

CHAPTER III

SIMULATION ON MATLAB

This chapter contains experiments including four principal topics: signal and linear system, baseband digital transmission, digital transmission through bandlimited channels, and digital transmission via carrier modulation. All of these experiments were designed to facilitate learning process concerning basic digital communication theories of undergraduate students. The graphic user interface (GUI) of MATLAB provides students with interactive features that enable them to easily understand the changing in output signal according to the variation of input parameters. In this chapter, GUI interfaces of basic digital communication theories are presented including Fourier series, pseudo-noise (PN) bit generator, convolution, line code, power spectrum density, NRZ rectangular, raised-cosine, root-raised cosine, BPSK, and QPSK.

3.1 Opening Window

As seen in figure 15, there are four main topics in this graphic user interface covering signal and linear system, baseband digital transmission, digital transmission through bandlimited channels, and digital transmission via carrier modulation. In addition, four PDF files containing questions for students in each topic and one minute oral introduction are provided accordingly.

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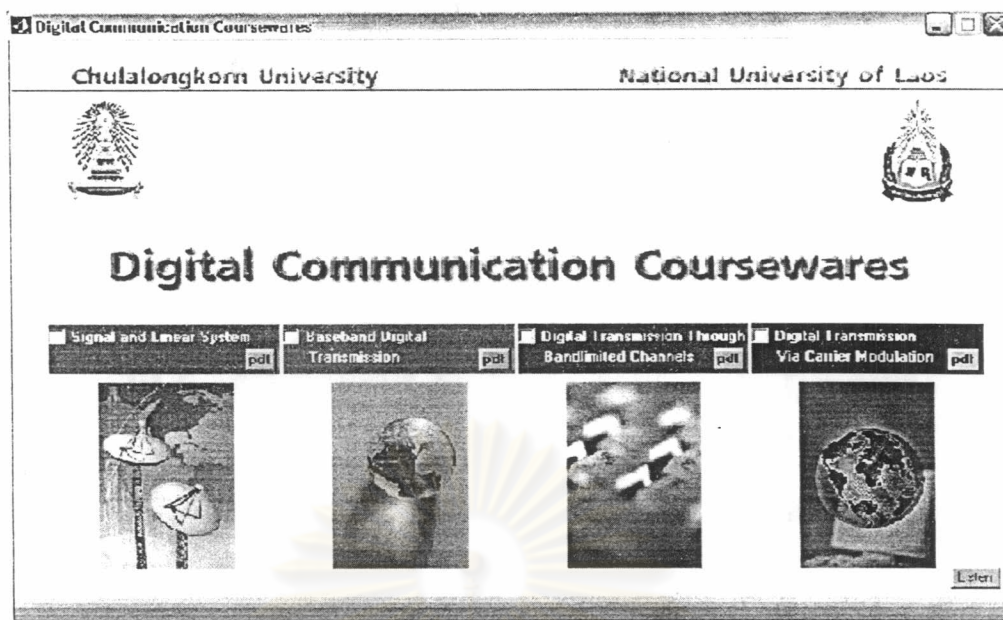


Figure 15 PACKAGE windows.

3.2 Fourier Series, PN Bit Generator and Convolution

In the first part of GUI, two main experiments about Fourier series, PN generator and convolution respectively are provided so as to give understanding about signal and linear system.

Instruction User Guide

For Fourier series experiment, students can select to study Fourier series of seven types of signal half-rectified sine wave, full-rectified sine wave, cosine, triangle, clipping triangle, rectangular, and half-duplex rectangular. As seen in figure 16, the GUI shows a comparison between a waveform of a selected signal type and that of its Fourier transform and for convenience, equations of each signal type are also supplied to users. Moreover, three parameters; amplitude, order, and period of the Fourier series equations are made to be adjustable for perceiving the effect of changing in parameters toward the output signal of Fourier transform. Noticeably, in the case of order numbers, the more the values of order numbers, the more similarity between the shape of original signal and output signal of Fourier transform.

