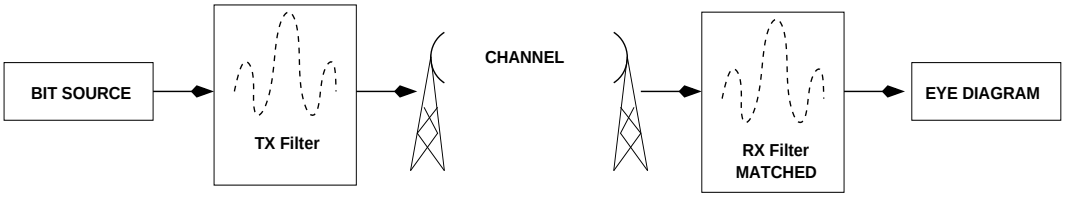
Experiment # 3

Baseband Pulse Transmission

- *Name:* *Experiment Date:*
- *Student No.:* *Day of the week:* *Time:*
- *Grade:* */ 10*



1 Purpose

This experiment will illustrate some topics on baseband pulse transmission. In the first part of the experiment, you will simulate a very simple digital communication system, from source to destination. For the implementation phase, two DSP target platforms will be used, one operating as a transmitter and a neighbouring station as a receiver. The transmitter will have a bit source and transmitter (TX) filter, and the other will have a receiver (RX) filter which will provide the output with which to produce an eye diagram. The "channel" will be comprised of the CODEC filters on both platforms, plus the coaxial cable linking them.

During the experiment you will verify some of the problems found in transmitting a pulse over a band limited channel and will study some of the alternatives to mitigate these problems.

At the end of these two parts, the following concepts should be clear:

- Limitations imposed by channel bandwidth and noise on pulse transmission;
- Inter-Symbol Interference (ISI): its causes and its effect on the signal;
- The use of square-root raised-cosine filters;
- How to use the eye diagram (or eye pattern) to detect features on a pulse train;

2 Background Reading and Preparation

Though there are many very good references on digital communications, throughout the lab portion of this course you may find useful to refer to [1], [2], [3] and [4] in addition to the course notes. It is most advantageous for you to read different authors discussing the same topic, as they will provide you with different points of view. This will help you to create a meaningful mental representation of the individual topics, and will lead to a very good understanding of the subject.

3 Experiment

There are two parts for this experiment, as usual: simulation and implementation. You will first simulate the complete transmitter (TX), channel, and receiver (RX) system using `Simulink` to see how different pulse shapes and channel bandwidths will affect the data at the receiving end. On the second part, you will run a program on the DSP that generates pulses, shapes them via a square-root raised cosine filters, passes them through a channel with noise, and then "receives" the data using a matched filter. You will be required to use concepts from Signals and Systems, DSP and Communication Systems, in addition to the knowledge gained in ECE417.

3.1 Simulation of Baseband Pulse Transmission

From `Simulink`, open the model relative to the first portion of the experiment, found in `www.comm.utoronto.ca/~bkf/ECE417/exp03/first_parta.slx`. Your model should be **somewhat similar to what is shown on** Figure 1 below.

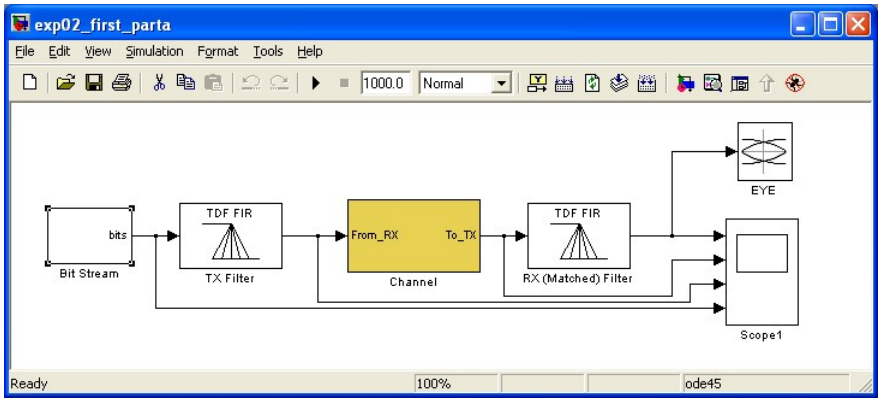


Figure 1: Simulation model for the first part

In this model, you will find two new pre-defined blocks: a bit generator and a channel. The bit generator block will generate a pseudo-random stream of bits, with the level "high" (bit 1) represented by level 1 and the "low" (bit 0) represented by -1. Also, seven zeros are inserted between bits, in order to simulate a slower "bit rate". Since all simulations in this lab use a rate of 1/48000 *numbers generated per simulation second*, this zero-padding will produce 48000 numbers

