APPLICATION NOTE

# End-to-End Electrical-Optical-Electrical Flow in Keysight ADS

KEYSIGHT

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# Introduction

Photonics components and optical fibers have become essential elements in modern technologies. With the advent of big data, and AI platforms, the demand for hardware platforms that can accommodate high bandwidth, consume less power, and transmitting data over long distances with minimal signal distortion and loss, increased significantly.

Modern systems, from data centers to telecom networks and AI clusters, need far more bandwidth and far lower power than electrical copper links can provide. Copper interconnects face many limitations such as losing signal integrity over distance, generating heat, consuming large amounts of power, and struggling to scale beyond tens of gigabits per second. On the other hand, optical fibers solve these problems by carrying light instead of electrical current, enabling extremely high data rates over long distances with minimal loss and immunity to electromagnetic interference.

This is why data centers rely heavily on photonics. Connecting thousands of servers, GPUs, and switches at high speeds simply isn't feasible with copper. The same motivations extend to telecom systems, autonomous vehicles, medical imaging, and sensing, all of which depend on the unique advantages of light-based communication.

Because modern systems increasingly depend on photonics, engineers must design systems that convert electrical signals into optical signals and back again to electrical signal (Electrical-Optical-Electrical (EOE)). Every real optical link begins and ends with electrical devices like central processing unit (CPU's), Graphics Processing Units (GPU's) and highspeed serializer/deserializer (SerDes) lanes, so understanding how electrical components interact with optical components is essential to fully evaluate the performance of the system.

This is why we modeled the entire E-O-E flow in Keysight Advance Design System (ADS). Since the development and integration of Photonic Designer into Keysight ADS, the full chain is achieved through many components available in ADS such as the electrical signal generators, the optical modulators or lasers, the optical fiber, the photodiode and TIA, and the electrical receiver along with powerful simulation engines available in the software. By simulating this mixed-domain flow, engineers can evaluate signal integrity, optimize performance, and ensure compliance with highspeed standards long before the hardware implementation is carried out. In short, the global shift toward photonics directly creates the need for accurate and reliable EOE flow modeling, because it is the only way to design reliable, high bandwidth optical systems that meet the demands of modern technologies.

# Understanding Electrical-Optical-Electrical EOE Flow

## Overview

The EOE flow represents the complete end-to-end signal journey in any optical communication system. This section explains how the flow works, what physical mechanisms involved and why co-simulation of electrical and optical domains is crucial for accurate system design.

EOE flow is a chain of connected subsystems that are governed by different physical mechanisms such as electromagnetics, semiconductors, photonics and high speed digital signal processing. The EOE link consists of three parts, as it is shown in Figure 1.

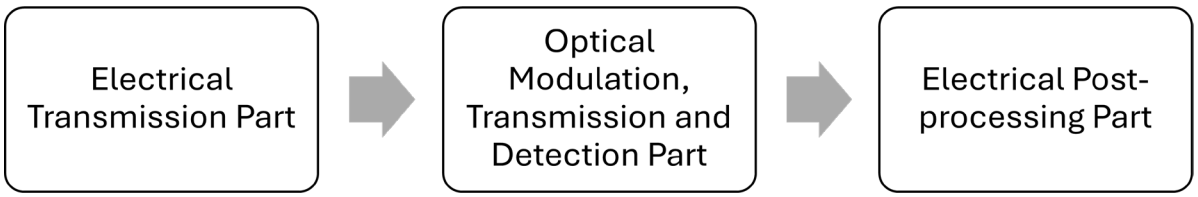


**Figure 1.** The EOE link

Figure 1 shows the EOE link. The link consists of three parts. The first part is electrical transmission where the date is generated and encoded, the output of this part is a high-speed electrical waveform that drives the optical components. The second part is the optical modulation, transmission and detection. This is the core of the photonic link. The optical signal is modulated based on electrical waveform using devices such as Micro Ring Modulator (MRM), and Mach-Zehnder Modulator (MZM). The signal of each channel is multiplexed and passed through an optical fiber to the receiver side. The third part is the electrical postprocessing of the signal. At the end of the optical path, the signal is converted back to the electrical domain using photodiodes.

## EOE Co-Simulation

In real systems, electrical and photonic components interact, and analyzing them separately can lead to inaccurate results. Because of the cross-domain dependence, EOE simulation must be holistic. Modeling only the optical path or only the electrical path can't predict real world performance. Therefore, the co-simulation of the EOE flow bypasses this limitation and produces accurate results than simulating each part alone, which is exactly what Keysight ADS provides. Keysight ADS enables full EOE co-simulation by integrating electrical circuit models such as drivers, TIAs with Photonic Designer components such as modulators, lasers and optical fiber. Keysight ADS enables system level simulation through powerful simulation engines such as Harmonic Balance, Circuit Envelope, and Channel Sim. This unified environment allows engineers to sweep parameters across electrical and optical domains, and evaluate end to end links through eye diagrams.

# Setting Up the EOE Simulation

In this section we will explain how to set up the simulation in Keysight ADS for all three parts of the EOE system. First, we will begin by setting up a one channel transmission link and then extend it to cover a 4-channel Wave Division Multiplexing (WDM) system. Figure 2 shows the full EOE link as it is implemented in Keysight ADS.

