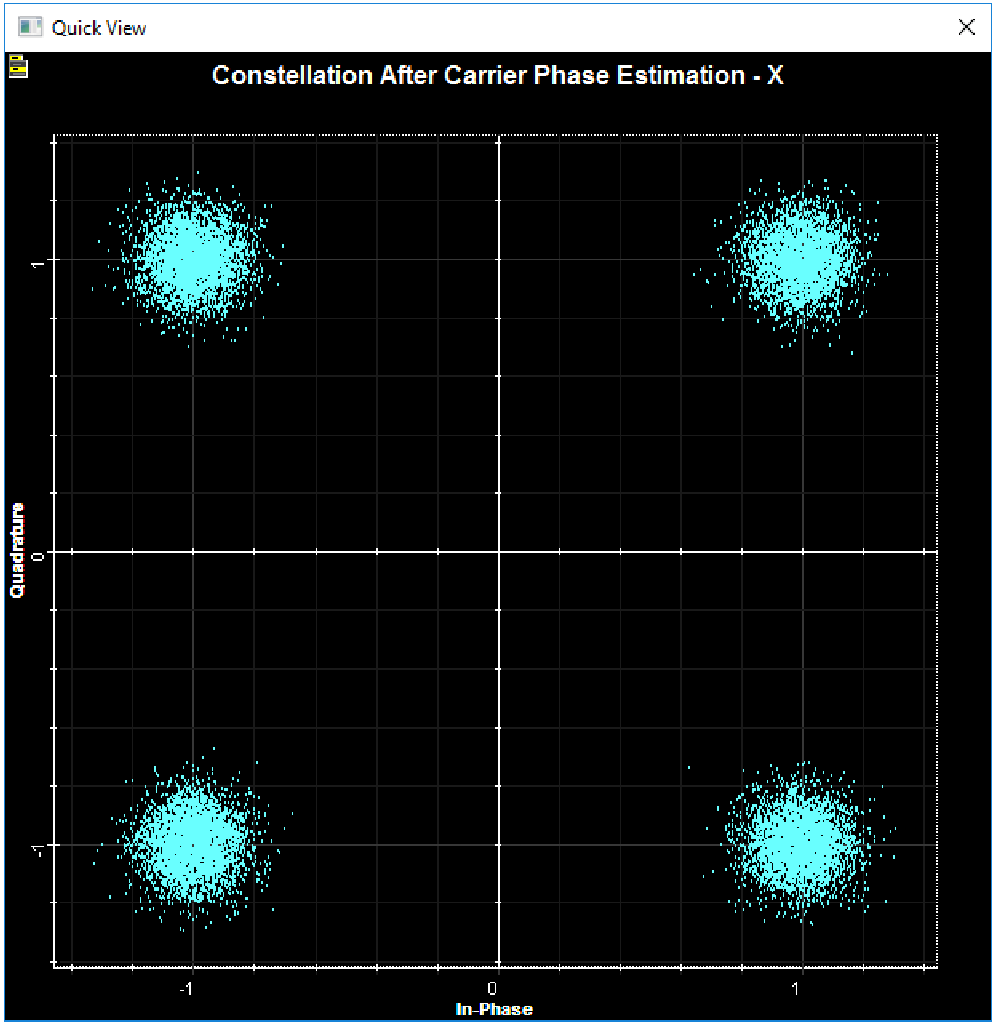
- The mixing with the local oscillator introduces a frequency and phase offset, leading to a rotating constellation diagram.
- A spectral based, feedforward method is used to estimate the frequency offset (by maximizing the periodogram of the power order of the received signal: 4 for QPSK/16QAM & 8 for 8PSK/64QAM)

