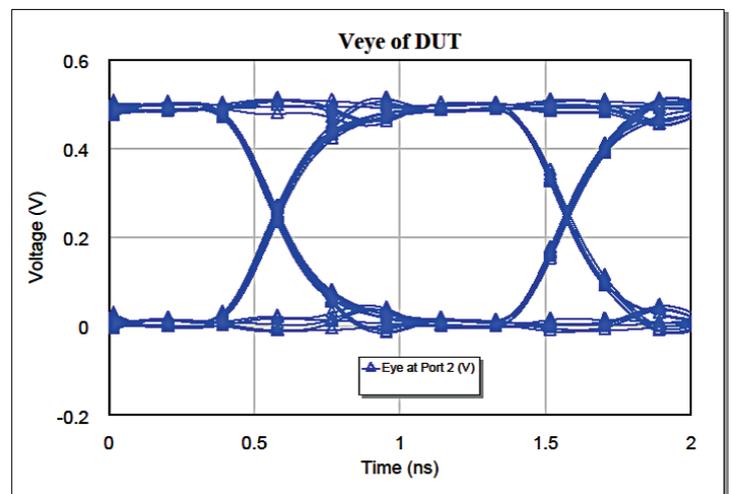
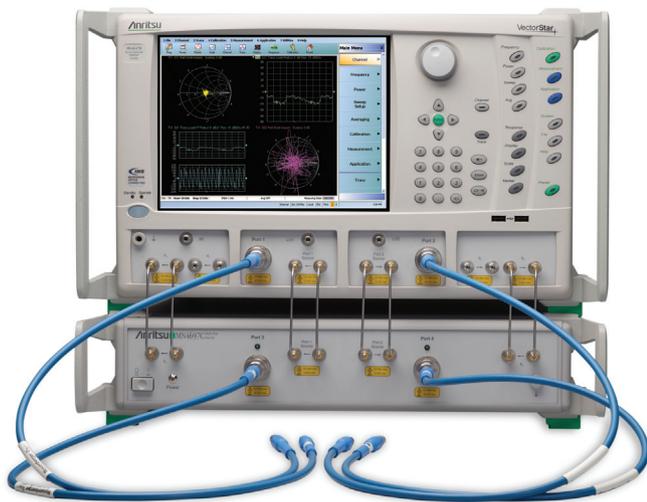


# Creating Eye Diagrams using VectorStar™ SnP files and AWR Microwave Office®

## MS4640B Series Vector Network Analyzer



## 1 Introduction

As data rates and design complexity continues to increase, signal integrity becomes an integral part of the design and verification process. At first glance, one might assume that because digital signals are represented by discrete voltage (or current) levels, signal integrity may not be of major concern to digital designers. However, digital signals are fundamentally analog in nature, and all signals are subject to effects such as noise, distortion, and loss. Over short distances and at low bit rates, a simple conductor can transmit digital signals reliably without much distortion, but at high bit rates and over longer distances or through various media, various effects can degrade the electrical signal to the point where errors occur and the system or device fails. Today, it is common to see devices and systems operating at multi-GHz data rates. Digital signals being transmitted over relatively long transmission lines or through differing materials also present signal integrity challenges. Because of these challenges, a host of variables can affect the integrity of signals, including transmission-line effects, impedance mismatches, signal routing, termination schemes, and grounding schemes. One tool used to characterize these effects is the eye diagram. With eye diagrams, engineers can quickly evaluate system performance and gain insight into the nature of channel imperfections that can lead to errors when a receiver tries to interpret the value of a transmitted data bit.

This application note reviews basic eye diagram definitions and terminologies. It will include a measurement example showing how to import a S-Parameter File of a device measured by an Anritsu VectorStar VNA into AWR's Microwave Office application to generate an Eye Diagram.

## 1.1 Eye Diagram Fundamentals

An eye diagram is commonly used to quantify the quality of signals in high-speed digital transmissions. A common way to generate an eye diagram is to use an oscilloscope to overlay sweeps of different segments of a long data stream. When many such sweeps have been overlaid, positive and negative pulses are superimposed on each other producing an eye diagram, so called because the resulting image looks like the opening of an eye.

In an ideal world, eye diagrams would look like rectangular boxes. However, since real world signals are imperfect, the signal transitions do not line perfectly on top of each other, and an eye-shaped diagram results. Differences in timing and amplitude from bit to bit cause the shape of eye to change. By interpreting these changes in the eye diagram, engineers can easily view signal impairments in terms of amplitude and time distortion.

For this application note, instead of using an oscilloscope, we will use a software signal modeling tool, AWR's Microwave Office, to generate the eye diagram. The Device-Under-Test (DUT) will be simulated by an SnP file generated by using an Anritsu VectorStar VNA to measure the s-parameters of the DUT.

