University of Glasgow | School of Engineering

Communication Systems 3: Laboratory 3
Analysis of Eye Diagrams

The objective of this experiment is to gain experience of using an oscilloscope to analyse eye diagrams for digital signals. These diagrams can reveal the SNR, Jitter, and timing error in a digital signal.

You must record your observations, measurements, and work as you go along during the timetabled laboratory session individually. You will use these observations to complete a short lab report to determine attendance and award of grade for the lab assessment. Your report must be **completed within 1 week** of your lab session. See end of the notes for a breakdown of what should be in the report.

Equipment

The test and measurement equipment used in this experiment are:

- Keysight DSOX1202G or DSO-X1102G Digital Oscilloscope
- BNC Lead
- PicoScope
- You will need a USB memory stick to save oscilloscope traces for your report

Using the PicoScope as a source for custom waveforms

A PicoScope can be used as a source for custom waveforms that are created by an array of different file types. First, using a BNC lead connect the PicoScope waveform generator (Gen) output to channel 1 on the Keysight DSOX1202G and open the PicoScope 6 software. To test the connection between the PicoScope, use the waveform generator to create a 100Hz Sine wave with a peak-to-peak amplitude of 200mV. This can be accessed via the button with the triangular wave icon at the right-hand side of the top control panel on the application window.

Now, a custom waveform can be generated using Python, Wolfram Mathematica or even excel (doable but clunky). Creating a signal from this sequence of bits, we will need to duplicate multiple discrete samples per bit of data, i.e. for a sequence {0,1,….} we will want to create a signal that has 10 sample points per bit in the sequence. i.e. {0,0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,1,…….}

Using save the data as a CSV file.

Return to the PicoScope 6 software and in the waveform generator chose the arbitrary function and in the panel that opens import the data sequence you created into the software. You can set the signal amplitude to 200mV peak to peak and enable the generator output so you see the random bit sequence on the Keysight Oscilloscope.

Using the oscilloscope for eye diagram analysis

To create an eye diagram using the oscilloscope, press the display button, enable the infinite persistence, and the scope should display on the screen something similar to Figure 1. This is called the eye diagram, or eye pattern, and we can use this to determine certain parameters about a signal as it visually depicts the change in voltage levels in the modulated signal. From the shape we can infer the average time between bits in the digital signal

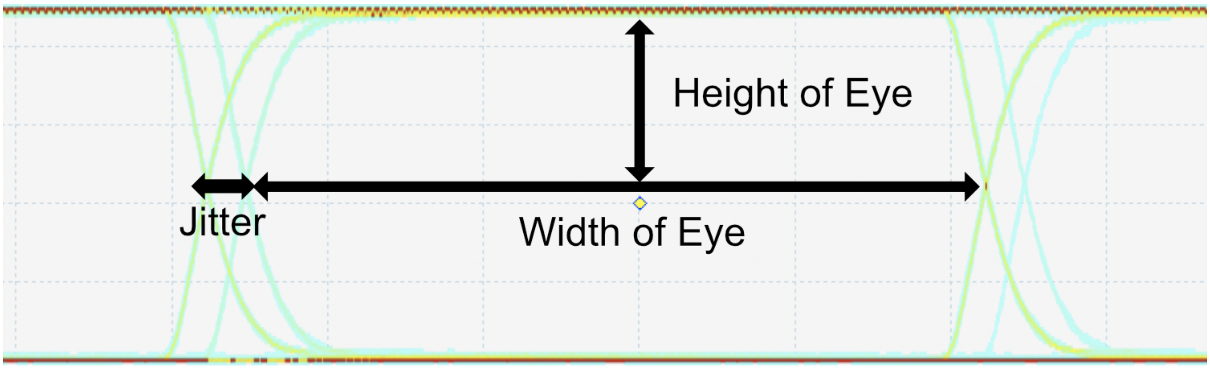

Figure 1 The height of the eye is the clear area in the middle where no trace lines are visible. The width of the eye is the clear area in the middle of the eye shape.