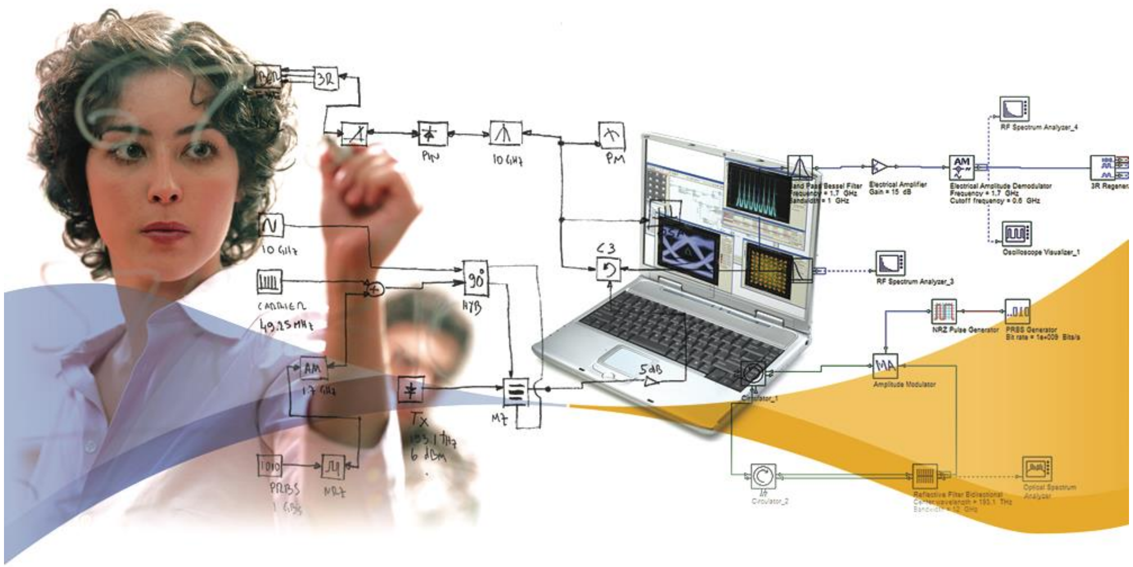


QPSK constellation (after CPE)

QPSK B2B

- **Carrier phase estimation**: The blind phase search (BPS) algorithm is used to recover and remove the remaining phase mismatch between the local oscillator and the signal.
- Several test phases are applied and the estimated phase is selected from the minimum distance sum obtained between the rotated symbols and the test phases





QPSK transmission example

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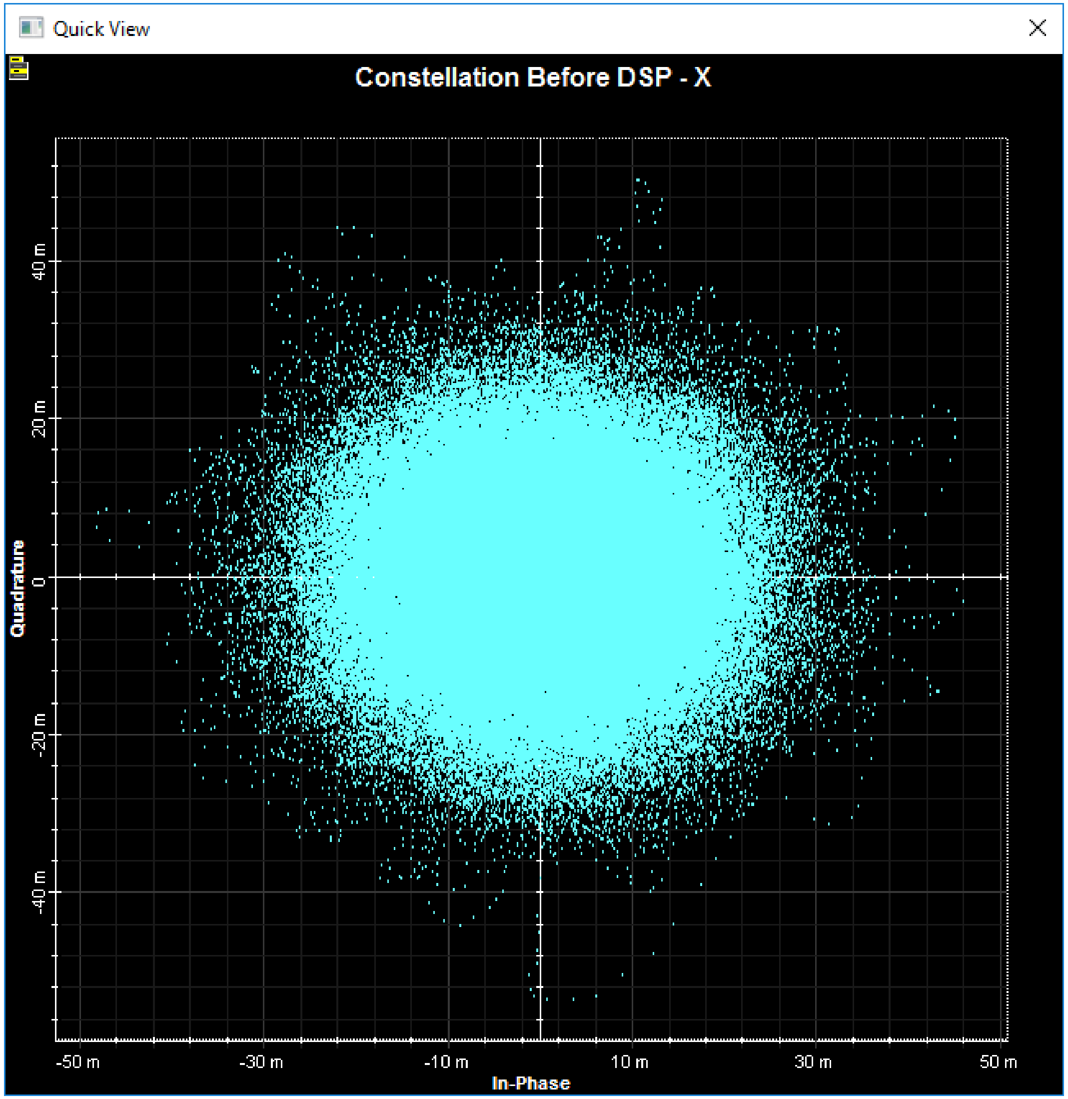
QPSK constellation (before DSP)