## 1.2 Introduction to Histograms

Histograms are used to statistically analyze time and amplitude data of eye diagrams, offering important computational information when observing impairments in high-speed digital signals. This next section will highlight the key statistical definitions that formulate the basis of eye diagram measurements.

Mean and standard deviation are two important aspects of the time and amplitude distortion in a high-speed digital data stream. For a definition of these terms, consider the normal distribution shown in Figure 1. According to this graphic:

- Mean is the sum of data values divided by the number of values
- Standard Deviation, two sigma, is  $\pm 1\sigma$ ,  $\pm 34$  percent (or 68 percent) of mean
- Standard Deviation, six sigma, is  $\pm 3\sigma$ ,  $\pm 49.85$  percent (or 99.7 percent) of mean

The mean of a data set is simply the arithmetic average of the values in the set. It is obtained by summing the values and dividing by the total number of values. The standard deviation is a measure of the spread of data.

The  $2\sigma$  (2 sigma) standard deviation is approximately 68 percent of data points within  $\pm 1\sigma$  of the mean for a normal distribution. The  $6\sigma$  standard deviation is approximately 99.7 percent of data points within  $\pm 3\sigma$  of the mean for a normal distribution.

If many data points in a histogram are close to the mean, then the standard deviation is small. On the other hand, if many data points are far from the mean, then the standard deviation is large. When all data values are equal, the standard deviation is zero. It is important to understand these terms as they will play an important part in the upcoming amplitude and time distortion definitions.

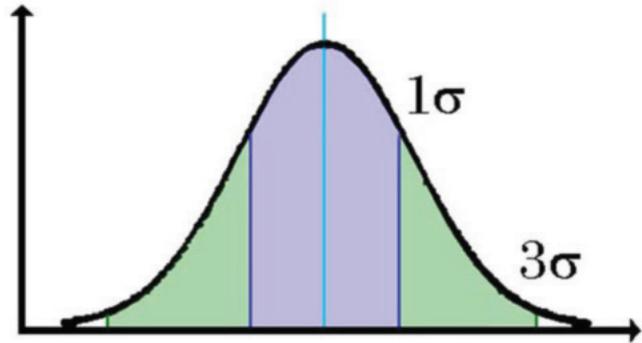


Figure 1: This graph depicts a "normal" distribution of data

## 1.3 Eye Diagram Terminology

A number of terms are used to describe amplitude and time characteristics for eye diagrams. Amplitude and time distortion terms are typically based on calculations from histogram data derived from the eye diagram.