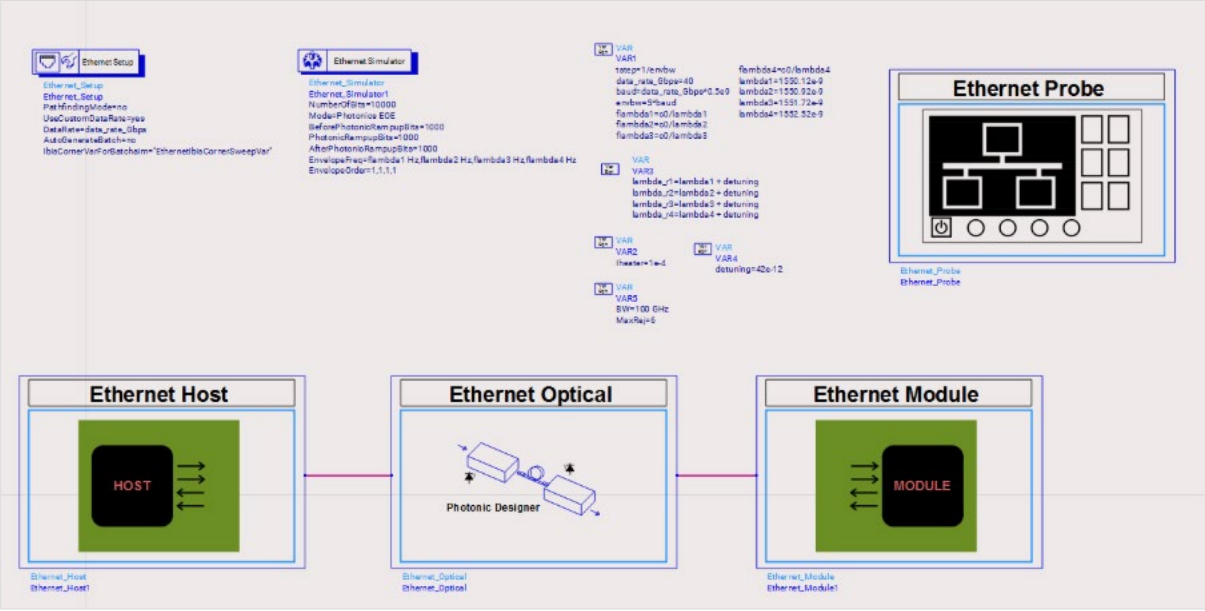


**Figure 2.** EOE flow as it is implemented in Keysight ADS

# Setting Up a Single Channel Transmission Link

This subsection describes the design flow for implementing a single channel optical transmission link using a Microring Modulator (MRM), an optical source, an optical fiber, and a PIN photodiode (PD) behavioral model. In this configuration, the MRM functions as the central modulation element, converting the electrical drive signal into an intensity modulated optical waveform. Users can adjust the MRM characteristics through parameters such as the ring radius, junction capacitance, operating wavelength, coupling coefficient (kappa), and other device specific settings that determine the modulator's resonance behavior and overall performance.

In the single channel setup, the optical source provides a continuous wave carrier that is fed directly into the MRM. The modulated optical output then propagates through the optical fiber, allowing users to evaluate transmission effects such as dispersion or attenuation. At the receiver side, the PIN photodiode behavioral model converts the incoming optical signal into an electrical output suitable for further analysis. Figure 3 illustrates the complete single channel transmission link as implemented in Keysight ADS, where each component can be configured through its parameter interface, and detailed documentation is available for users who wish to explore the underlying models or adjust advanced configuration options.

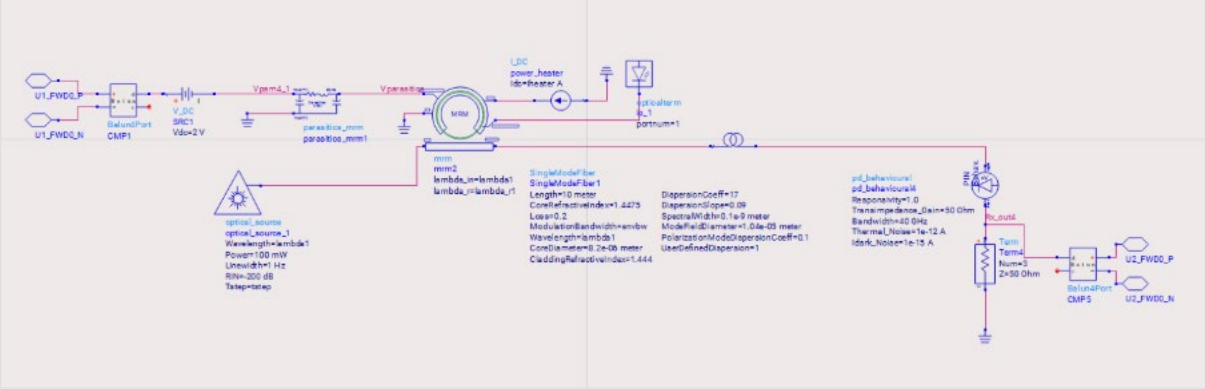

**Figure 3.** Single-Channel Transmission Link as implemented in Keysight ADS

# Ethernet Optical Block (Optical Part)

Configuration of Ethernet Optical component relies on the previous design, since the user should link the optical circuit to the ethernet optical component. First the user should place an ethernet optical component in a schematic. By double clicking on the component a dialog box will pop up as it is shown in figure 4.