per simulation second while achieving a "simulated bit rate" of 6000 bits per simulation second. A "bit" here is either a level of 1 or -1. The bit generator is shown below on Figure 2.

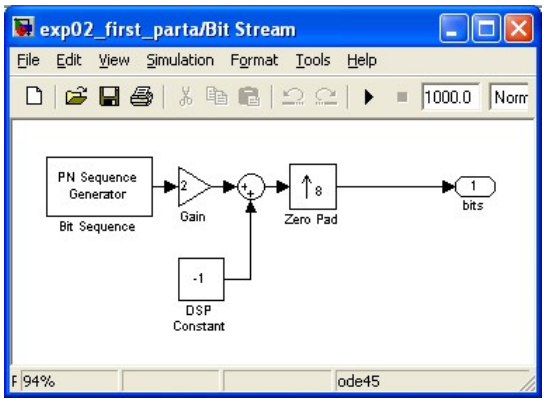


Figure 2: Bit generator block

The channel block provides you with a very simple model for a communication channel. You will simulate a channel which imposes some band limitation and noise to your signal. There are four alternatives for the signal path, which will determine the channel bandwidth from "infinite"(no band limitation) to 3KHz bandwidth (severely limited).

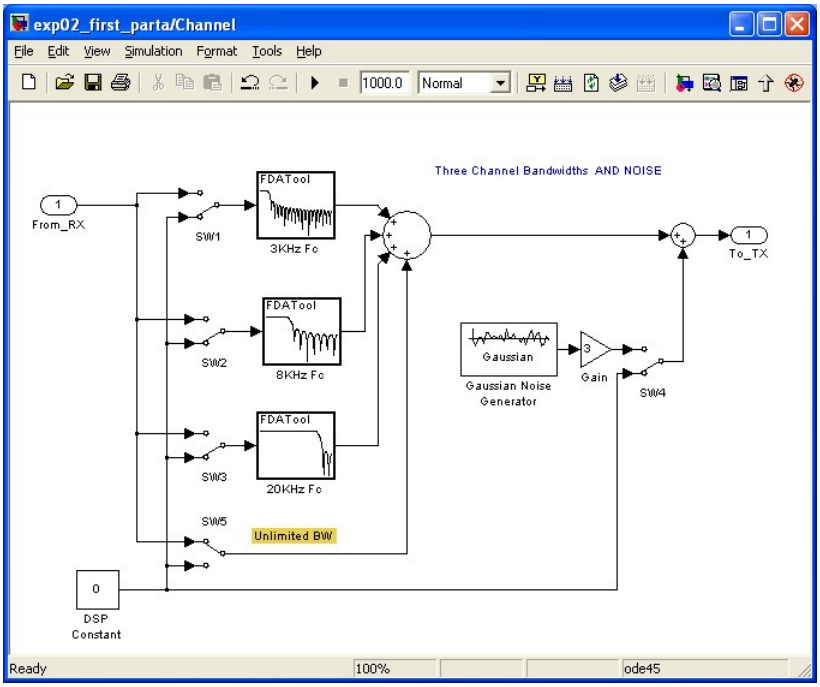


Figure 3: A simple communication channel

For obvious reasons, only one path should be used at a time; do not forget to disable all other paths when you enable one of them. Also, there is a switch for the simulation of noise added by the channel. By double clicking on the switch icon you toggle the switch. The channel model is presented on Figure 3 below. You may be required to redesign the filter(s) using the `FDAtool`.