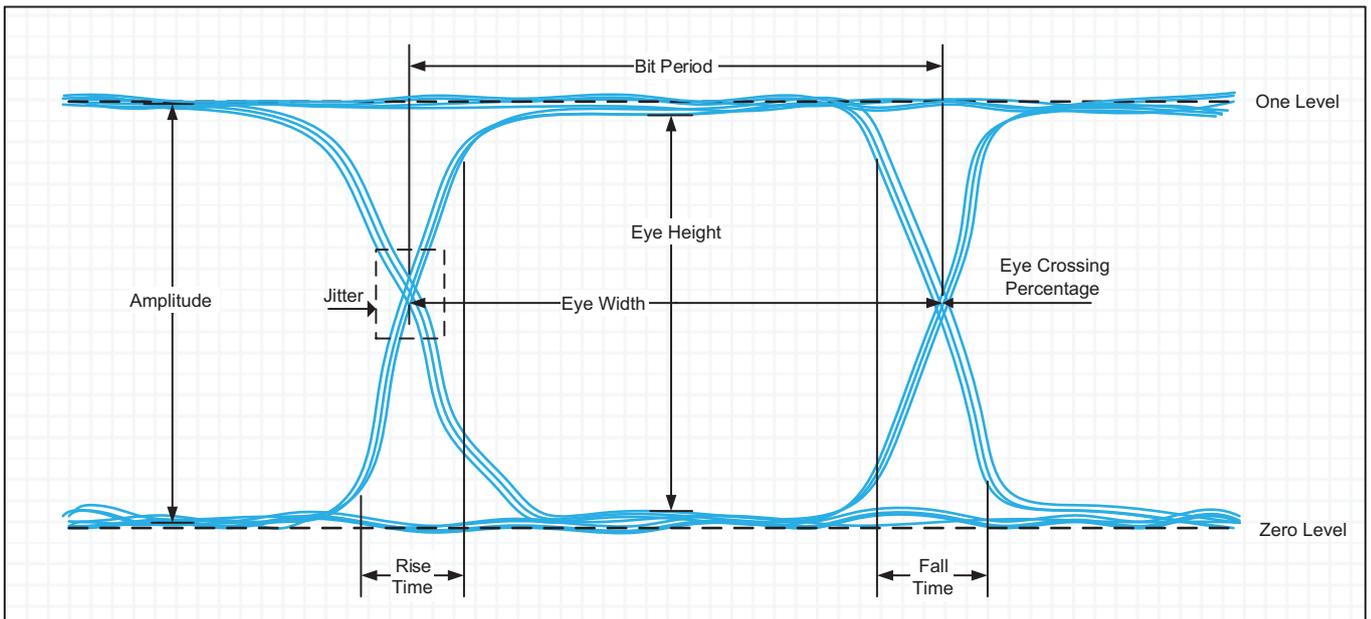


Figure 2: Eye Diagram Terminology

These terms include:

### One Level

The one level in an eye diagram is the mean value of a logic one. The actual computed value of the one level comes from the histogram mean value of all the data samples captured inside the middle 20% (40 to 60% points) of the eye period.

### Zero Level

The zero level in an eye diagram is the mean value of a logic zero. The zero level is computed from the same 40 to 60% region of the baseline area during the eye period as the one level. The actual computed value of the zero level comes from the histogram mean value of the data captured inside the middle 20 percent of the eye period.

### Eye Amplitude

Eye amplitude is the difference between the one and zero levels. The data receiver logic circuits will determine whether a received data bit is a "0" or "1," based on the eye amplitude. The calculation values used are the mean values of the one and zero histograms, measured during the middle 20 percent region of the eye crossings.

### Eye Height

Eye height is a measure of the vertical opening of an eye diagram. An ideal eye opening measurement would be equal to the eye amplitude measurement. For a real eye diagram measurement, noise on the eye will cause the eye to close. As a result, the eye height measurement determines the eye closure due to noise. The signal to noise ratio of the high speed data signal is also directly indicated by the amount of eye closure. The definition for eye height is derived from computing the difference between the inner  $3\sigma$  points on the inside of the histograms of the one and zero levels.

The eye amplitude and eye height definitions are important amplitude terms since the data receiver logic circuits will ultimately determine whether the data bit is a "0" or "1," based on the eye amplitude. Furthermore, because any data bits scattered beyond the  $3\sigma$  points into the open eye will indicate a possible error in the detection, the BER is dependent on the eye height.

### Eye Crossing Percentage

The eye crossing percentage is a measure of the amplitude of the crossing points relative to the one and zero level. It provides a clear indication of how well the system's data pulse symmetry is performing.

To determine the eye crossing percentage, the one level, zero level and crossing level must first be found using histograms. The crossing level is determined by taking the mean value of a thin vertical histogram window centered on the crossing point. The crossing percentage is then calculated using the following equation:

$$\text{Eye Crossing Percentage} = 100 * \left( \frac{\text{crossing level} - \text{zero level}}{\text{one level} - \text{zero level}} \right)$$

Eye crossing percentage is valuable for measuring amplitude distortions caused by differences in the one- and zero-level durations. It also reveals pulse symmetry problems for diagnosis. When the eye crossing symmetry value deviates from the perfect 50 percent point, the eye closes, which degrades BER.

### **Bit Period**

The bit period is a measure of the horizontal opening of an eye diagram at the crossing points of the eye and is usually measured in picoseconds for a high speed digital signal (i.e., 200 ps is used for a 5Gbps signal). The data rate is the inverse of bit period (1 / bit period). The bit period is commonly called the Unit Interval (UI) when describing an eye diagram. The advantage of using UI instead of actual time on the horizontal axis is that it is normalized and eye diagrams with different data rates can be easily compared.

### **Eye Width**

Eye width is a measure of the horizontal opening of an eye diagram. It is calculated by measuring the difference between the statistical mean of the crossing points of the eye. Sometimes defined as (mean right -3\*sigma) - (mean left + 3 sigma).

### **Rise Time**

Rise time is a measure of the mean transition time of the data on the upward slope of an eye diagram. The measurement is typically made at the 20 and 80 percent or 10 and 90 percent levels of the slope.

### **Fall Time**

Fall time is a measure of the mean transition time of the data on the downward slope of an eye diagram. The measurement is typically made at the 20 and 80 percent or 10 and 90 percent levels of the slope.

