

Lab Manual:  
Communications Principles  
  
Using the EMONA Communications board for NI ELVIS III



Lab 14: SNR & BER measurements

List of Updates

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| **Date** | **Details** |
| 2/16/2019 | Completed final document |
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# Lab 14: SNR & BER measurements

## Learning Objectives

After completing this lab, you should be able to complete the following activities.

1. Create an eye diagram
2. Identify the optimum sampling point in a noisy signal
3. Calculate Signal to Noise measurements
4. Calculate Bit Error Rates (BER) for digital signals
5. Plot BER vs. SNR diagrams for a digital signal
6. Create a noisy baseband channel between transmitter and receiver

## Prerequisites

You should have completed Lab 1 and Lab 2 and be familiar with the equipment, its use and the handling precautions for the equipment.

## Required Tools and Technology

|  |  |
| --- | --- |
| Platform: NI ELVIS III Instruments used in this lab:   * Oscilloscope-Time * Oscilloscope-FFT * Function Generator | * Install Instruments: [http://www.ni.com/documentation/en/ni-elvis-iii/latest/getting-started/installing-the-soft-front-panel/](http://www-preview.ni.com/documentation/en/ni-elvis-iii/1.0/getting-started/installing-the-soft-front-panel/) * Access instruments   <https://measurementslive.ni.com>   * View User Manual   <http://www.ni.com/en-us/support/model.ni-elvis-iii.html>   * View tutorials <https://www.youtube.com/playlist?list=PLvcPIuVaUMIWm8ziaSxv0gwtshBA2dh_M> |
| Hardware: Emona Communications Board Components used in this lab:   * Four BNC to 2mm banana-plug leads * Assorted 2mm banana-plug patch leads * Set of headphones or earbuds | * View User Manual <http://www.ni.com/en-us/support/model.emona-communications-board-for-ni-elvis-iii.html> |
| Software: NI ELVIS III Function Generator Files used in this lab:  ECB\_positive1V\_DC.csv  ECB\_1Vrms\_noise\_20kHz.csv | * Access instrument <https://measurementslive.ni.com> |
| Software: LabVIEW 2018 or later  LabVIEW 2018 ELVIS III Toolkit SP2 or later  LabVIEW 2018 code used in this lab (Provided with ECB):  ECB\_EYE\_BER\_CONSTELLATION viewer\_LV2018 |  |

## Expected Deliverables

In this lab, you will collect the following deliverables:

* Calculations
* Data from measurements
* Observations

Your instructor may expect you complete a lab report. Refer to your instructor for specific requirements or templates.

## Section 1: The noisy baseband channel

## 1.1 Theory and Background

Your studies of communications and telecommunications so far will have inevitably included the issue of noise. Noise is important because it interferes with the reproduction of the message at the receiver. For analog messages such as speech and music, noise can be heard as hiss, crackle and pops that are superimposed on the recovered message. For digital messages such as data, noise results in corrupted bits: that is, bits read incorrectly. In both cases, information is lost.

It’s not a surprise then that the noise performance of modulation schemes and systems is quantified, especially when we want to compare between them. A widely used method for doing so is *signal-to-noise ratio* (SNR). As its name implies, SNR is simply the ratio of signal voltage (or power) to noise voltage (or power). The equation for calculating SNR is:

Where: S = signal voltage or power; and

N = noise voltage or power



The greater the signal relative to the noise (which is desirable), the greater the SNR. That said, simple ratios can be misleading when dealing with signals and so decibels are often preferred. The equation for calculating SNR as a decibel is either:

 or 

To perform these calculations, a measurement of the signal’s voltage (or power) and the noise’s voltage (or power) must be made. In most laboratory environments, the noise is controlled and can be removed from the signal. This makes separate measurements of signal and noise a relatively simple matter. However, in the field, the signal may not be available alone and so an alternative calculation must be used:



Obviously, the two SNR ratio equations produce different numbers. However, the greater the SNR of the system the smaller the difference between the values.

Importantly, the spectral composition of noise usually results in peak and peak-to-peak voltages that vary randomly and so it’s difficult to obtain a precise measurement of these. And, unless a test signal such as a sinewave is used, the peak and peak-to-peak voltage of message signals can vary also. That being the case, it’s better to measure the RMS value of signal and noise voltages for SNR calculations.

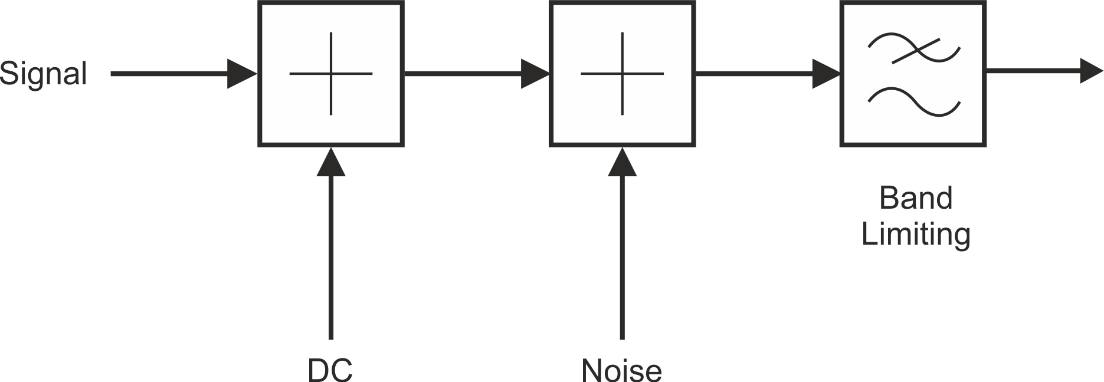


Figure 1: block diagram of noisy channel

In order to understand the noise added to the signal in the channel we can model the noisy channel as having an additive noise component and a band limiting component. These components are shown in Figure 1.