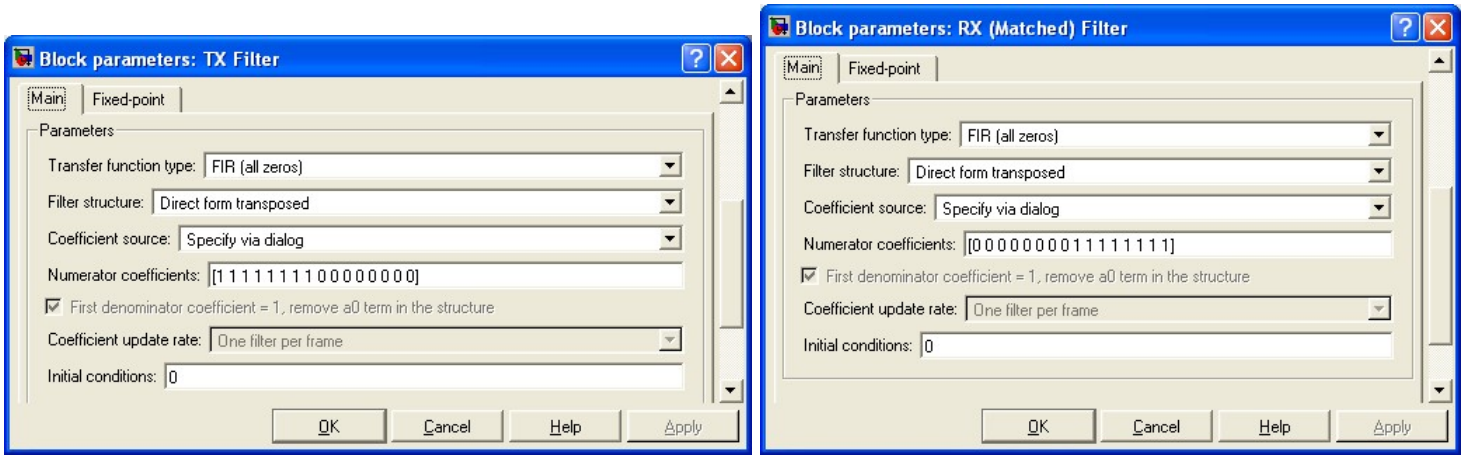
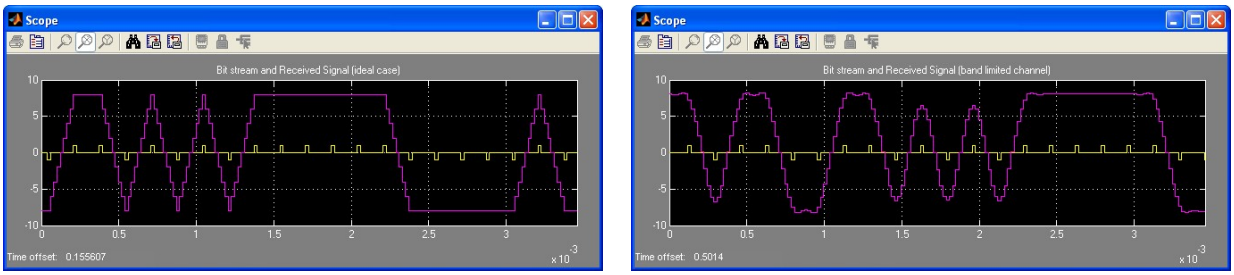


Figure 4: Transmitter and Receiver Filters

Take some time to explore the model, by double clicking on all the parts. If you believe you can implement any of the parts in a better fashion, feel free to do so. Be prepared to explain the consequences of the change. You can run and stop your system at will. You are required to find the display (scope) configuration that makes more sense to you. There is not a single configuration to do so. Run the model and configure your scope.