### **Jitter (RMS and Peak-to-Peak)**

Jitter is the time deviation from the ideal timing of a data bit event and is perhaps one of the most important characteristics of a high speed digital data signal. To compute jitter, the time deviations of the transitions of the rising and falling edges of an eye diagram at the crossing point are measured. Fluctuations can be random and/or deterministic. The time histogram of the deviations is analyzed to determine the amount of jitter. The peak-to-peak jitter is defined as the full width of the histogram, meaning all data points present. RMS jitter is defined as the standard deviation of the histogram. The units for a jitter measurement on a high speed digital signal are normally in picoseconds.

## **2 Measurement Example**

For this example measurement, the following equipment and Software was used:

- Anritsu MS4647B VectorStar VNA
- WildRiver Technology CMP-28 Channel Modeling Platform (DUT)
- AWR Microwave Office 11.01 with Nonlinear Simulator (MWO-2xx)

### **2.1 Measurement Procedure**

The first step in creating the eye diagram is to make S-Parameter measurements of your Device Under Test (DUT).

1. Make S-Parameter Measurements on the VectorStar VNA
  - a. Perform 12-term 2 port calibration for the desired S-Parameter measurements on the VectorStar
  - b. Set Frequency Range:
    - i. Start = 70 kHz
    - ii. Stop = 70 GHz

It is recommended to make measurements to the 5th harmonic of the clock signal to capture the full signal span (ie 10 Gb/s NRZ clock is 5 GHz → 5th harmonic is 25 GHz).

- c. Make S-Parameter measurements on DUT and save SnP file.
2. Start AWR Microwave Office Application

3. Create Circuit Schematic
  - a. From the Menu, select: Project -> Add Schematic -> New Schematic
  - b. Name and create your schematic
4. Add Pseudorandom Bit Sequence Generator to schematic as shown in Figure 3.
  - a. Select Elements Tab
  - b. Select Ports -> Signals from the Elements window
  - c. Select PORT\_PRBS and drag it into the Schematic window

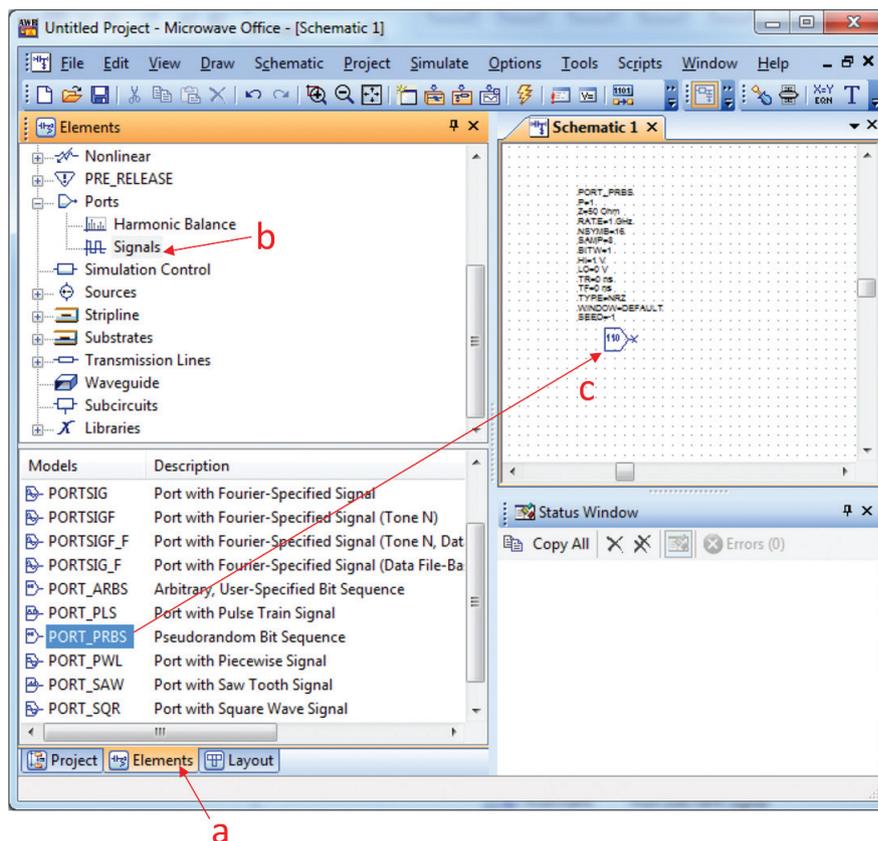


Figure 3: Add PRBS Port to Schematic

5. Add SnP data file from VectorStar
  - a. From the Menu, select: Project -> Add Data File -> Import Data File...
  - b. In the Browse For File Dialog: Change File Type to Touchstone Files
  - c. Open the SnP file saved in step 1
6. Add SnP file as a Subcircuit in the schematic
  - a. From the menu bar, click on the Subcircuit Icon



- b. A dialog box with the SnP file that was just imported in step 5 will open
- c. Select Normal Grounding Type and press OK
- d. Click inside the schematic window to place the subcircuit

7. Add Measurement Port
  - a. From the menu bar, click on the Port Icon



- b. Click inside the schematic window to place the port
  - c. Select the port and press "CTRL-R" to rotate it 180°
8. Connect the Schematic as shown in Figure 4.