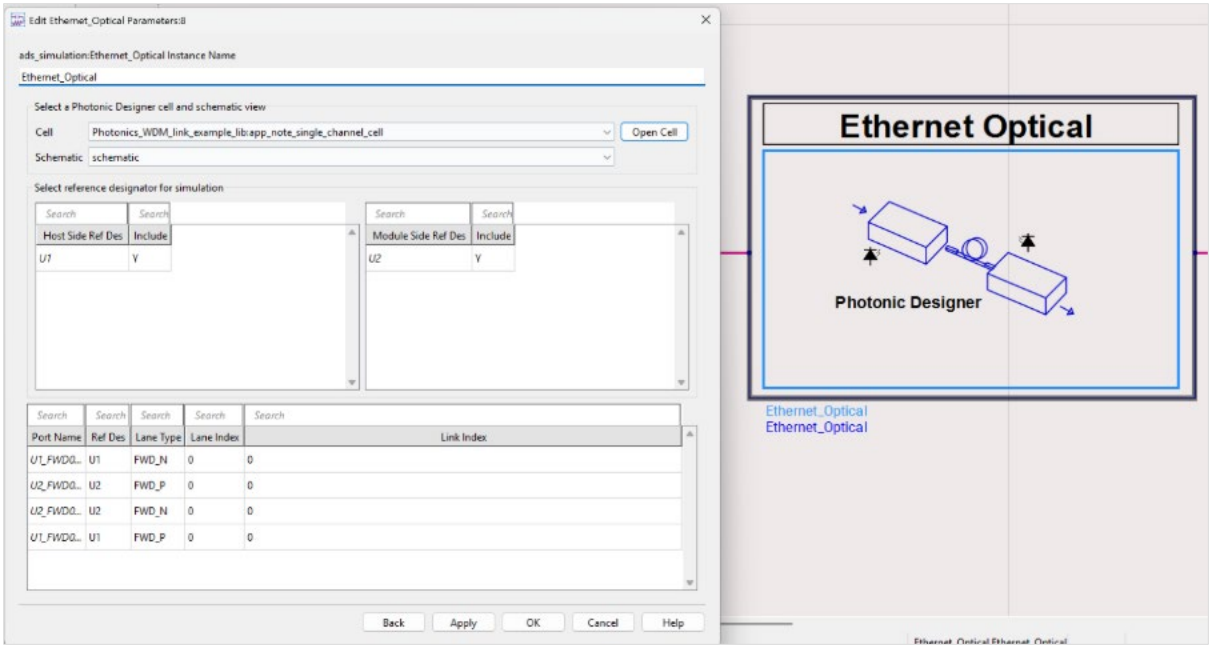


**Figure 4.** Ethernet Optical Configuration

Figure 4 illustrates the configuration step of the ethernet optical component. In order to connect the single channel circuit designed in the previous subsection, the user can select the name of the cell in which the design is implemented. As it is shown in figure 4, in the cell field the user can choose the schematic by clicking on the drop-down menu. Once the cell is set to the desired schematic, the user can proceed to the next steps which are select reference designator for simulation and specify the port names, lane types, and lane index. First, the user has to set the host side to U1 and include it in the simulation by selecting the letter Y which stands for “Yes”, in this case there are two options “Y” for “Yes” and “N” for “No”. The same applies to the module side. Host and module side will be explained in the next subsection. The next step is to specify the port name, Ref Des, Lane Type, Lane Index.

The port names should be unique and descriptive, and the user should carefully specify the names corresponding to the pin names in the child cell. For the Ref Des column, the user can either select U1, or U2 where U1 is referring to the ethernet host, and U2 is the ethernet module.

# Ethernet Simulator

The Ethernet simulator in Keysight ADS provides a complete environment for modeling, analyzing, and validating highspeed Ethernet links across both electrical and optical domains. In this setup as it is shown in figure 5, the Photonics EOE mode is selected and the number of bits to be simulated set to 10000.

In the Ethernet Simulator, the Simulation Mode includes two important parameters:

- Estimated number of before Photonic EOE rampup bits.
- Estimated number of after Photonic EOE rampup bits.

These parameters define how many bits are simulated before and after the main portion of the waveform that will be analyzed. They act as padding around the useful data.

At the same time, many transmitters Tx and receivers Rx models in ADS have an Ignore_Bits parameter. This tells the model to discard a certain number of initial or final bits because they may be distorted by startup transients.

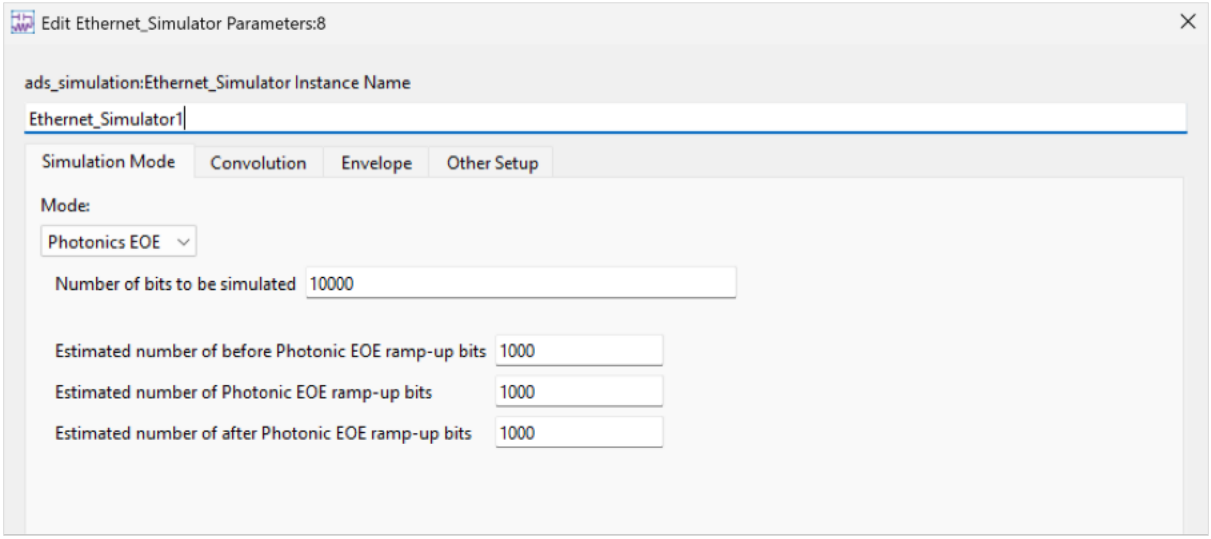


**Figure 5.** Ethernet Simulator Configuration

# Ethernet Setup

The Ethernet Setup component allows the user to specify the setup parameters for running an Ethernet Designer simulation. To run the simulation, the user must add it to the schematic to setup the ethernet host, and ethernet probe components. Only one ethernet setup component is allowed on the schematic.