Here are some questions, based on hypothetical scenarios:

- *In this question, the answer is the result of a convolution. Your input stream to the TX filter is 1 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0. Draw what you should see after the RX Filter.* **(1pt)**



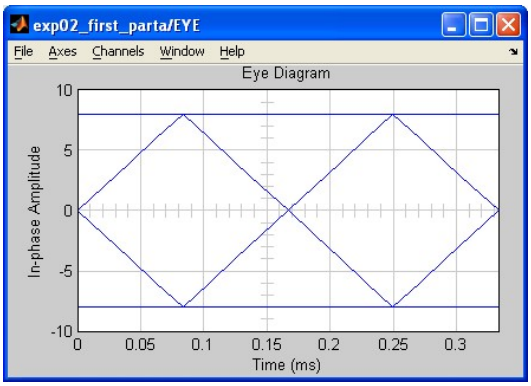
(a) Received Signal (unlimited BW)

(b) Received Signal

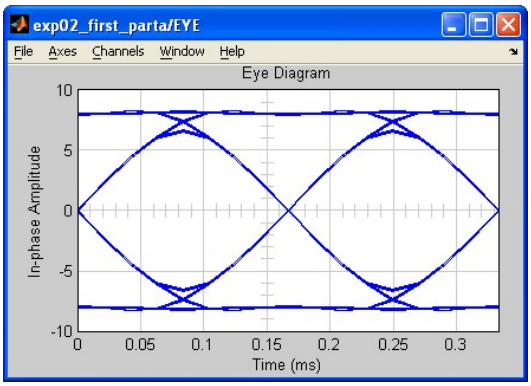
Figure 5: Scope shots for two scenarios

- *The two following questions refer to Figure 5. From the scope shot on the left (5(a)), it should be obvious that the received signal represents somehow the transmitted bit stream (otherwise, what would be the point?). Why is the received signal shaped as it is? How can you recover the bit stream from the received signal?* **(2pt)**

- *From the scope shot on the right (5(b)), knowing that the RX and TX filters have remained unchanged, what has changed now if you compare to the previous scenario? What is causing the "rounding of the edges"?* **(1pt)**



(a) Eye Diagram 1



(b) Eye Diagram 2

Figure 6: Eye Diagrams For Two Scenarios

- *Figure 6 above represent two Eye Diagrams. How are they obtained from the scope shots presented in the previous questions? Calculate the bit rate from the eye diagram.* **(2pt)**

- *Switch the channel bandwidth to the smallest bandwidth, run your model and observe that the output has changed. How did the smaller bandwidth impacted the transmitted signal?* **(1pt)**

Now open the other model found in the `www.comm.utoronto.ca/~bkf/ECE417/exp03/first_partb.slx` folder. Your new model should look **somewhat** like Figure 7 below.

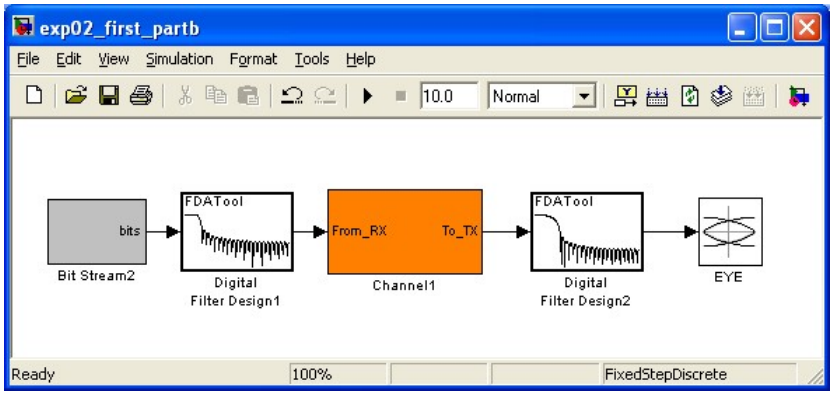


Figure 7: Simulation model for the second part

Keep in mind that the effect of the convolution of an impulse followed by zeros with the impulse response of a filter (which is some sort of *sinc* function with a finite number of samples), will be the impulse response itself. The overall response after TX filter, channel and RX filter should follow the Nyquist criterion for zero Inter-Symbol Interference. In other words, the overall response for a hypothetical unlimited channel should produce the Eye Diagram on Figure 8. The TX and RX filters for this case are general low-pass filters following the Nyquist Criterion for zero ISI.