The measurements of the S and N signals are taken at the front end of the receiver in order to take account of the band limiting effect of the channel on both the signal and the noise.

## 1.2 Implement: Model the noisy band-limited channel

For this experiment you’ll use the Emona Communications board blocks to add noise to a message (a digital data signal) at baseband. This signal will then be band-limited to model both a channel’s band-limited nature AND any low pass filters at the receiver front end. The distorted signal at the receiver will be typical of a signal passing through a real-world channel. Phase delays from the channel will also be present in this model. You’ll then use this signal for determining signal-to-noise ratio figures for a variety of noise levels. As well, you observe the effects of noise and band-limiting on digital data signals using Eye Diagrams.

It should take you about 45-60 minutes to complete this experiment.

**Powering up the ELVIS III + EMONA Communications Board**

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| --- | --- |
| 1. | Ensure that the NI ELVIS III Application Board power button at the top left corner of the unit is OFF (not illuminated). |

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| 2. | Carefully plug the Emona Communications board (ECB) into the NI ELVIS III ensuring that it is fully engaged both front and back. |

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| 3. | Ensure that you have connected the NI ELVIS III to the PC using the USB cable and that the PC is turned on. |

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| 4. | Turn on the Application Board *Power* button by pressing it once and confirm that it is illuminated. The LEDs on the ECB should also be illuminated. If they are not, then switch the unit off immediately and check for connection or insertion errors. |

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| 5. | Open the Instrument Launcher software in your browser and select and RUN the following instruments. |

Table 1 Function Generator Configuration

|  |  |
| --- | --- |
| Channel 1 | Custom |
| Update rate | 1kS/s |
| Waveform file | ECB\_positive1V\_DC.csv |
| Gain | **-1 (NB: negative gain !)** |

Table 2 Function Generator Configuration

|  |  |
| --- | --- |
| Channel 2 | Custom |
| Update rate | 100kS/s |
| Waveform file | ECB\_1Vrms\_noise\_20kHz.csv |
| Gain | 1 |

To determine signal-to-noise ratio, you need a model message signal with noise added to it. The first part of the experiment gets you to set one up. For this purpose, any signal can be used to model a message including a sinewave, speech or a digital data signal. We’ve decided to use a digital data signal as most new communications systems these days are digital and you’ll be able to use the signal when you investigate Eye Diagrams later in the experiment.

The SEQUENCE GENERATOR has two independent sequences, X & Y.

X is a short sequence, repeating after 31 bits, whereas Y repeats after 255 bits. Conveniently, X has a bipolar output but Y does not. It only outputs as a 0-5V level signal. The longer sequence is best for detailed noise measurements as so in this experiment we will be using the Y sequence and level shift it to become bipolar before transmission through the channel.

* 1. Why is a longer sequence preferable than a short sequence for noise measurements?

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* 1. Why do you need to level shift the digital signal to become bipolar?

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| 6. | Connect the set-up shown in Figure 2.  **Note:** Insert the black plugs of the oscilloscope leads into a ground (*GND*) socket. | |