In this example, we set the data modulation type to PAM4. By default, no encoding is applied to the PRBS sequence. Then we set the IBIS corner type to typ (typical). The IBIS interpolation mode specifies the IBIS interpolation mode to be used on the IBIS data, and it is set to linear.

Figure 6 illustrates the Ethernet Setup dialog box.

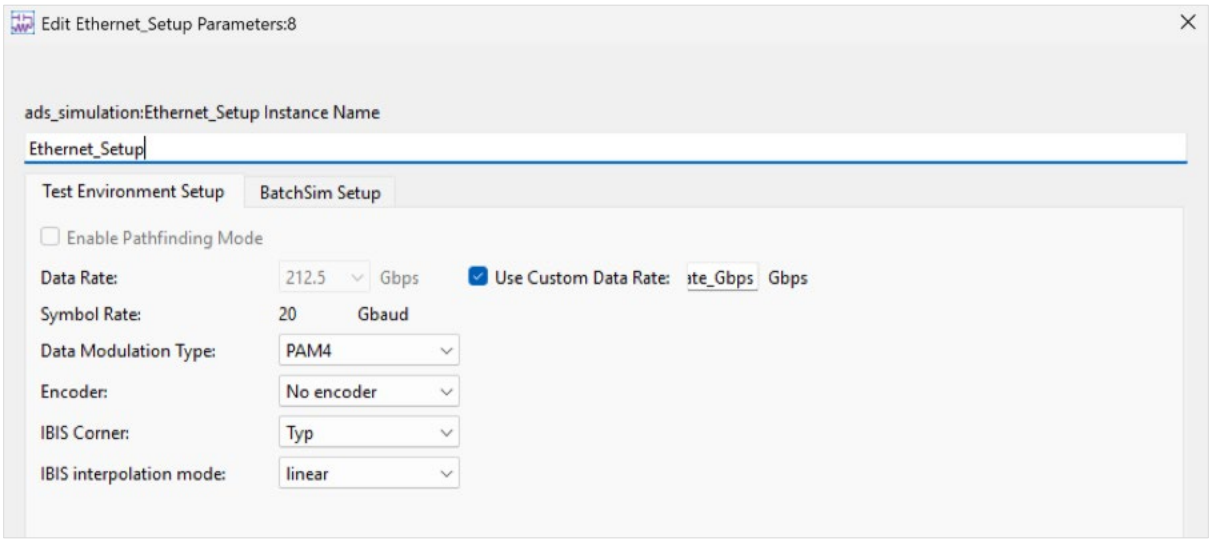


**Figure 6.** Ethernet Setup

# Ethernet Host (Transmission Electrical Part)

The transmitter side of the link is defined through the Ethernet Host component, which drives single forward channel labeled FWD0. The channel is instantiated as an AMI-based transmitter that references an IBIS model file that can be generated by clicking build model button as it is shown in figure 7. Similarly, the user can generate the .ibs file for the receiver section as well.