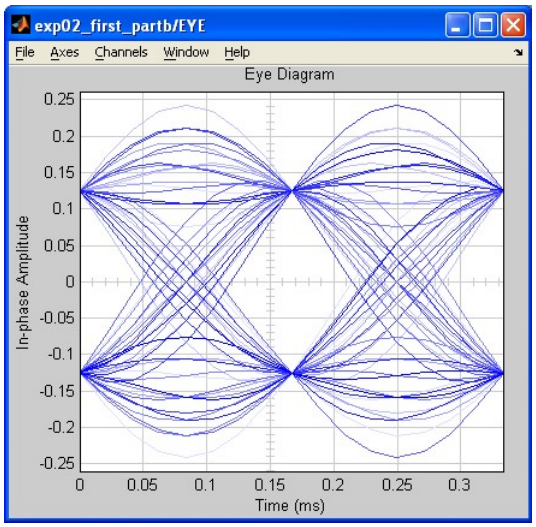
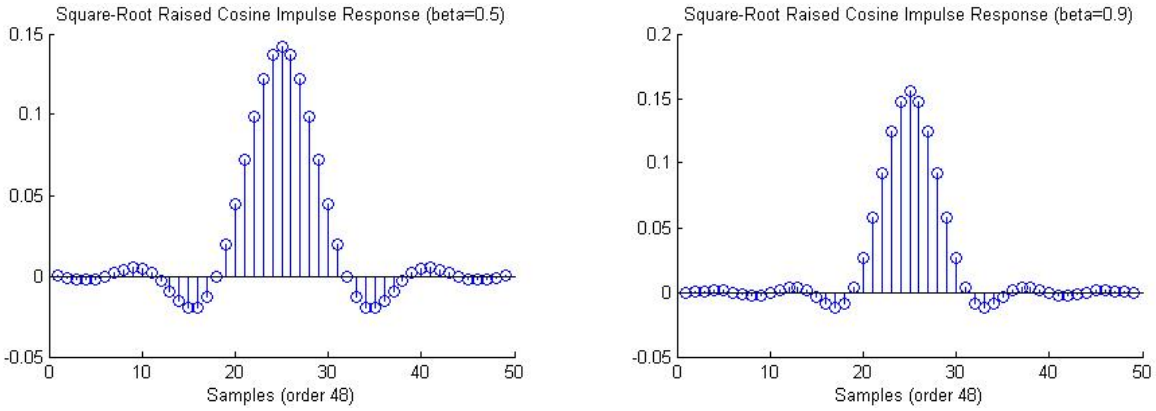


Figure 8: Eye Diagram for zero Inter-Symbol Interference

One should note that despite the fact that the diagram above presents zero ISI, there is a significant

overshoot on the response. This overshoot is a waste of energy and it can be avoided with no detriment to the detection of the bit stream at the receiving end. Square-root raised cosine filters will mitigate the problem, at the limited expense of bandwidth. Moreover, this type of filters will provide the ideal *matched* pair to improve signal-to-noise ratio (SNR). This will be seen later in the theory. The Figures 9(a) and 9(b) below present two square-root raised cosine filter impulse responses, designed for 0.5 (50%) and 0.9 (90%) excess bandwidth.