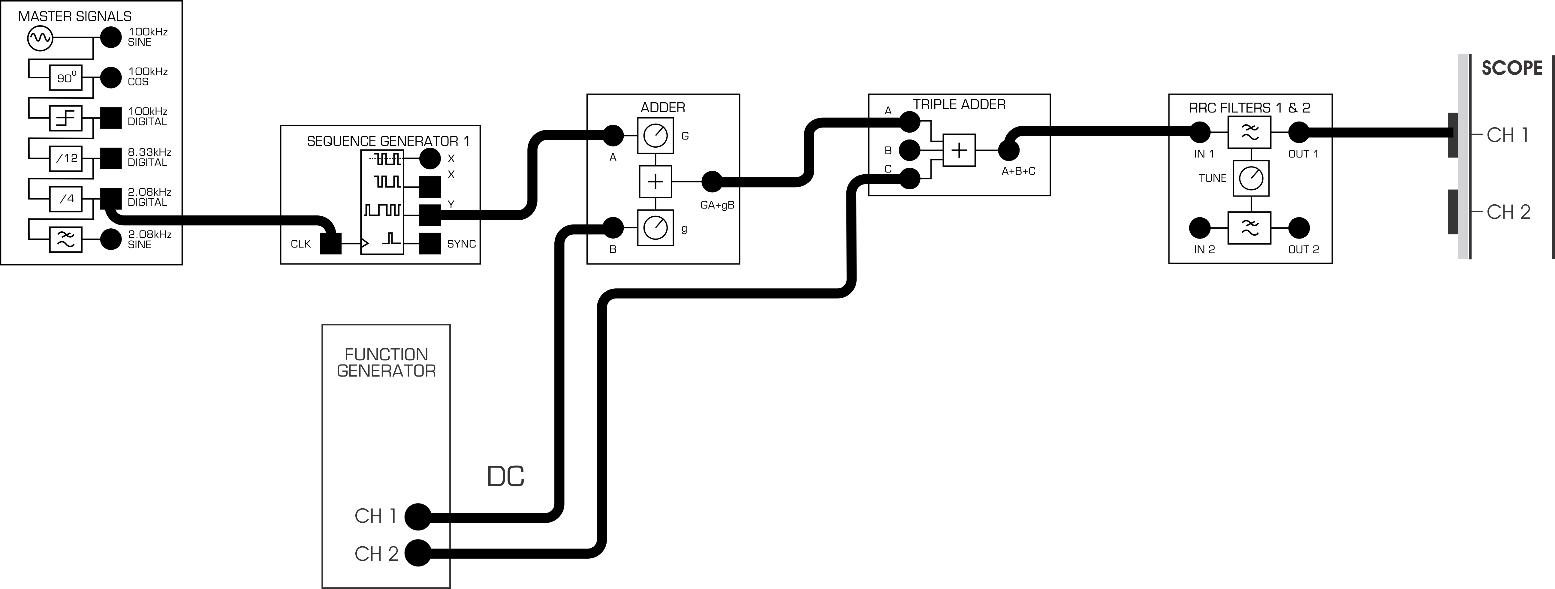


Figure 2: Patching for level shifting, additive noise & bandlimiting at baseband

This set-up can be represented by the block diagram in Figure 3 on the next page. The SEQUENCE GENERATOR module is used to model a digital data signal for a message and the TRIPLE ADDER module is used to add noise from the Noise Generator module’s output to it.

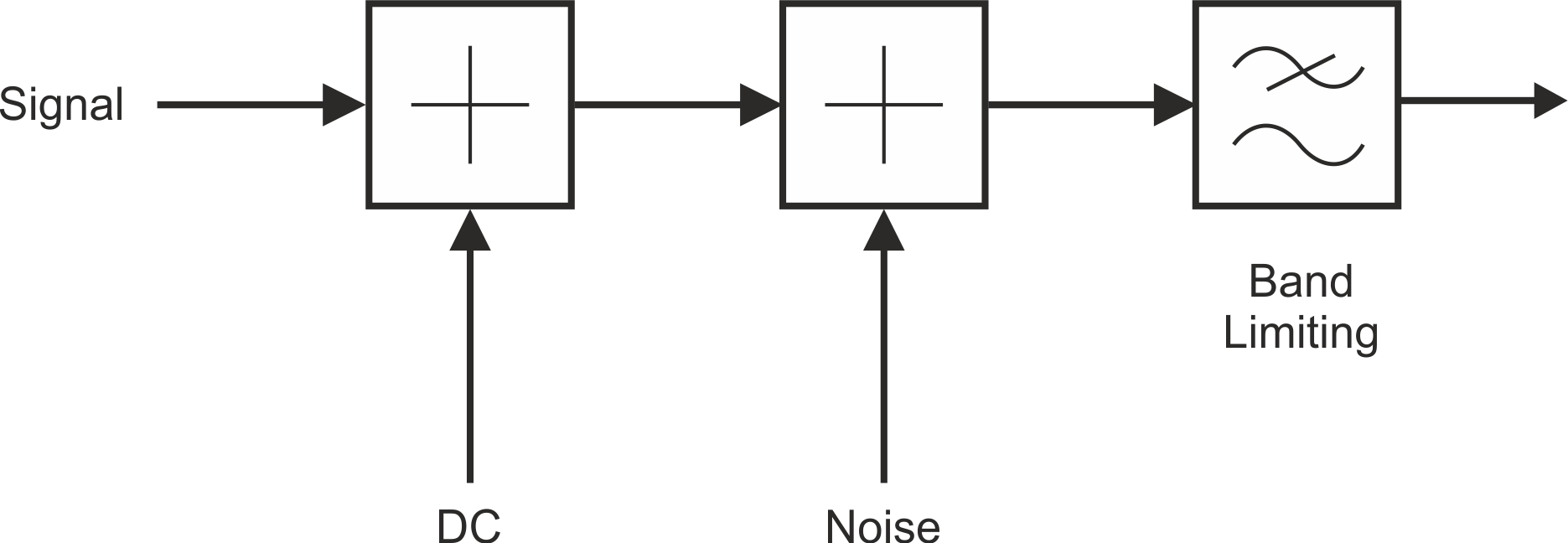


Figure 3: Block diagram for level shifting, additive noise & bandlimiting at baseband

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| --- | --- |
| 7. | Launch and run the NI ELVIS III Oscilloscope instrument. |

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| 8. | Set up the scope per the procedure in Experiment 1 with the following changes: |

Table 3 Scope Configuration

|  |  |
| --- | --- |
| Channel Voltage range | 1 V/div |
| Horizontal Timebase | 100ms/div |
| Trigger | Immediate |
| Probe Attenuation | 1x |

|  |  |
| --- | --- |
| 9. | Activate the scope’s Channel 1 to observe the output of the RRC FILTER 1 with Channel 1. |

|  |  |
| --- | --- |
| 10. | Remove the noise signal which comes from FUNCTION GENERATOR Channel 2, by temporarily unplugging this noise lead from the input C of the TRIPLE ADDER, so only the data signal is viewed on Channel 1. |
| 11. | Set the RRC FILTER 1 ‘TUNE’ control knob to fully clockwise (maximum corner frequency). |
| 12. | Vary the ADDER gains G & g until the output has an amplitude of approximately 1V peak with zero DC offset. Adjust this further whilst viewing the Measurements tab of the scope instrument, and set the RMS value to as close to 1V as possible.  HINT: having a scope timebase of 100ms/div will assist in having a stable value to tune. |

Now that you have a bipolar digital signal you will add noise to the signal. This added noise is modeling the addition of noise in the transmission “channel”. Since the noise is being added it is typically called an “Additive White Gaussian Noise” (AWGN) channel. This assumes the added noise is gaussian, however you could in practice add other types of noise to your modeled channel.