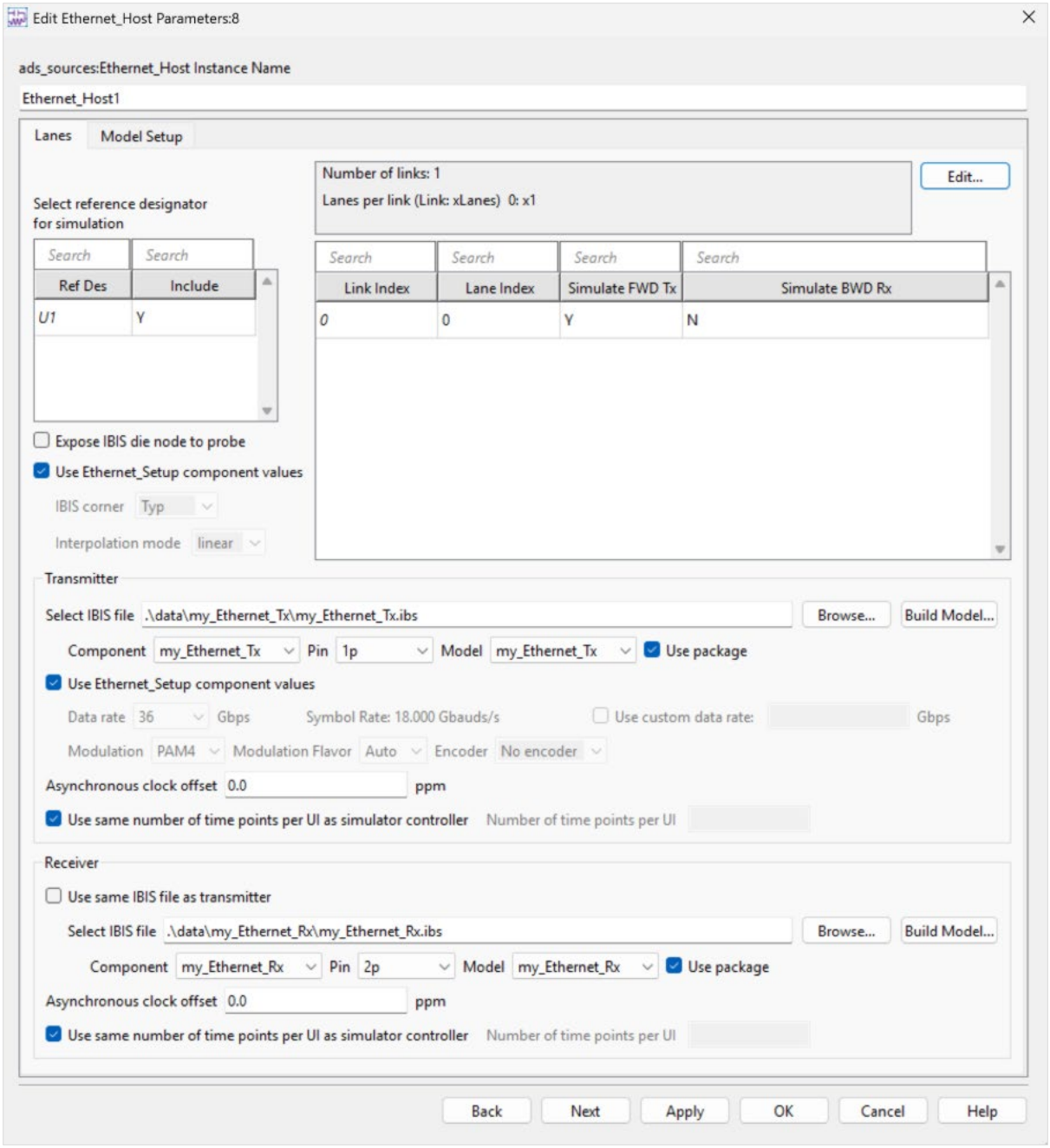


**Figure 7.** Ethernet Host Configuration

In this set up we only enabled the forward direction of the signal, hence, simulate FWD is set to Y “yes”. FWD is the signal direction from Host to Module and BWD is the signal direction from Module to Host.

# Ethernet Module (Post Processing Part)

The receiver side is defined through the Ethernet Module component, which terminates the single forward channel at the output of the photodetector. The ethernet module is configured the same way we did for the ethernet host as it is shown in figure 8.

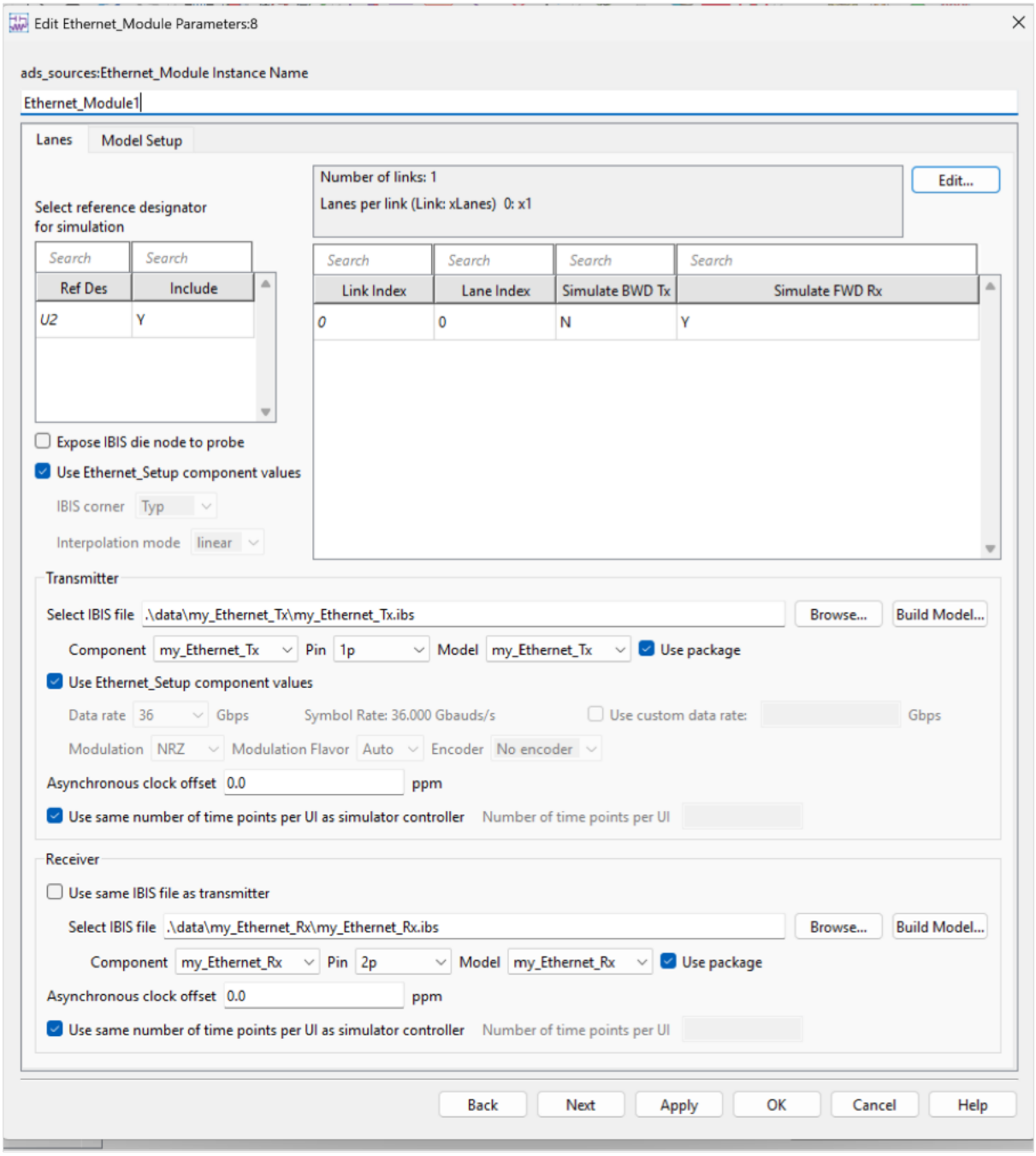


**Figure 8.** Ethernet Module Configuration

# Transmission Lines

Once the three parts of EOE are configured, the user should establish components connectivity, and that is done by Inserting a wire between the ethernet host and ethernet optical components and ethernet optical and ethernet module. The wire can be attached to any point on symbol boundaries of the components.