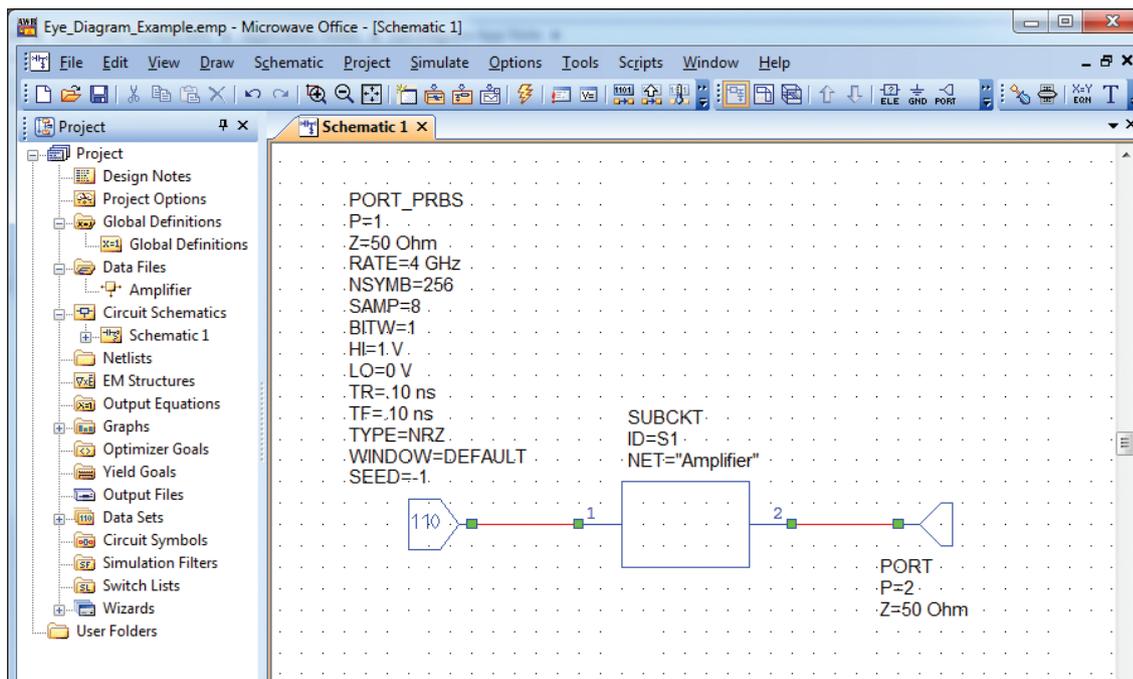


Figure 4: Example Schematic

9. Double click on the PORT\_PRBS parameters to change them:
  - a. NSYMB = 256
  - b. TR = 0.1 ns (Rise Time)
  - c. TR = 0.1 ns (Fall Time)
10. Create Eye Diagram Graph
  - a. From the Menu, select: Project -> Add Graph
  - b. Name your Graph
  - c. Select Rectangular Graph Type and press Create
  - d. A new window with your graph will appear

11. Add desired measurement
  - a. Right Click inside Graph and select "Add New Measurement"
12. Configure the new measurement as shown in Figure 5.
  - a. Measurement Type = Nonlinear -> Voltage
  - b. Measurement = Veye
  - c. Data Source Name = Schematic 1 (Or whatever you named your schematic)
  - d. Measurement Component = Port\_2
  - e. Click OK