Trigger Settings

Triggering is important in any sampling as this determines the relative time between samples, however when the trigger is not set correctly this can lead to distortions in measured signals or errors in streams of data in a communication system. By pressing the Trigger button, the soft keys will allow you to change the type of trigger used and level used to determine the trigger time. Using the edge trigger, vary the trigger level and observe what happens to the Jitter for different trigger values. Why do you think there is a variation between these different settings?

Next, choose the trigger setting that leads to the smallest jitter and using the cursors, measure the time of the jitter.

Using the PicoScope 6 software, increase the frequency of the signal generated to 50Hz, 100Hz, 200Hz, and 300Hz. What happens to the shape of the eye? Can you determine what the symbol rate is from the eye diagram based on the changes you see? Do these link to frequency selected from the PicoScope? If not, what might be the reason?

Save images of the scope screen to support the statements you will make in your report.

Hint: Remember to clear persistence after every change.

Height and Width of the eye

Using the cursors, measure the height and the width of the eye diagram and keep a note of these in your lab book. Next, using the same signal you generated in the previous task add AWGN random noise to this signal with an a SNR of 24dB, 18dB, 12dB, 8dB and 6dB. Remember, SNR is a power ratio, therefore you will need to consider the RMS voltage for the signal wave to determine the RMS voltage for the noise (hint a quick google search will help you out).

Also, noise can vary between every one of the 10 samples per bit in your signal, so you need to generate the same number of noise samples as signal samples.

Your signal may now vary greater than a value of 1, to prevent errors when importing into PicoScope 6 you need to rescale the signal so that all the numbers are a ratio of the maximum numbers in your signal data.

By importing each waveform into PicoScope 6, one at a time, generate a signal with 200Hz and if you can see a clear eye, measure the height and width of the eye diagrams. What happens to the height and width of the eye with changes in SNR? Can you always clearly see a clear eye for each SNR?

Save images of the scope screen to support the statements you will make in your report.

Limited Link Bandwidth

Using the **Math function** on the Oscilloscope, select **Low Pass Filter,** initially set the bandwidth to 10MHz. Turn off the live time domain trace by double pressing the **1** key and enable infinite persistence for the **Math function**. Next, slowly reduce this bandwidth down to 40kHz, note any changes you see in the eye diagram, especially to the corner areas. Why do you think the eye diagram changes the way it does as you lower the bandwidth?

Save images of the scope screen that will support the statements you will make in your report.

PAM-4

In the previous examples we have used an on-off keyed bit sequence. Next, we want to generate a PAM-4 modulated signal, i.e. a signal that has 4 voltage levels so that we can send 2 bits of data at the same time instead of 1 bit in on-off keying. You can then generate a set of CSV files for modulated signals with SNR of 24dB, 18dB, 12dB, 8dB and 6dB.

On the oscilloscope, turn off the **Math function**, and look at the live trace from channel 1. For each case, again measure the height and width of the eye diagram. What do you notice when the SNR increases? By comparing the results for the same SNR for NRZ and PAM4, what differences do you see?

Save images of the scope screen to support the statements you will make in your report.

Shannon Hartley theorem tell us that the effective number of distinguishable voltage levels *M* is linked with the signal to noise of the systems. How does this link to what you see from the results on the scope?

$$M = \sqrt{1 + \frac{S}{N}}.$$

Further reading here*: https://en.wikipedia.org/wiki/Shannon–Hartley_theorem*

Lab Report

Using the submission link on Moodle, write a short report describing the experiment, any key findings, and specifically reference:

1) Using appropriate experimental data or images, explain the linkage of the height and width to the SNR of the signal.
2) Using appropriate experimental data or images, explain the linkage between SNR and the Shannon Limit (in bits/s/Hz) for a PAM-4 signal.

This report should be 3 pages maximum. Please plot any data recorded with appropriate headings, axes labels, and add these into the report as in-line figures with captions. The document should be uploaded as a PDF within 7 days of your in-person lab.