The Connect HSD Components window is displayed with a list of ethernet host pins on the top-left side and ethernet optical component pins on the top-right side. When clicking connect all, the pins on the two sides with matching Ref Des (Reference Designator) and Signal ID are automatically connected. The connected pins are moved from the top tables to the bottom one.

Alternatively, the user can manually connect the pins between the two top tables. Click on one row in the top-left table and click on another row in the top-right table. Then click the Manual Connect option. The selected pins are connected and moved from the top to the bottom. Then click OK.

The connection dialog box is closed. Now, when you hover the cursor over the wire in the schematic, a tooltip appears to show signals connected by the wire. Figures 9 and 10 illustrate the connectivity from Ethernet Host to Ethernet Optical components and Ethernet Optical to Ethernet Module components respectively.

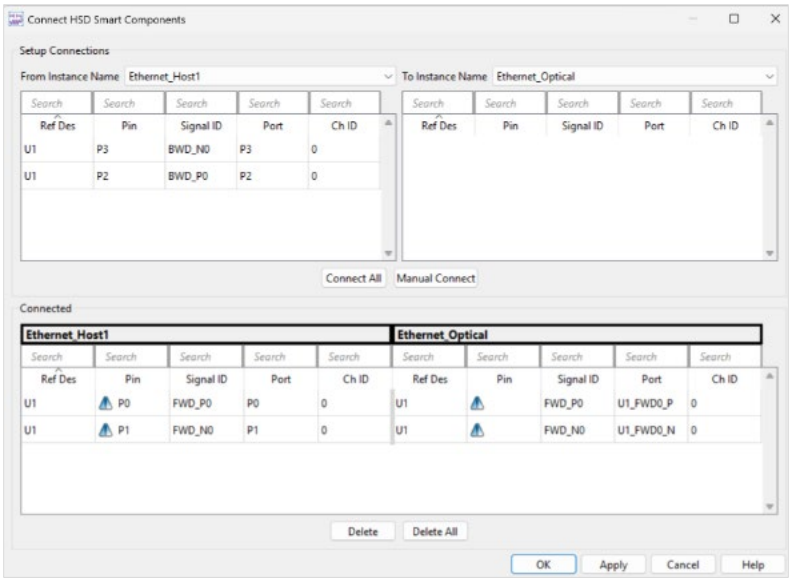


**Figure 9.** Ethernet Host to Ethernet Optical Connectivity

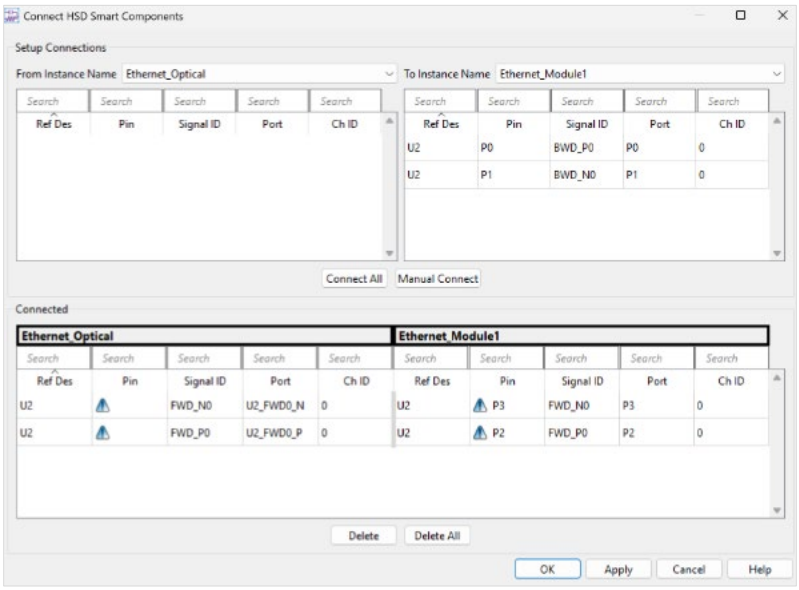


**Figure 10.** Ethernet Optical to Ethernet Module Connectivity

# Ethernet Probe

The Ethernet Probe in Keysight ADS is a measurement and analysis block used to extract key performance metrics from an Ethernet signal during simulation. It acts as the interface between the simulated waveform and the Ethernet analysis engine, allowing ADS to interpret the signal according to Ethernet standards such as NRZ or PAM4.

To configure the Ethernet Probe block, we click the component where the dialog box will pop up. Then we navigate to Select Signals tab, in this section we have on the left the available signals from which the user can select the signals for which the analysis will be performed. From the left side, the user can select the output signals (at the Ethernet Module side) and click add. Then the selected signals will appear in the right side in the selected signals sections as it is shown in figure 11.

The other tab that we are interested in in this example is select measurement. In this tab as it is shown in figure 12, the user can click on the desired signals to be analyzed and then specify the measurements from the available measurements section, and add them one by one to the selected measurements section.