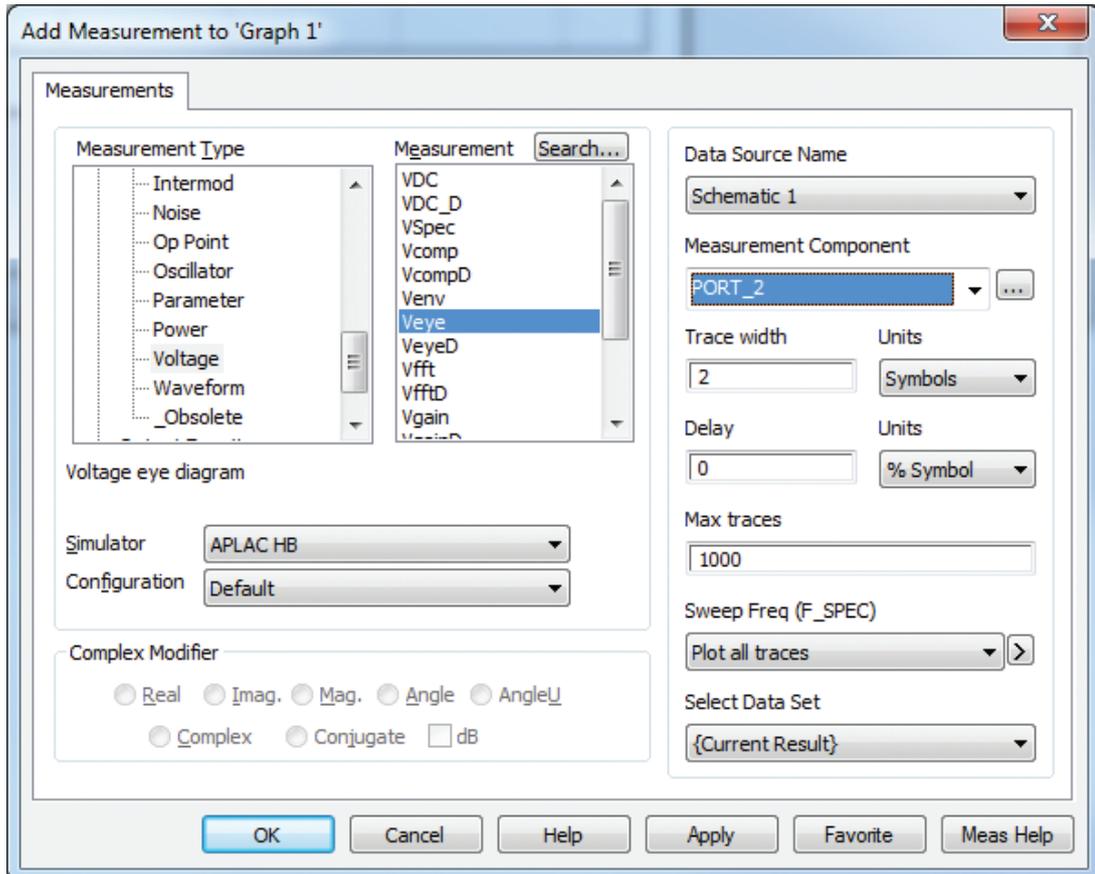


Figure 5: Add Measurement Dialog

13. Run Simulation to get Eye Diagram
  - a. Press the Analyze button on the menu bar



You should now have an eye diagram that looks like Figure 6.