QPSK 160 km

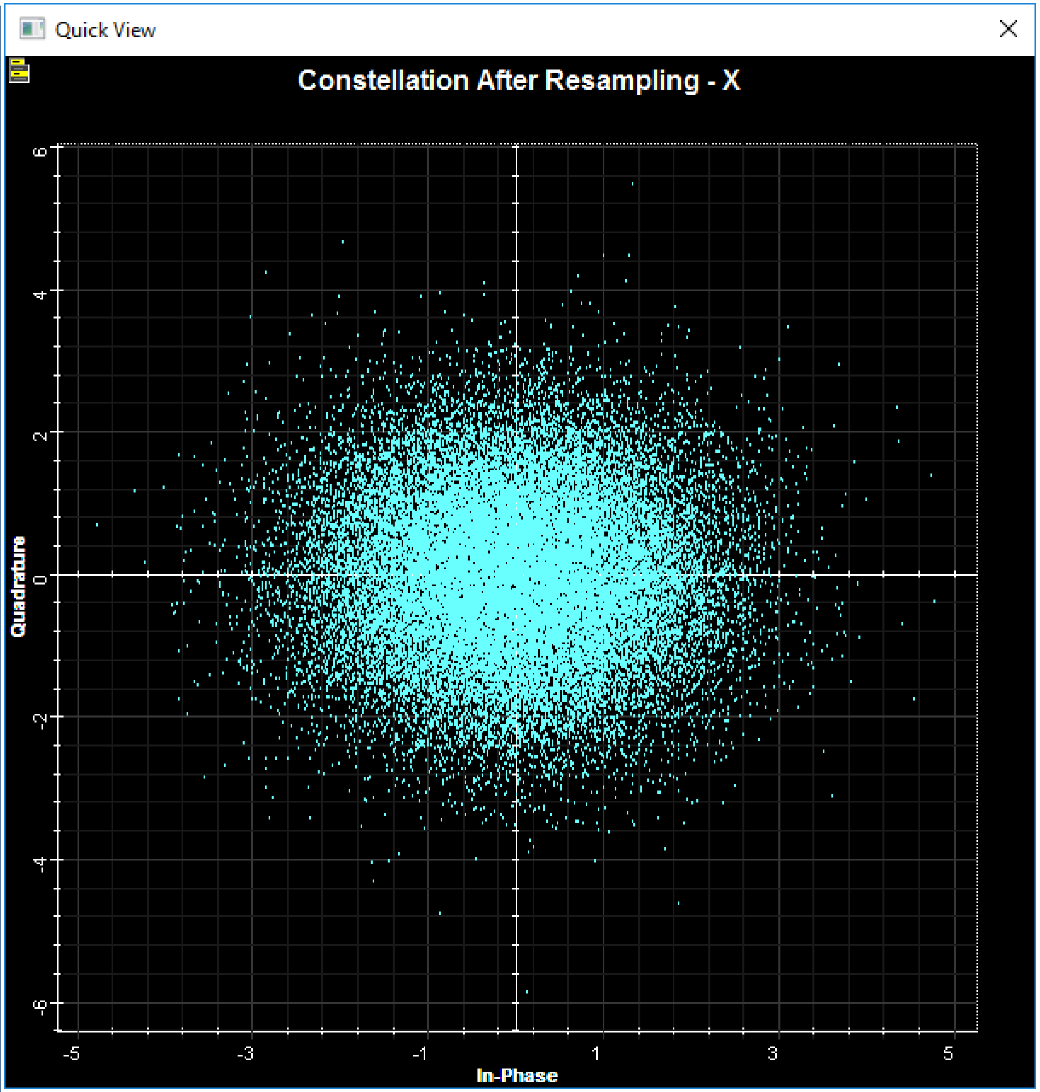
- This is the IQ constellation before pre-processing
- The total number of samples is equal to the binary sequence length (65536) x Number of samples per bit (4): 262144