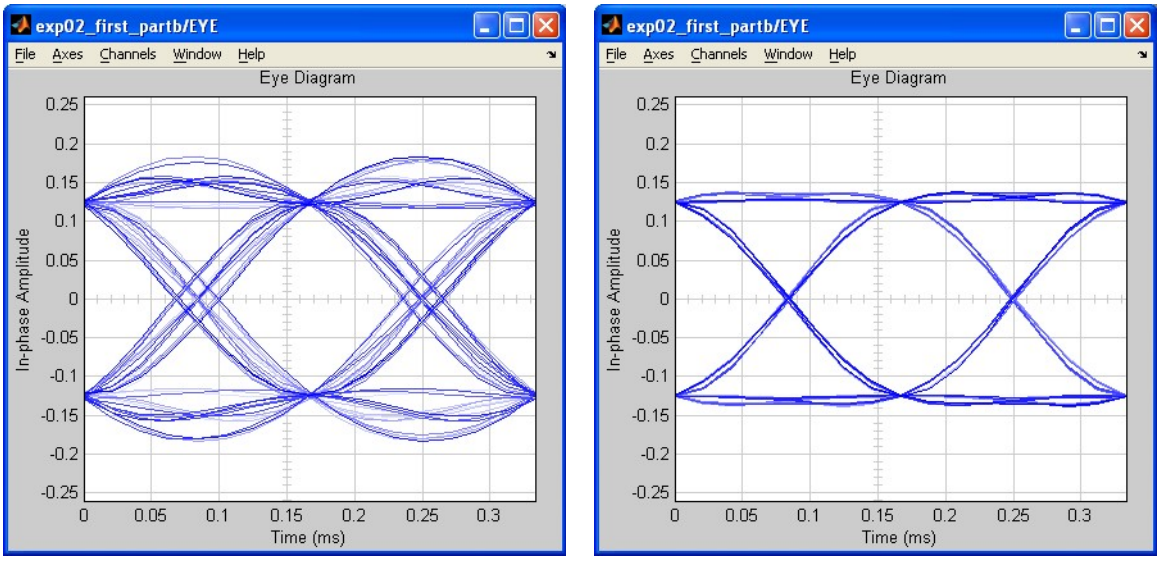


(a) 50% Excess BW

(b) 90% Excess BW

Figure 9: Impulse Response for Square-Root Raised Cosine Filters

Figures 10(a) and 10(b) below show the Eye Diagrams produced with the use of square-root raised cosine filters with excess bandwidth of 50% and 90%.



(a) 50% Excess BW

(b) 90% Excess BW

Figure 10: Eye Diagrams For Zero ISI with Square-Root Raised Cosine Filters

Next you will *experiment* with some of the parameters closer to the real world.

For your new model, design TX and RX filters following the Nyquist Criterion of zero ISI. Use an order 48 square-root raised cosine filter with 50% (beta = 0.5) excess bandwidth. Run the system, starting with a straight through channel. Note that, again, you will have to find the appropriate display configuration that will produce meaningful plots. Play with the given model to find the right configuration. Once you understand what the eye diagram represents, you will find it easier to configure the *real* oscilloscope during the implementation phase below.

- *Show how you determined the cutoff frequency.* **(1pt)**

3.2 Transmitter and Receiver Implementation

In this part, you will implement a transmitter/receiver system, by running a program on the DSP target hardware. Open `Code Composer Studio`, and select (click on) the project called `ECE417_Exp05_Pulse_Transmission`. This will make the project active.

Compile the project now. Before you run the executable, you will need to load a script so that you can select the excess bandwidth of the matched filters using a slider, as well as switch noise on and off and choose noise levels. At his point, your project should be compiled without errors, and ready to run. Follow this procedure in order to load the script:

1. In the `CCS Debug` environment, choose the menu `Tools -- Gel Files`. This will open a pane (likely on the bottom right corner);
2. Under `Script`, right-click on an blank cell and choose `Load GEL`. The `GEL` file is the actual script that will run and change parameters on the code in real-time;
3. Load the file called `noise.gel`, which is found within the same directory where your main c code is located;
4. Now go back to the top menu, and click on the menu item `Scripts`. You should see three items: `Noise Switch`, `Noise Level` and `Filter`. Use the mouse to open all three of these sliders.
5. Set `Filter` to 1, set `Switch Noise` to 0 and `Noise` to 0.

Since your project has been compiled and it is ready to run, run it. Connect all appropriate cables between the board output and the oscilloscope. The output produced will be displayed on *one channel only*. When you see it running, turn your attention to the c code.

Look at the c program called `pulse_trans.c`. The individual parts of the code are commented. You will see what the transmitter, channel and receiver are doing.

The transmitter implements a bit generator based on a Pseudo-noise sequence generator, and it produces positive and negative values interpolated by a number of zeros (seven). This sequence is passed through a transmitter filter, which can be selected by the user via the `Filter` slider. The resulting value is sent to the "outside world"(the channel) scaled appropriately.

The receiver, then, collects samples from the "outside world" and passes them through a receiver filter (matched to the transmitter filter). This filtered value is sent to a D/A converter to be viewed in the oscilloscope. The "channel" on the code adds scaling and noise to the output of the transmitter. No bandwidth limitation is imposed by the channel on the code.