In this experiment we have a baseband channel, in that the signal has not been translated in frequency up to the carrier range and back again. Typical baseband channels are data signals running on ethernet cables or even data signals on busses between circuits.

The TRIPLE ADDER module sums the three inputs with unity gain. If an input is not connected, its contribution to the sum is zero. The output from the TRIPLE ADDER is the sum of the signal plus the noise.

* 1. Replace the noise signal, and remove the signal by unplugging the signal lead from the input A of the TRIPLE ADDER. What is the RMS voltage of the noise only ? (HINT: for a stable reading, set scope timebase to 100ms/div)

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* 1. What observations can you make about the level of noise compared to the level of the signal both quantitatively and qualitatively?

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Replace the signal lead into the TRIPLE ADDER so you have both signal and noise present.

With so much noise it is hard to imagine how any amount of the signal can be utilized at the receiver. Typically, a channel with have its own particular frequency response which bandlimits the original signal. As well this response will bandlimit the noise as well. A receiver will often have bandlimiting on its input to eliminate any signals which are out of band such as additive noise. In this next part of the experiment we will model this bandlimiting with a single filter RRC FILTER 1.

|  |  |
| --- | --- |
| 13. | View the output of the RRC FILTER 1 filter with scope Channel 1 whilst viewing the input to this filter with Channel 2. Both channels should be set to 1V/div. |
| 14. | Starting with the TUNE knob set to fully clockwise (maximum corner frequency), turn the knob to approximately the 9 o’clock position whilst viewing the signal. Notice how the noise is heavily attenuated. |

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| --- | --- |
| 15. | Remove the added noise by unplugging the noise lead from the TRIPLE ADDER C module. Move Channel 2 to view the bit clock (2.08kHz) and trigger the scope on the bit clock. Adjust the scope timebase to 500us/div and Channel 2 voltage range to 2V/div. Settings are shown in Figure 4. |

|  |  |
| --- | --- |
| 16. | Adjust the RRC FILTER 1 TUNE control knob to place the positive edge of the bit clock in the middle of the bandlimited data signal as shown in Figure 4. Use Single mode on the scope to check the accuracy of your setting.  Once this sampling instant has been set, do not vary this RRC1 TUNE setting anymore. |

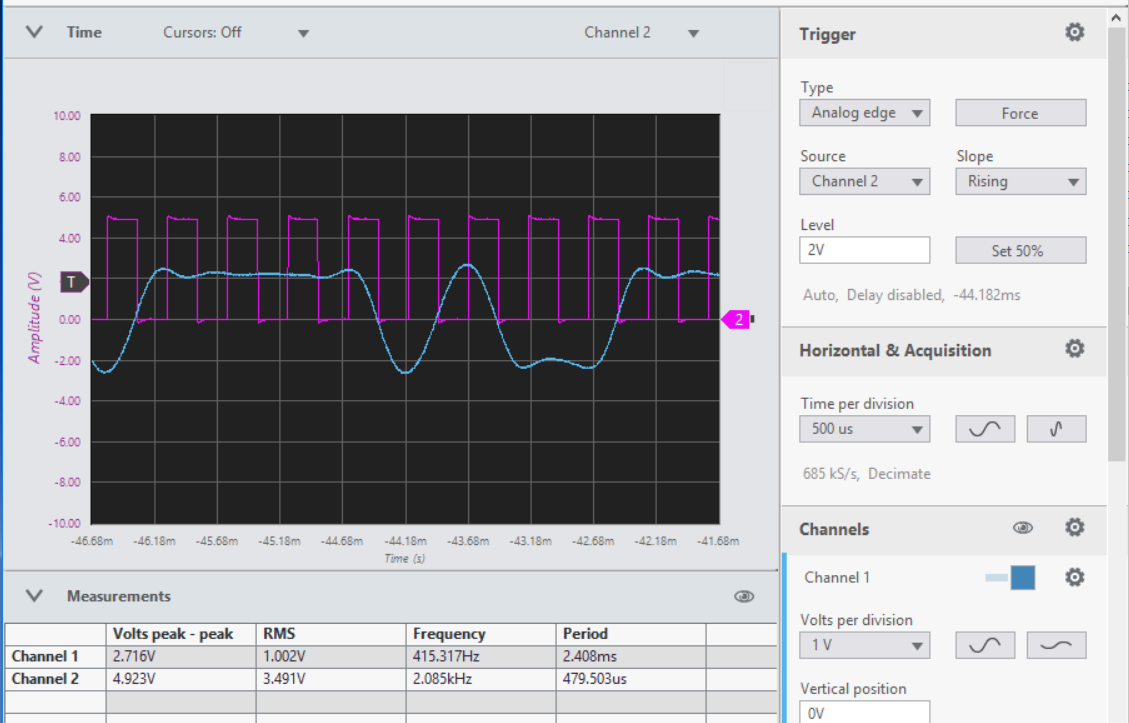


Figure 4: Sampling occurs at the bit clock positive edge

The SAMPLE & HOLD module which will be used in the next section and will input this signal to sample the incoming data signal at the positive edge of the bit clock. This will sample each bit at precisely the instant at which the signal itself (without noise) is at a maximum, as shown above in Figure 4.