QPSK constellation (after resampling)

QPSK 160 km

- Prior to re-sampling the following stages are performed:
  - **Add noise to signal**: Any noise source (noise bin) that falls within the bandwidth of the transmission channel will be converted into a signal and added to the optical sampled signal.
  - **DC Blocking**: DC Blocking is applied to offset any imperfectly biased voltages in the modulators.
  - **Normalization**: The received signal is normalized to the appropriate m-QAM or m-PSK grid
  - **Filter stage**: Filtering can be applied to remove out of band noise
- The input sampled signal is re-sampled at a rate of 2 samples/symbol. Interpolation is used to adapt the sampled signal waveform to the new sampling rate (linear, cubic, or step).
- The 1st (Value = a) and N/2+1 (Value = b) sampled signals are used for re-sampling (where N = Samples per symbol).



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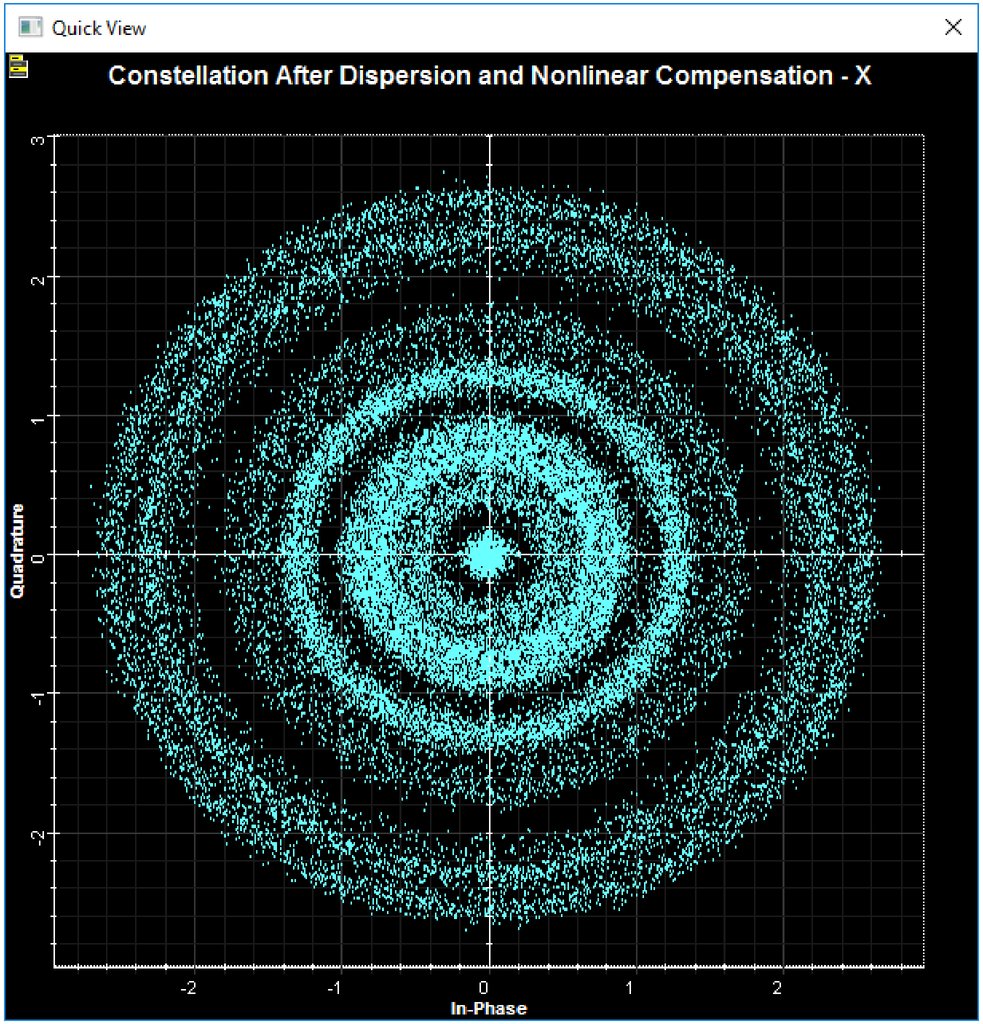
QPSK constellation (after CD)