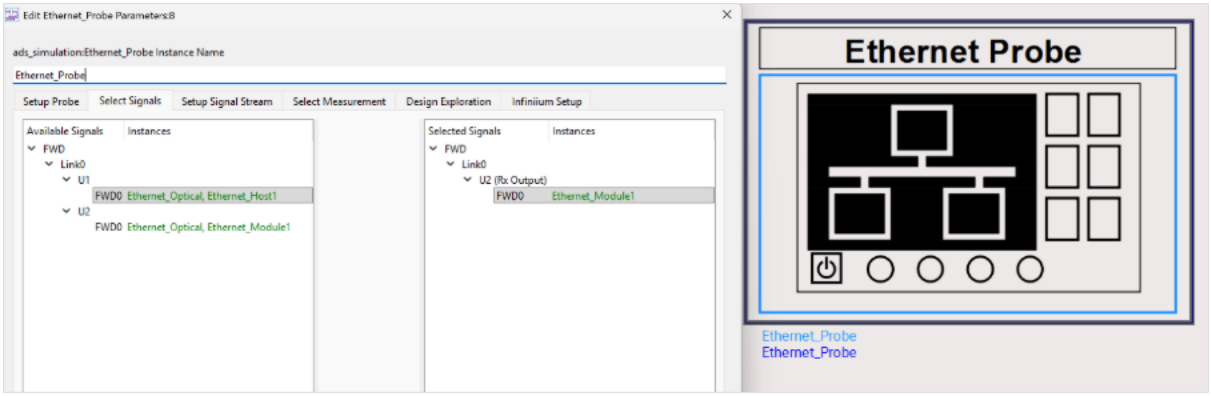


**Figure 11.** Ethernet Probe: Select Signals

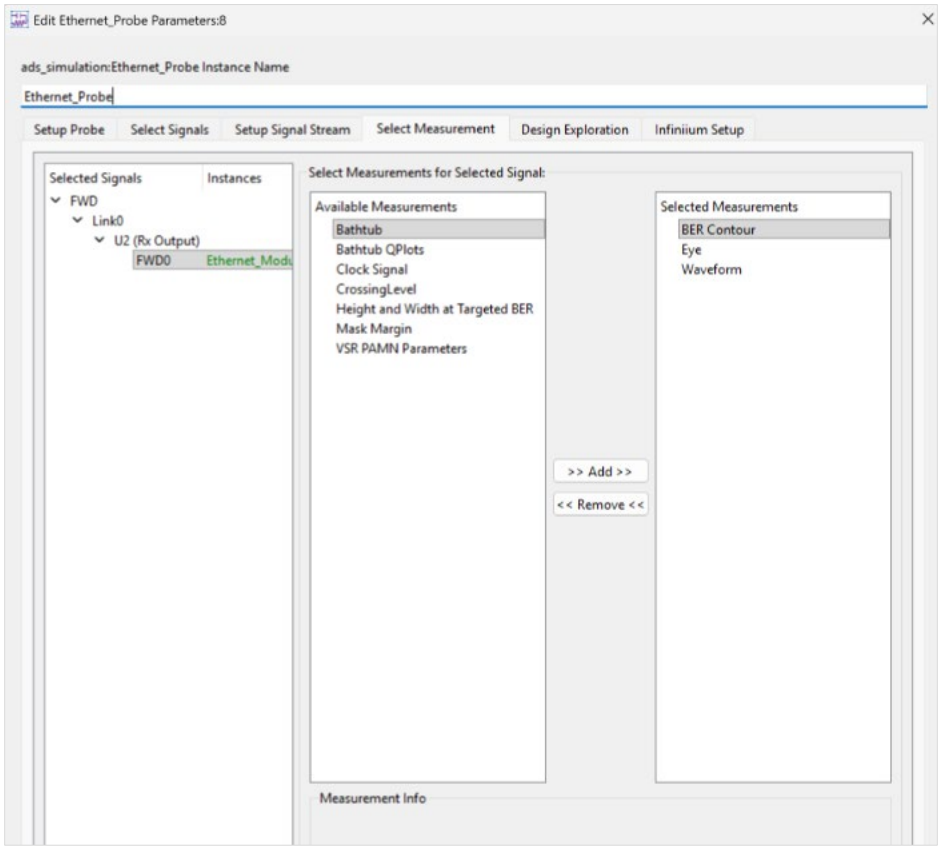


**Figure 12.** Ethernet Probe: Select Measurement

# Setting Up 4 Channel WDM System

After completing the single channel transmission link and verifying the operation of each individual component, the same design principles can be extended to construct a four channel WDM system. The workflow remains consistent: each channel is built using an optical source, a microring modulator, an optical fiber path, and a photodetector at the receiver. The main difference lies in scaling the architecture to support multiple wavelengths simultaneously and incorporating wavelength selective components such as the multiplexer and demultiplexer. By following the same setup steps used in the single channel case, users can replicate the configuration for each of the four channels and then integrate them into a unified WDM link.

In the 4channel WDM configuration, the optical fiber is placed between the wavelength multiplexer and demultiplexer. Each modulated optical signal from the four modulators is first combined by the multiplexer, transmitted through the fiber as a multiwavelength optical stream, and then separated again by the demultiplexer before reaching the corresponding photodetectors (PIN diodes). Figure 13 illustrates the design flow of the 4 channel WDM System as implemented in Keysight ADS. Users can configure each component in the system using input parameters, and each component has documentation that the user can refer back to.