## 1.3 Implement: Setting the 0 dB reference point for BER measurement

With the sampling instant already setup we are ready to begin taking BER measurements. It is helpful to have a reference point of 0 dB S/N ratio. This is a 1:1 ratio of signal to noise.

Remember, the dB value of a S/N ratio is 20 log10(S/N).

Next we will again measure the S & N levels and set them equal. Viewing the signal will be at the output of the TRIPLE ADDER.

* 1. Remove the noise signal by unplugging the noise lead from the input to the TRIPLE ADDER (it should already be removed from the previous step). What is the RMS voltage of the signal only ? (HINT: set timebase to 100ms for stability)

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* 1. Replace the noise signal, and remove the signal by unplugging the signal lead from the input to the TRIPLE ADDER. What is the RMS voltage of the noise only?

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Notice that the noise level is lower than when previously measured.

* 1. Why is the noise level lower than previously measured in Section 1.2?

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| 1. | Connect the noise signal from the FUNCTION GENERATOR to the AMPLIFIER module and take that amplifier’s output to the TRIPLE ADDER. This allows you to adjust the noise level considerably. Adjust the noise level until it measures the same level as the signal alone (which you measured in Question 1-5) |

|  |  |
| --- | --- |
| 2. | Replace the signal lead into the TRIPLE ADDER A so you have both signal and noise present. |

Be careful to not make any changes to the knob control settings as the reference point of S/N = 1 (or 0 dB) is now set up.

## 1.3 Implement: Setting up the BER instrumentation

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| 1. | Modify the set-up as shown in Figure 5 to include the BER instrumentation. |

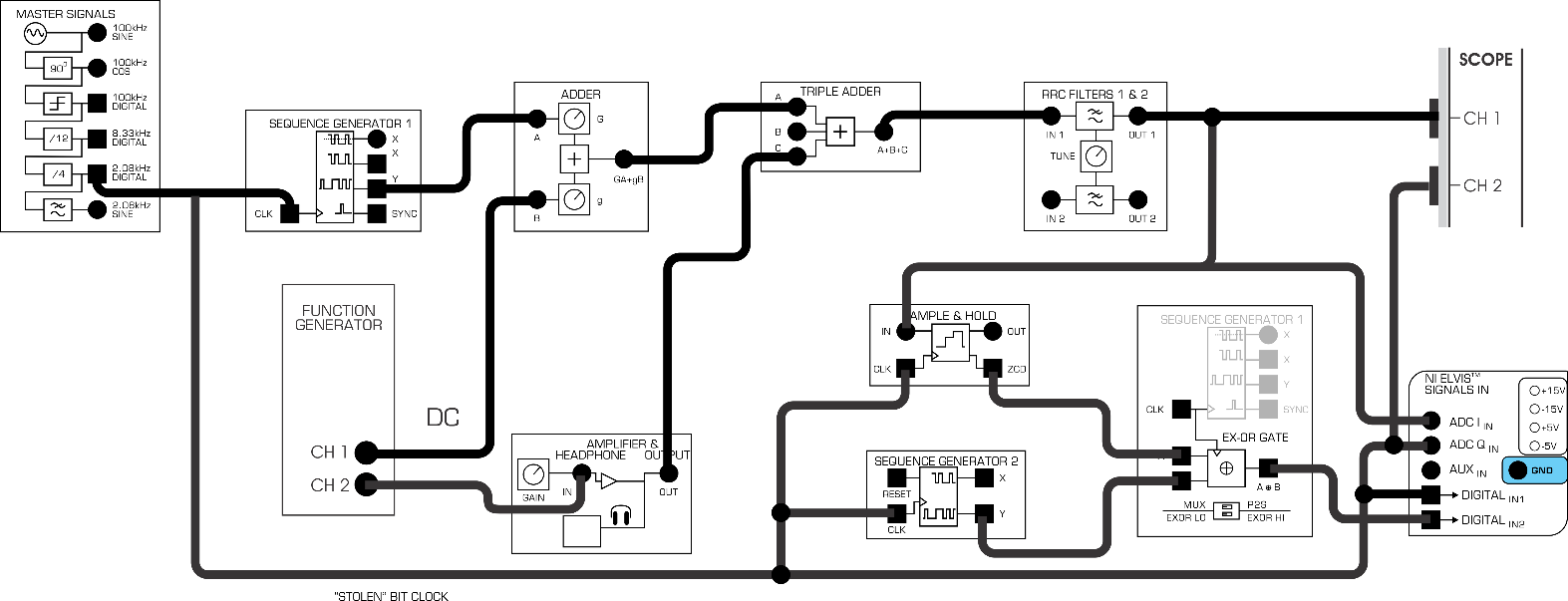


Figure 5: Patching to include BER instrumentation.