QPSK 160 km

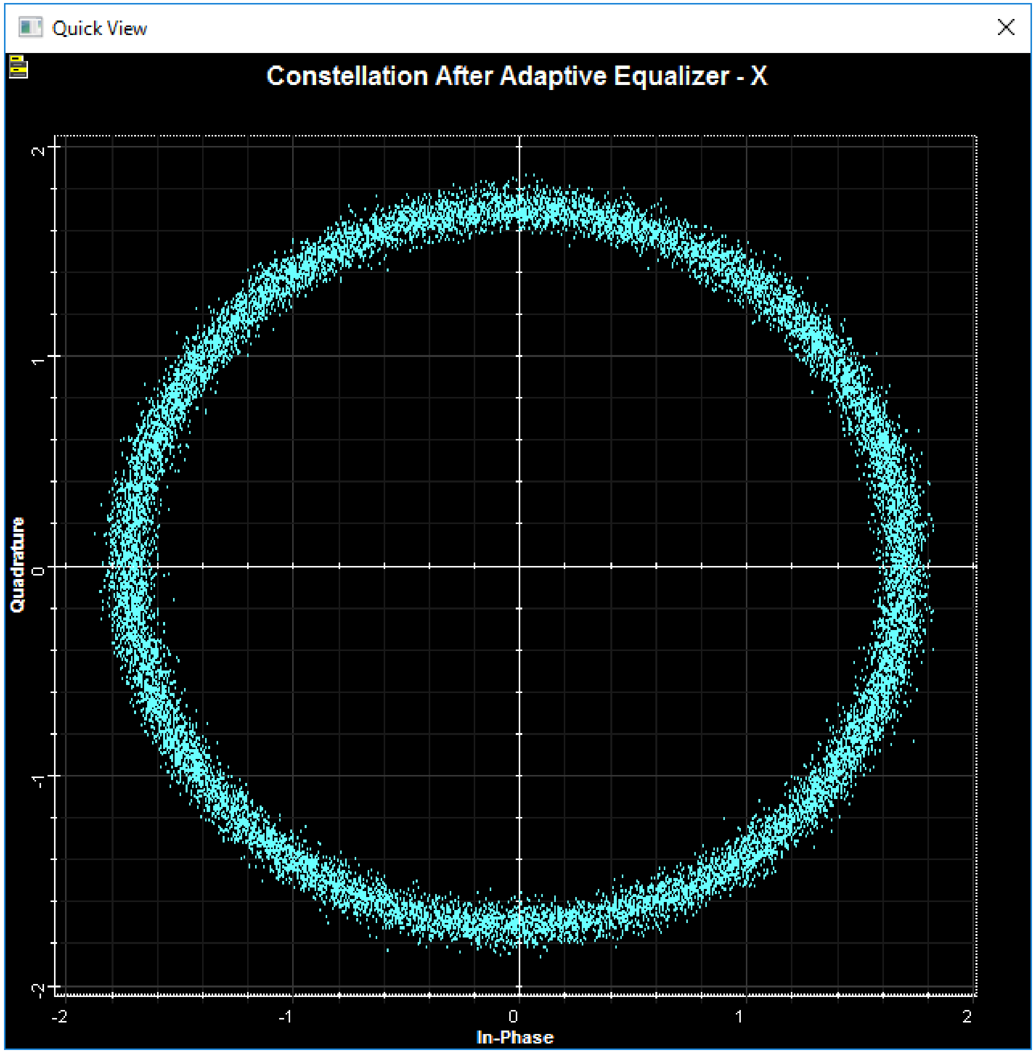
- **Chromatic dispersion** is a static, polarization-independent, phenomenon. Digital filtering can be used to compensate for chromatic dispersion resulting from propagation over fiber. The dispersion compensating filter can be implemented in either the frequency domain or time domain
- **Nonlinear compensation** (not enabled here) is performed using a digital back propagation (BP) method. The received signal can be digitally propagated through an inverse fiber model to compensate for CD and fiber nonlinearity.