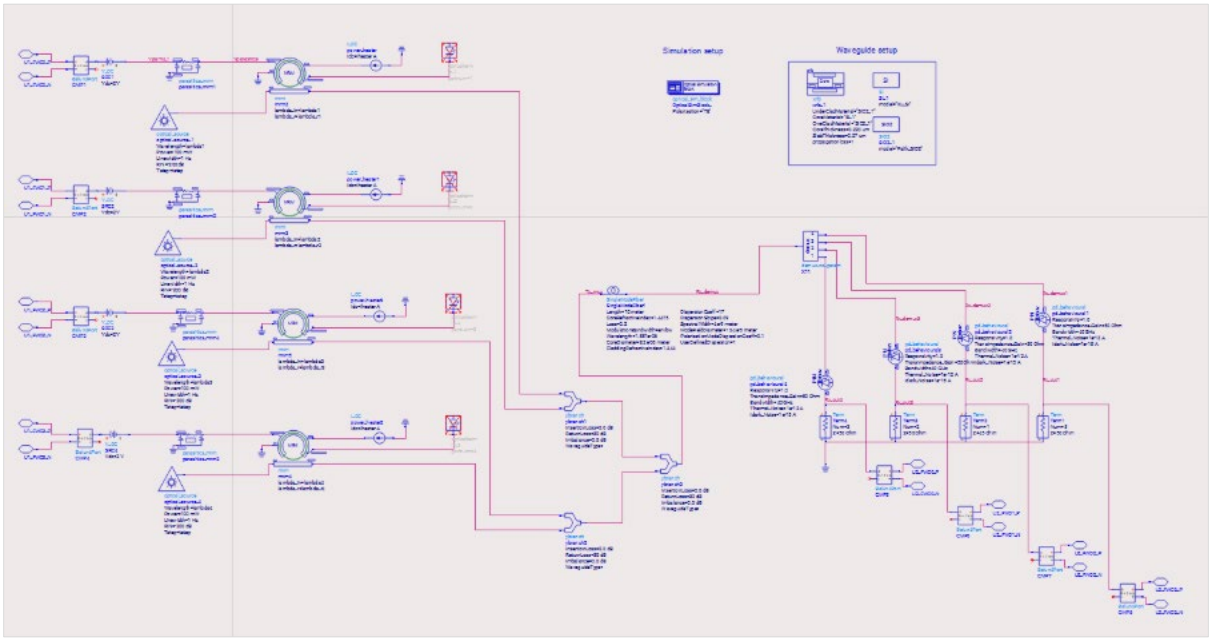

**Figure 13.** Design of a 4 Channel WDM System in Keysight ADS

# Results: Eye Diagram, and BER Contour

With all components of the EOE flow configured, the next step is to analyze the performance of the complete link. The results section presents the key metrics obtained from the Ethernet Simulator including eye diagrams, BER contour, and waveform. These results allow us to evaluate how the electrical transmitter, photonic components, fiber channel, photodetector, and electrical post-processing components interact, and to verify whether the overall link meets the expected performance targets for the 4channel WDM Ethernet system. Figure 14 illustrates the eye density, BER contour of each channel in this example and the waveform at the receiver side.

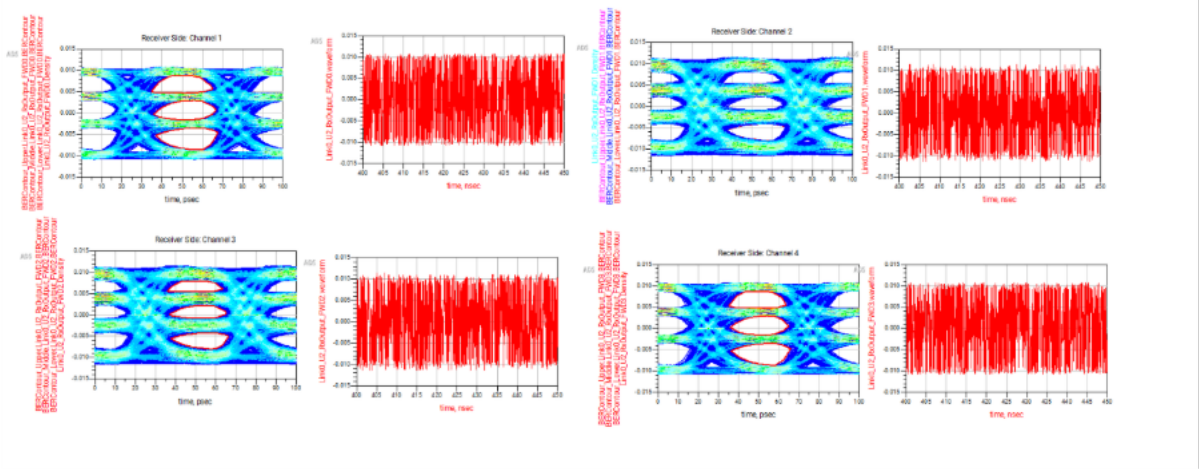


**Figure 14.** Eye Density, BER Contour and Waveform

# Summary and Conclusion

This application note demonstrated how to build and simulate a complete 4 channel Electrical-Optical-Electrical (EOE) flow in Keysight ADS, combining electrical transmitter models, photonic components, WDM multiplexing/demultiplexing, fiber transmission, and electrical post-processing. By configuring each part of the link, from the Ethernet Host and optical modulators to the WDM MUX/DEMUX, fiber channel, and receiver electronics, we created a realistic representation of a modern multi wavelength Ethernet system.

The results highlight the importance of end-to-end co-simulation when evaluating high speed optical links. Eye diagrams, and waveform integrity measurements showed how electrical impairments and optical distortions interact across the full chain.

By modeling the complete EOE flow within a unified environment, engineers can accurately predict link behavior, identify performance bottlenecks, and optimize both electrical and optical components before hardware development. This approach reduces design risk, accelerates development cycles, and ensures that multi-channel high speed Ethernet systems meet the requirements of modern data center and telecom applications.

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