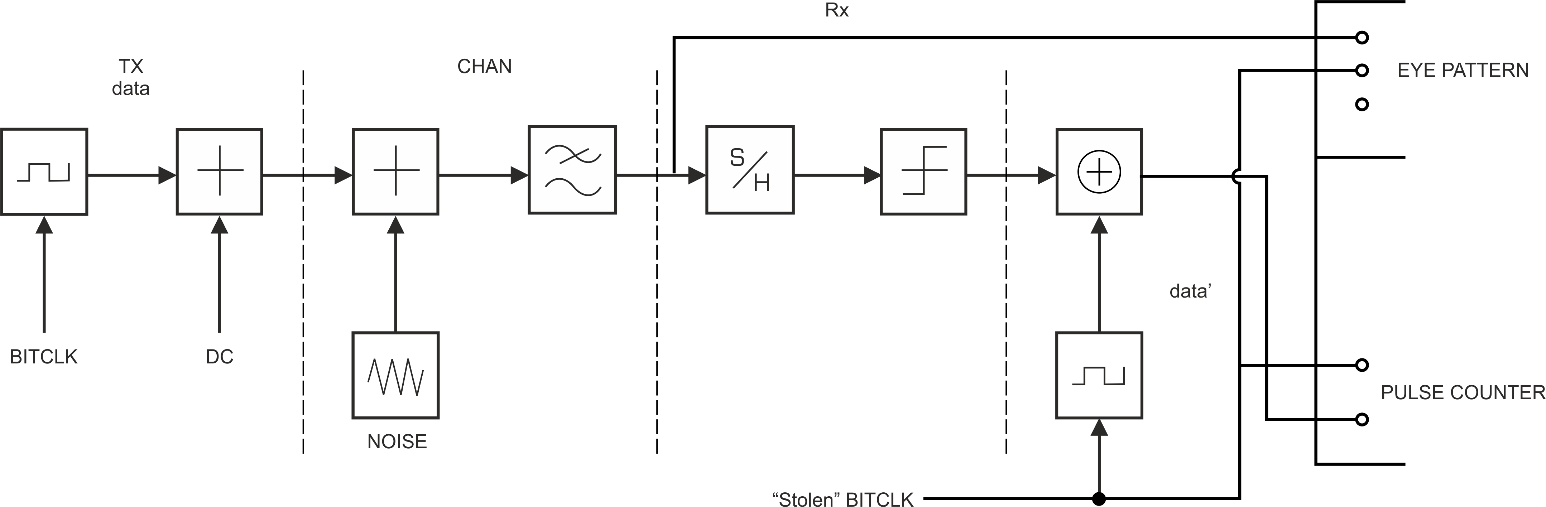


Figure 6:Block diagram of TX:CH:RX model including the BER instrumentation

The output from the SAMPLE & HOLD is the recovered data bit sequence. To measure the effect of the noisy channel on this data we will compare this known and repetitive sequence with a local replica of the sequence. We will also need to synchronize the recovered stream with the local stream so we can compare them one bit at a time.

A local replica sequence is available at SEQUENCE GENERATOR 2; output Y.

The EX-OR GATE module is used to “compare” the two sequences once synchronized.

* 1. Why is an EX-OR logic function useful ?

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Any errors will be output as half-bit-width pulses at the EX-OR modules output.

To implement the synchronization we firstly need to eliminate ALL the noise so that we have a zero-error sequence being recovered to synchronize the local sequence to.

|  |  |
| --- | --- |
| 2. | Remove the noise by unplugging the noise lead from the TRIPLE ADDER C. |

|  |  |
| --- | --- |
| 3. | View the EXOR output pulses with Channel 2 of the scope (Timebase to 2ms/div). There should be a steady stream of half-bit pulses. |

|  |  |
| --- | --- |
| 4. | Attach a lead to the EX-OR output and touch its unconnected end to the RESET input of Sequence Generator 2 for 1 second whilst viewing Channel 2. Then place it aside. |

The EX-OR GATE and SEQUENCE GENERATOR 2 combination implements a “sliding window correlator” to align the sequences. Every time there is an “error” detected, this “resets” the local sequence to its first bit. This resetting continues until there are no more errors and hence the sequences are aligned. Obviously for this to work both sequences need to be error-free.

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| 5. | Confirm that the pulses have stopped completely. |

* 1. Why do the pulses stop after synchronization?

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| 6. | View both inputs to the EXOR module with Channel 1 & 2 of the scope and confirm that they are the same and are synchronized (aligned). |

At this point if the bit clock is not varied or removed, then the transmitter and receiver local sequences will remain synchronized in time, no matter what the noise level is because we are “stealing” the bit clock from the transmitter and the clock timing circuit is not affected by noise in the analog signal path in our experimental setup.

This is convenient so that now we can vary the noise in the channel and take multiple measurements of the error rate at the receiver.