QPSK constellation (after AE)

QPSK 160 km

- The adaptive equalizer is used to compensate for residual chromatic dispersion, polarization mode dispersion (PMD) and to reduce inter-symbol interference. For dual-polarization systems, the butterfly structure is used for polarization demultiplexing.
- The two-stage constant modulus-radius directed (CMA-RD) algorithm is used



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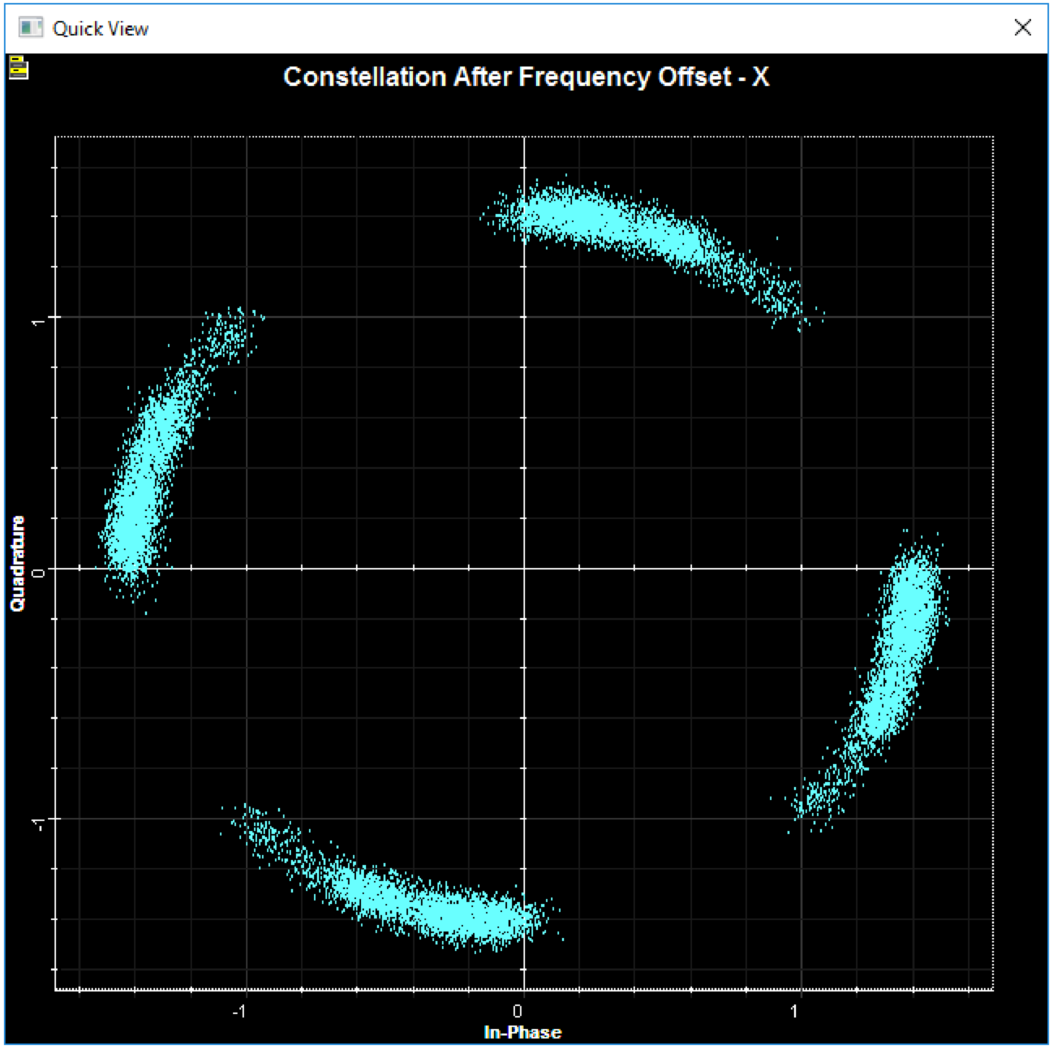
QPSK constellation (after FOE)