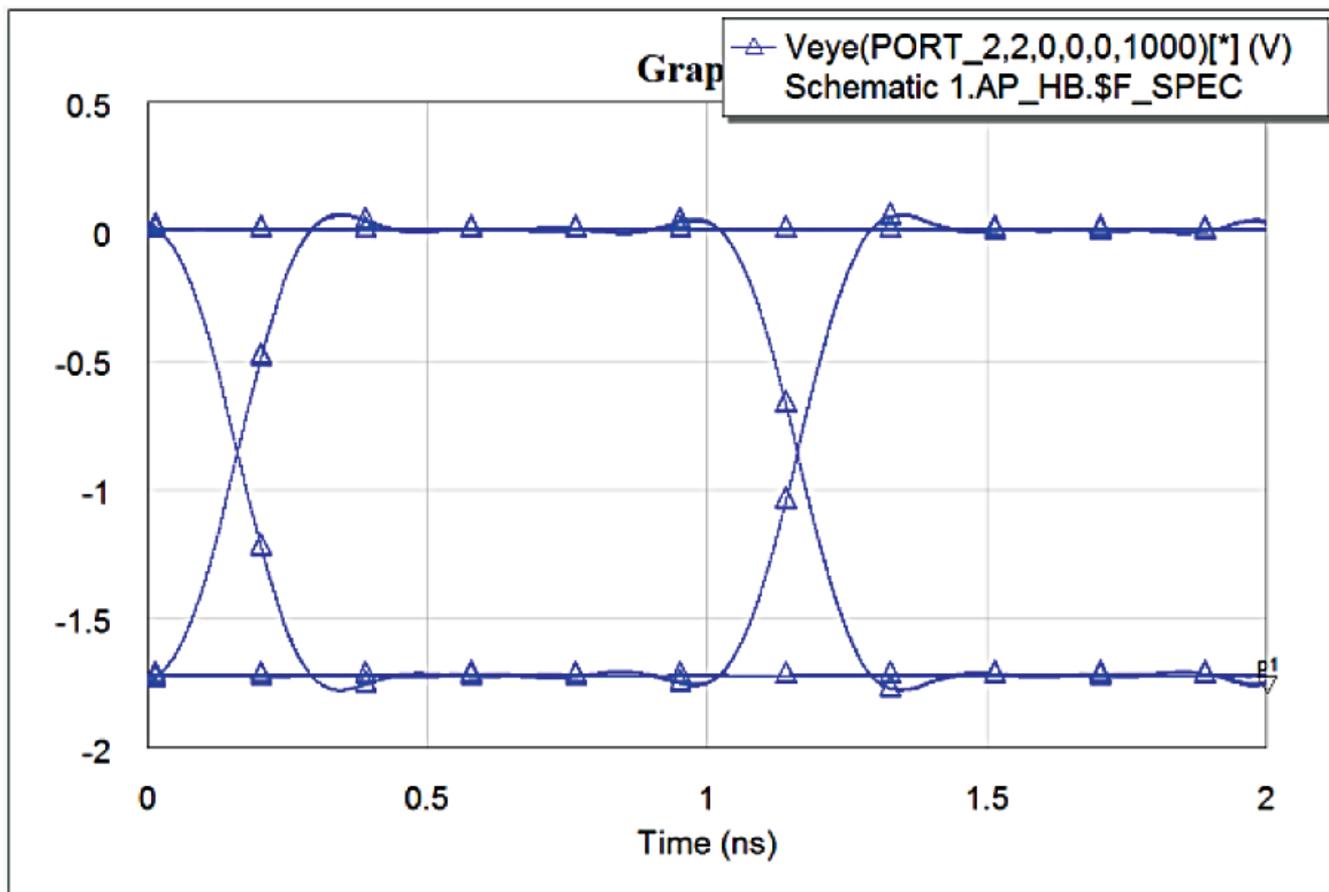


Figure 6: Example Eye Diagram

Next, we will see how to get eye parameters. To do this, we will create a tabular graph and add the desired parameters. For this example, we will add the following parameters: Eye Amplitude, Eye Corners, Eye Rise & Fall times, Eye Height, and Eye Width

14. Create Eye Diagram Graph

- a. From the Menu, select: Project -> Add Graph
- b. Name your Graph
- c. Select Tabular Graph Type and press Create
- d. A new window with your graph will appear

15. Add desired measurements

- a. Right Click inside Graph and select "Add New Measurement"

16. Configure the new measurement as shown in Figure 7.
  - a. Measurement Type = Nonlinear -> Waveform
  - b. Data Source Name = Schematic 1 (Or whatever you named your schematic)
  - c. Measurement Component = Port\_2
  - d. Measurement = Eye\_Amplitude
  - e. Click Apply
  - f. Measurement = Eye\_Corners
  - g. Click Apply
  - h. Measurement = Eye\_Fall\_Time
  - i. Click Apply
  - j. Measurement = Eye\_Height
  - k. Click Apply
  - l. Measurement = Eye\_Rise\_Time
  - m. Click Apply
  - n. Measurement = Eye\_Width
  - o. Click OK