Now that you have the code understood and running, let us see how to obtain the eye diagram.

4 Obtaining the Eye Diagram for Different Scenarios

4.1 For Different Matched Filters

The eye diagram, or eye pattern, is a common method utilized to observe the features on a received pulse train. In this part of the experiment, you will use channel noise and modify the TX and RX filters so that you can observe the effects on the eye diagram.

However, one needs to recall a special oscilloscope feature called the *Lissajous* Figure. You may have used this feature to measure phase differences between two channels of the oscilloscope (typically done in power electronics). This figure is obtained with the waveform on one input channel driving the horizontal sweep and the one on the other input channel driving the vertical sweep. The oscilloscope must be set to **X-Y mode**. This mode is obtained via the `Display -- Format` menu. Now that you have the right display mode, make th

For the eye diagram, you must use the output of the DSP target on one channel of the oscilloscope, and a saw-tooth signal (2.0 V_{pp}) coming directly from the signal generator on the other channel. You will have to adjust the frequency of the saw-tooth wave to generate a meaningful eye diagram. According to your knowledge of the pulse rate and cutoff frequency, what should the saw-tooth frequency be? That is, what is the period determined by the crossing points on the opening of the eye? After you find the right frequency, make the display steady (that is, **without** using the run/stop button).

Now let us look at the filter options. Option 1 selects a square-root raised-cosine filter with 50% excess bandwidth, with a 3KHz cutoff frequency. This is to say that if you have the square-root on RX and on TX, your overall response will be a raised-cosine filter cutting at 3KHz, which is what you would desire. Option 2, then, selects the 99% excess bandwidth filter.

As the system runs, choose different filters and observe the result on the eye diagram display. When you are ready, show your impressive result to the TA and have the TA sign the box. **(1pt)**

4.2 With Noise

After you try the different types of filters, add noise to your system by using the appropriate slider. You have to switch the noise on first using the switch slider. After you do that, change the noise gain up and down and observe the effect on the "closing" of the eye. Then you can do all this for each of the pulse shaping filter.

When you are ready, show it to the TA and have the TA sign the box. **(1pt)**

5 Accomplishments

The main objective of this experiment was to show how pulse shaping and the limitation on channel bandwidth will affect the transmission of a bit sequence generated at a certain rate. In order for you to observe that, you have simulated a basic digital communication system and modified the channel bandwidth, as well as the transmitter and receiver filters. You also implemented a transmitter/receiver system running in real time, and modified some of its parameters using sliders in real-time. You have also learned how to utilize the eye diagram to observe features on a signal representing a sequence of bits received by a digital communication system.

References

[1] S. Haykin and M. Moher *Introduction to Analog and Digital Communications*, 2nd Ed. - Wiley, 2007

[2] B. P. Lathi, *Modern Digital and Analog Communication Systems*, 3rd Edition. New York: Oxford University Press, 1998.

[3] S. Haykin *Communication Systems*, 4th Edition. Toronto: John Wiley & Sons, Inc., 2001.

[4] I.A. Glover and P.M. Grant, *Digital Communications*, Prentice Hall, 1998.

Preparation - Baseband Pulse Transmission

• *Name:*	*Experiment Date:*
• *Student No.:*	*Grade:* / 10

1. Draw a high-level block diagram of a "complete" digital communication sytem, from source to destination. Itentify the transmitter portion, the channel and the receiver portion of your system, and some of the relevant subsystems of each of these portions. Point out where noise could be added to the signal. (look at [1], p.232, Figure 6.1(a)) **(2pt)**

2. Explain what is the advantage brought by the use of a "matched" filter in a communication system. Explain how the matched filter is designed and detail its location in the communication system drawn above. **(2pt)**

3. Explain how an "eye diagram" or "eye pattern" is obtained, and what information about the transmitted/received data can be drawn from it. **(2pt)**

4. Explain inter-symbol interference (ISI): what causes it, how it is observed in the "eye diagram" and briefly describe the trade-offs involved in mitigating it. **(2pt)**

5. How is noise observed in the Eye Diagram? How will it affect the recovery of the transmitted data? **(2pt)**