QPSK 160 km

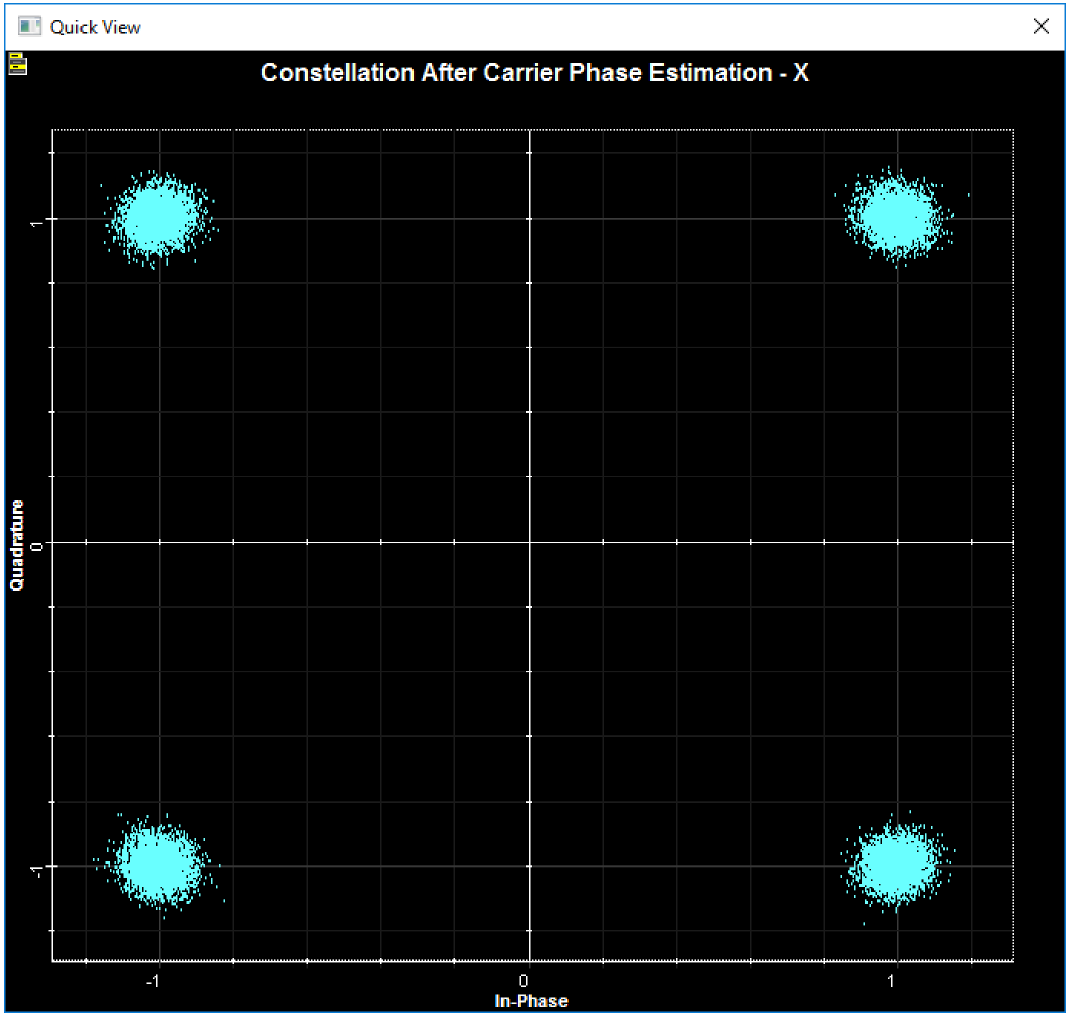
- The mixing with the local oscillator introduces a frequency and phase offset, leading to a rotating constellation diagram.
- Downsampling to



QPSK constellation (after CPE)