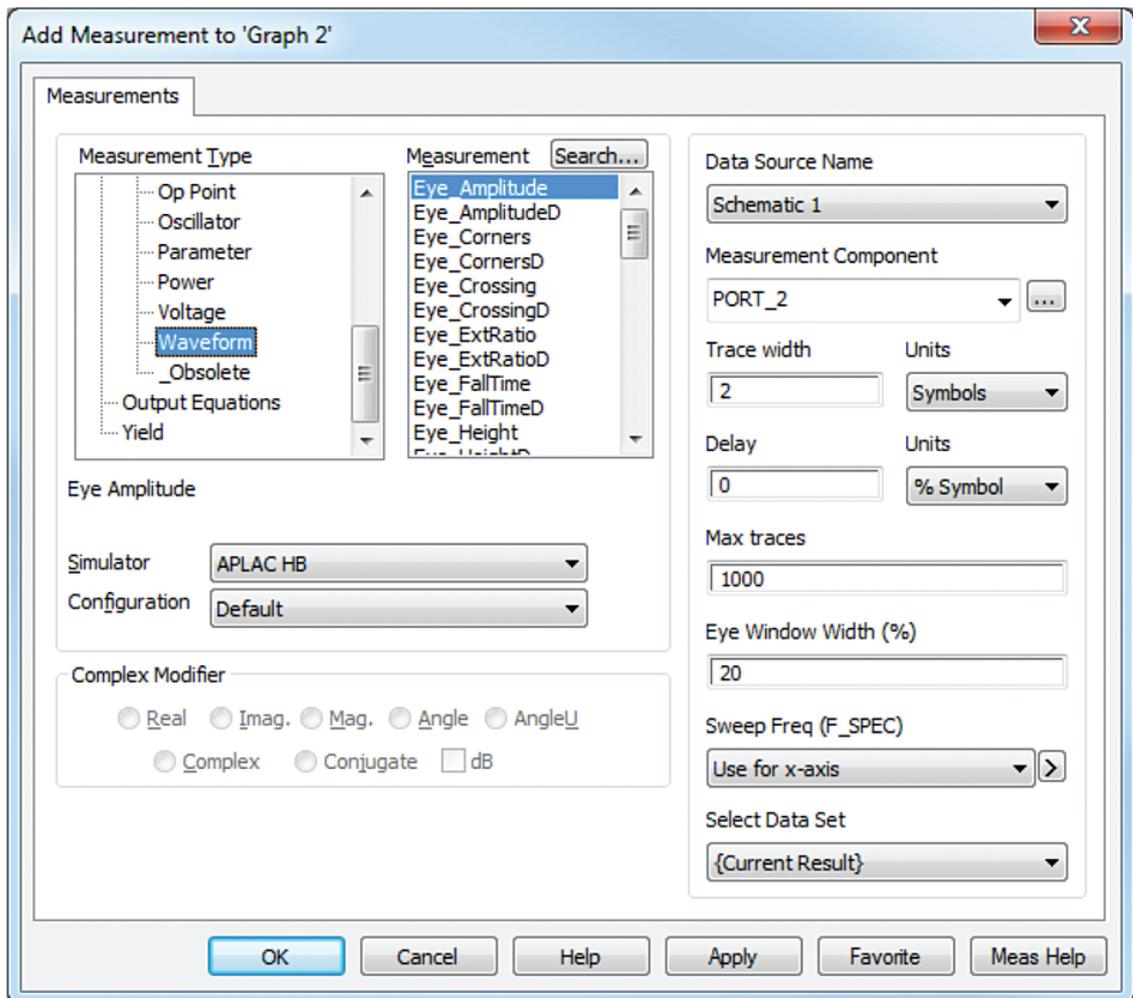


Figure 7: Add Tabular Graph Measurements

17. Run Simulation to get Eye Diagram
  - a. Press the Analyze button on the menu bar



Your tabular graph should now show the selected eye parameters like in Figure 8.

Eye Amplitude(P... Schematic 1.AP... Frequency	Eye Amplitude(P... Schematic 1.AP... Voltage	Eye_Corners(POR... Schematic 1.AP... Time	Eye_Corners(POR... Schematic 1.AP... Voltage FREQ = 0.003906...	Eye_FallTime(POR... Schematic 1.AP... Frequency	Eye_FallTime(POR... Schematic 1.AP... Time	Eye_Height(PORT... Schematic 1.AP... Frequency	Eye_Height(PORT... Schematic 1.AP... Voltage	Eye_RiseTime(POR... Schematic 1.AP... Frequency	Eye_RiseTime(POR... Schematic 1.AP... Time	Eye_Width(PORT... Schematic 1.AP... Frequency	Eye_Width(PORT... Schematic 1.AP... Time
0.0039063	1.7278	0.16209	-0.8558	0.0039063	0.12359	0.0039063	1.7058	0.0039063	0.12361	0.0039063	0.99844
		0.56136	-0.0038565								
		0.76138	-0.0038565								
		1.1605	-0.8558								
		0.76138	-1.7096								
		0.56136	-1.7096								
		0.16209	-0.8558								

Figure 8: Tabular Graph Results

### 3 Summary

Understanding eye diagram measurements is important for engineers dealing with high speed digital data transmission technology. The eye diagram is a powerful tool for assessing the quality of high-speed digital signals and can be used to calculate amplitude and time distortion parameters. By importing S-parameter data from an Anritsu VectorStar VNA into the AWR Microwave Office application, one can easily generate simulated eye diagrams with varying simulation parameters to fully characterize the time and amplitude characteristics of the device under test.

### 4 References

1. Anritsu Application Note, "Understanding Eye Pattern Measurements", Anritsu Application Note # 11410-00533, Rev. A, March 2010
2. On-Semiconductor Application Note, "Understanding Data Eye Diagram Methodology for Analyzing High Speed Digital Signals", Document # AND9075/D
3. D. Behera, S. Srivastava, & S. Tiwari, "Eye Diagram Basics: Reading and applying eye diagrams", EDN Network Article, December 2012, available at: <http://www.edn.com/design/test-and-measurement/4389368/Eye-Diagram-Basics-Reading-and-applying-eye-diagrams>

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