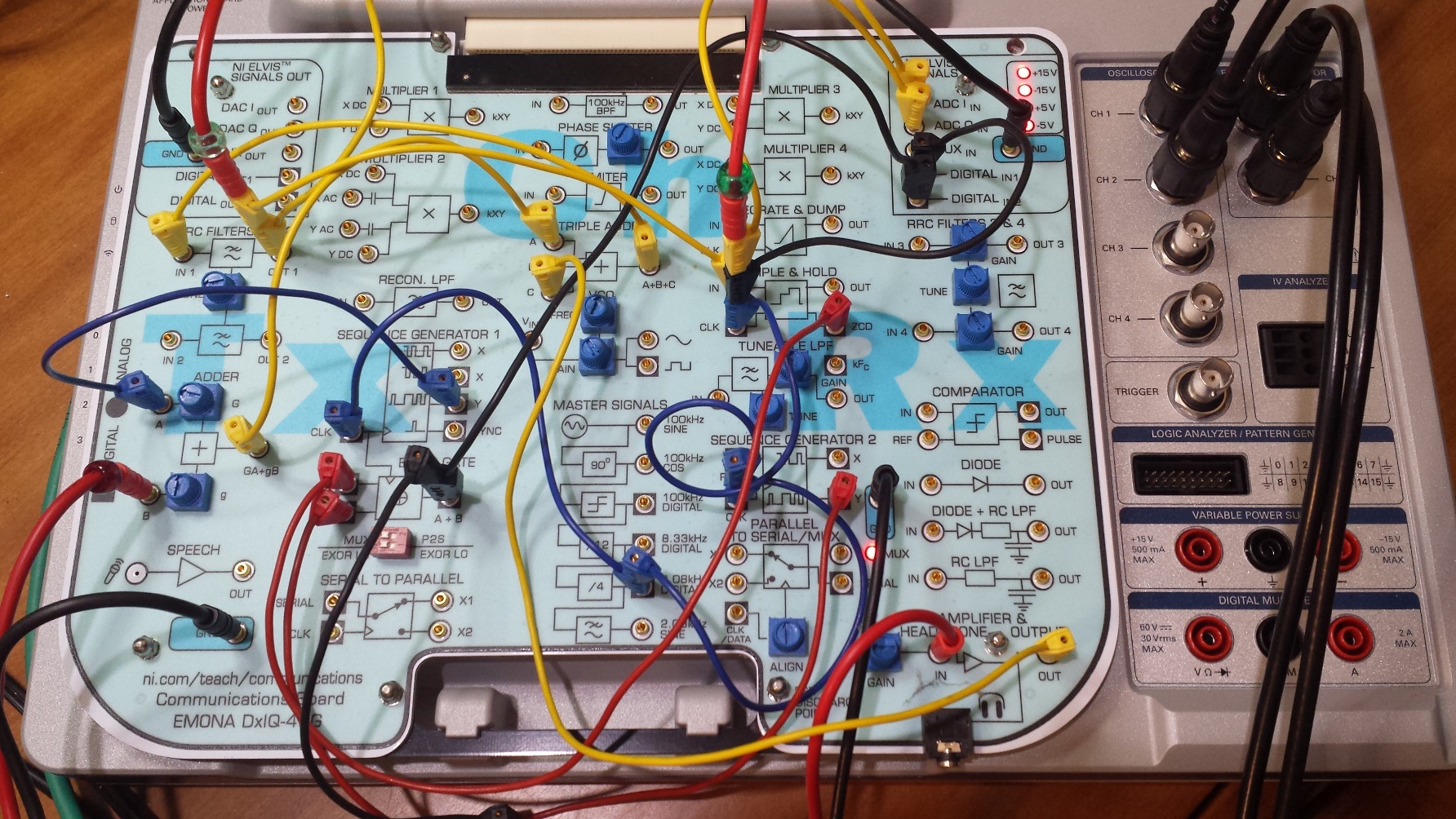


Figure 7:ELVIS III & ECB board with patching

## 1.4 Implement: Eye Patterns and BER vs. SNR measurements

A more insightful way of viewing noisy data is known as the “Eye Pattern” or “Eye Diagram”. This is simply the overlay of multiple bit periods over a period of time with persistance. Triggering on the bit clock is essential to achieve the alignment of the bits to be viewed.

|  |  |
| --- | --- |
| 1. | Launch the supplied instrument “ECB\_EYE\_BER\_CONSTELLATION viewer” by running the file “ECB\_EYE\_BER\_CONSTELLATION viewer\_LV2018”. You will need to “stop” the ELVIS III scope instrument as the Viewer software uses the scope resources itself. Ensure the scope leads are connected as per Figure 5. |