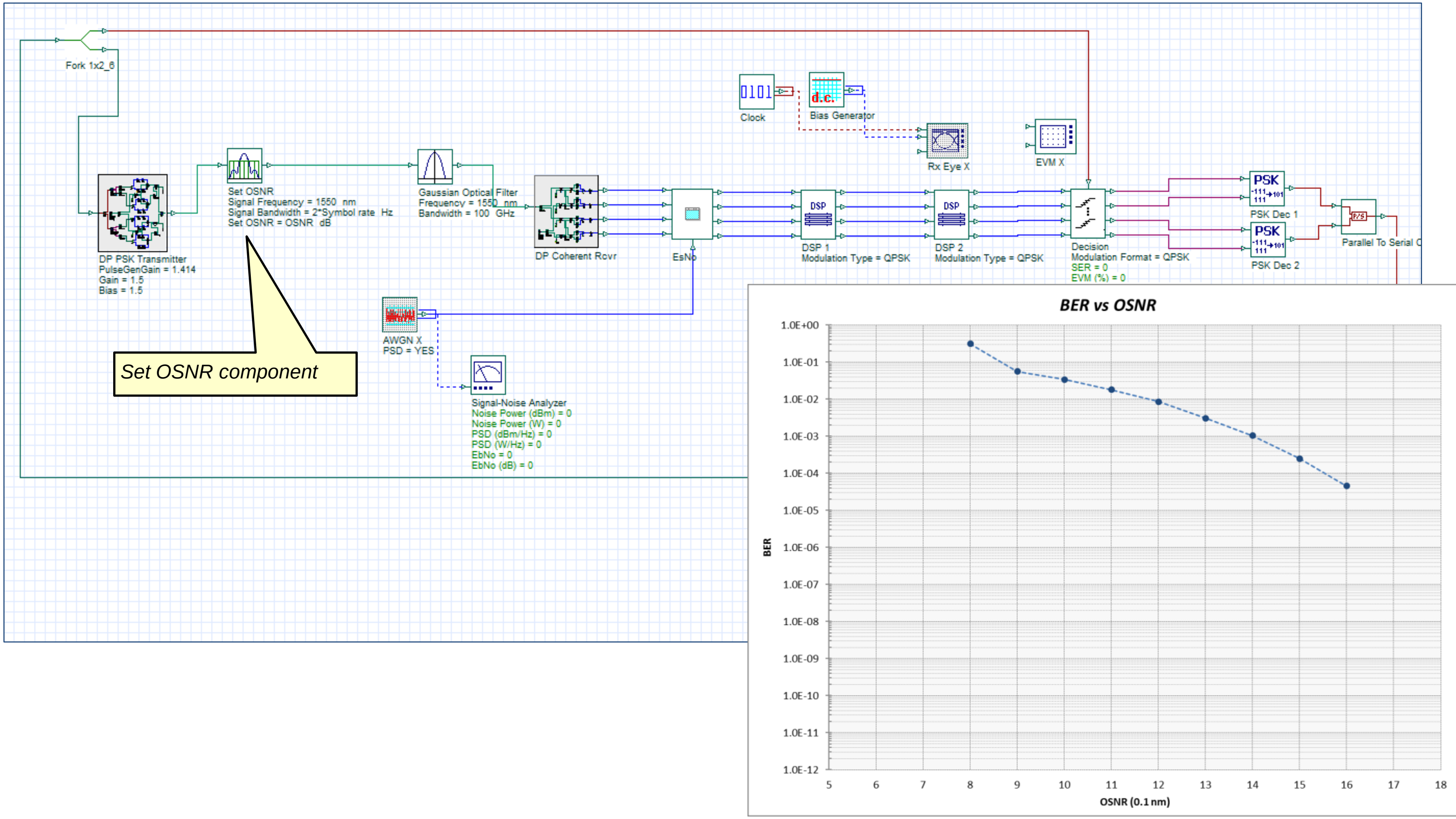
QPSK 160 km

- **Carrier phase estimation**: The blind phase search (BPS) algorithm is used to recover and remove the remaining phase mismatch between the local oscillator and the signal.



BER analysis (OSNR)

- The project “112Gbps Coherent DP-QPSK_B2B with DSP.osd” has been setup to perform BER waterfall curves based on OSNR settings. Simulations can be initiated from the Scripts tab.



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