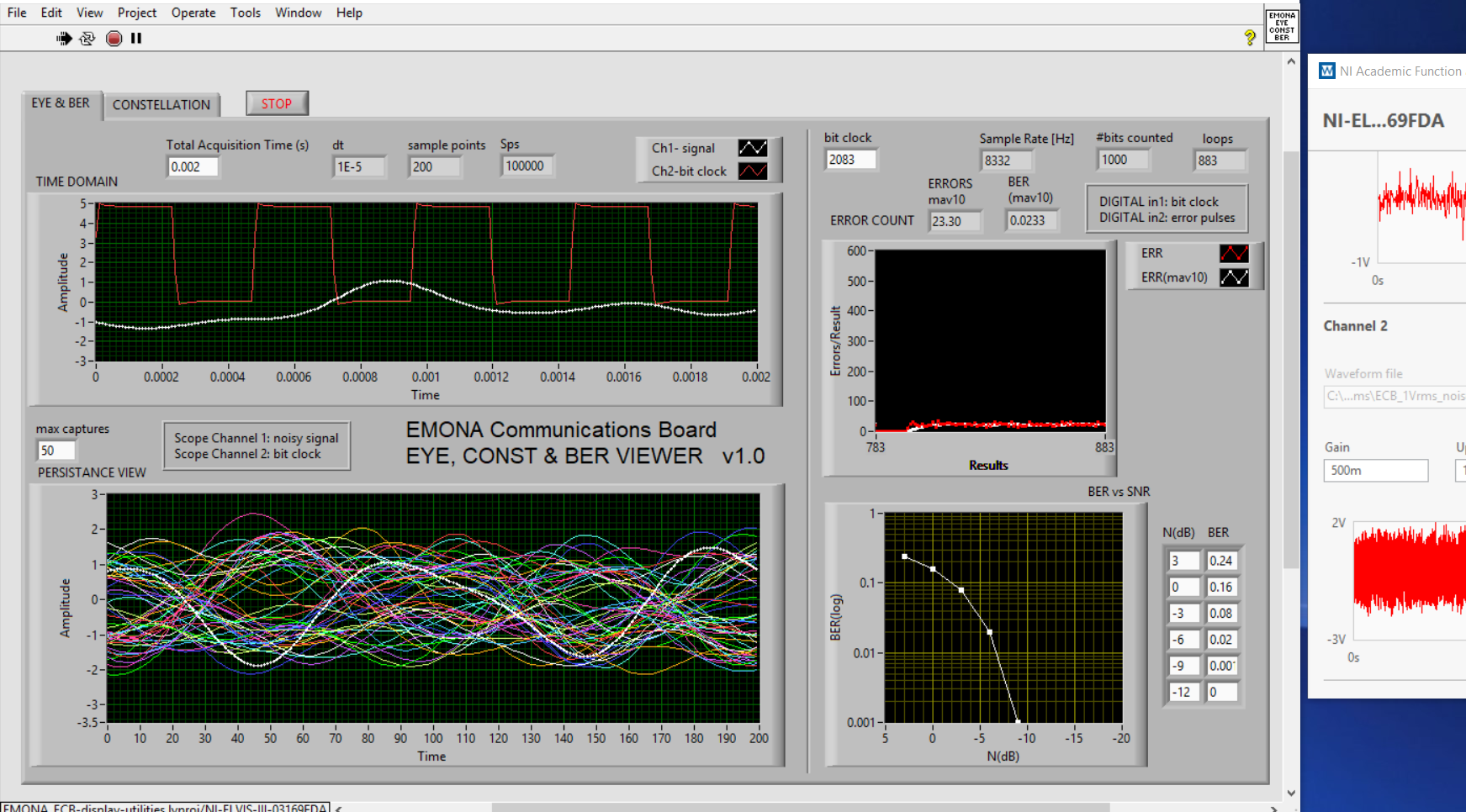


Figure 8: Example of eye pattern and BER plot using the “viewer” software

The viewer software has 4 sections.

1) a Time Domain display for both scope channels 1 & 2.

2) a Persistence view, where Channel 1 is overlaid a number of times and is triggered by Channel 2 connected to the bit clock.

3) bit error rate counter ERROR COUNT, which displays both the actual count and the moving average of the count.

4) Table and plot of the BER vs SNR values

Once you have the instrument running you can view the recovered signal in the time domain as well as in an Eye Pattern. You can also see the current error rate being measured, as the count of error pulses divided by the bit clock periods. The BER instrument is counting both of these signals.

Note that you will not be changing the signal level at all. Only the noise level will be changed.

|  |  |
| --- | --- |
| 2. | Reconnect the noise signal to the TRIPLE ADDER. |

Starting at N = +3dB (ie:SNR = -3 dB), the measurements procedure is as follows and should be tabulated into the Table 4 below:

Table 4

|  |  |  |  |
| --- | --- | --- | --- |
| **N (dB)** | **N (V/V)** | **S/N (dB)** | **BER** |
| +3 | 1.4 | -3 |  |
| 0 | 1 | 0 |  |
| -3 | 0.71 | 3 |  |
| -6 | 0.5 | 6 |  |
| -9 | 0.35 | 9 |  |
| -12 | 0.25 | 12 |  |

|  |  |
| --- | --- |
| 3. | Set the noise level by entering the relative noise level into the FUNCTION GENERATOR 2‘Gain’ setting, starting with Gain = 1.4. You will control the relative gain of the noise via this setting. |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 4. | Wait for about 15-30 seconds and then note the error rate at the MAV10 indicator. This is the moving average of the last 10 rates values.  Most importantly, observe the eye pattern as you change the noise level. Even though the eye appears “closed” there are not as many errors occurring as you might expect from viewing the eye pattern.  1-10 Why are so few errors occurring although the eye appears closed most of the time at certain noise levels?   |  | | --- | |  | |  | |  | |

|  |  |
| --- | --- |
| 5. | Vary the noise to the next suggested level from the table and repeat these steps 4 & 5. |

You do not need to re-synchronize the sequences each time. Remember, once synchronized the digital timing between the transmitter and receiver does not change even though the noise level in the signal changes.

|  |  |
| --- | --- |
| 6. | Once all readings are completed, enter them into the onscreen table in the Viewer to view the BER vs SNR plot and grab a screen capture for your report. Or even better, enter them onscreen as you go, so you can see the waterfall curve develop alongside the eye pattern and gain appreciation for the relationships being displayed. |

OPTIONAL: To see the errors occurring in real-time, view both the input to the SAMPLE & HOLD input (the noisy signal received) AND the error pulse stream out from the EX-OR GATE using the scope channels. (You will need to stop the ECB\_EYE\_BER\_CONSTELLATION viewer as it uses the scope lines and they cannot be shared.)