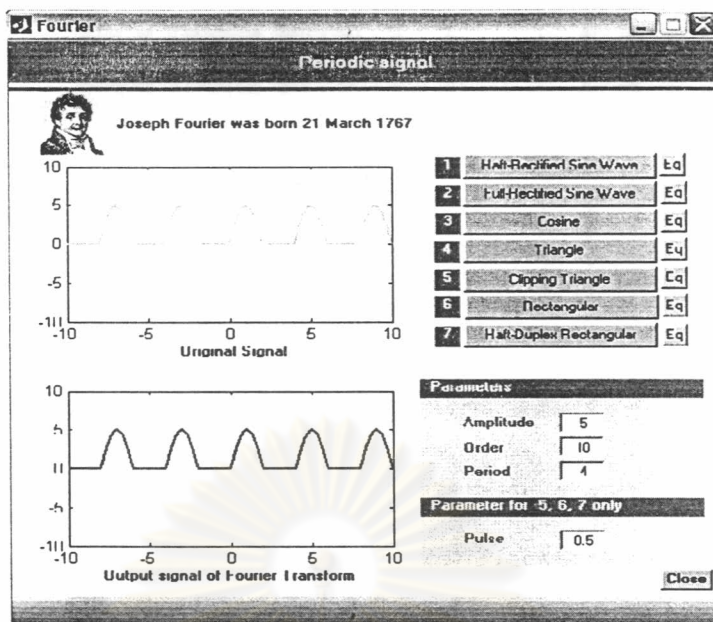


Figure 16 Fourier series

For PN bit generator experiment, as seen in figure 17, this GUI interface makes it possible for users to randomly set initial values of shift registers. After selecting initial values and clicking on the run button below, users can see the PN bit generator generating each bit of an output sequence one by one. The output sequence will repeat with period $2^k - 1$, when k is the width in bits of the shift register. For better understanding, a definition of PN bit generator is also provided for users.

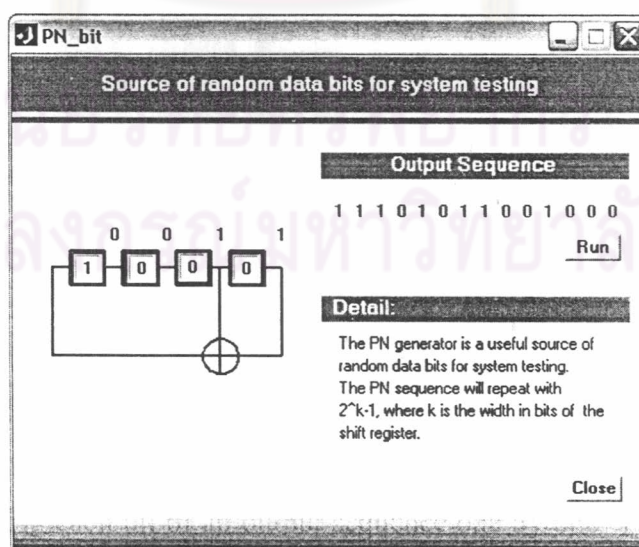


Figure 17 PN_bit windows.

In figure 18, animation of convolution among rectangular, triangle, bipolar square signal and exponential signal are illustrated. The types of input signals for convolution can be chosen by clicking at the checkboxes. The CONV button is used to start the convolution and the Pause button is intended for temporary stopping of the process.

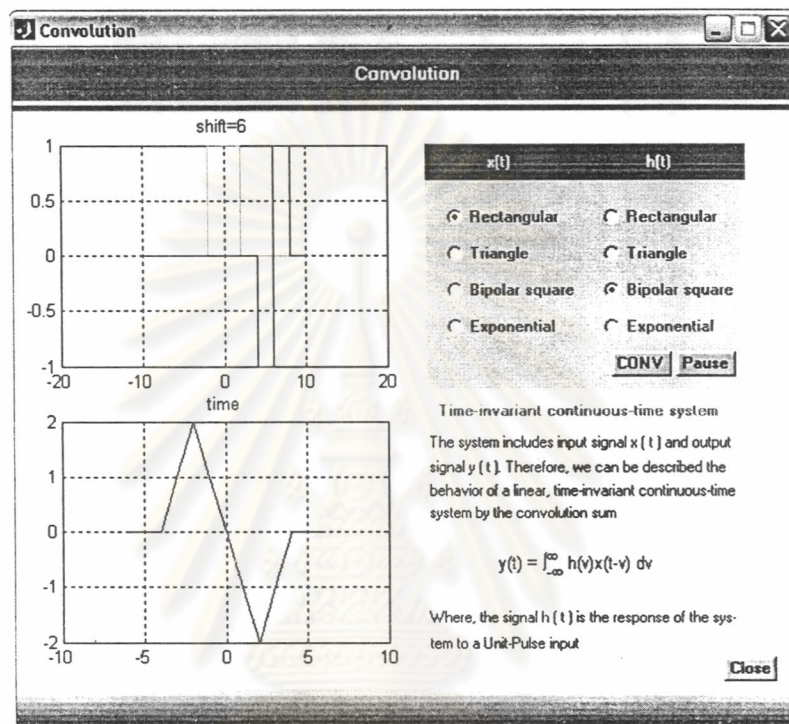


Figure 18 Convolution windows

3.3 Line Coding and Power Spectrum Density Analysis

In the second part of GUI, two main experiments about Line Coding and power spectrum density analysis respectively are provided so as to give understanding about baseband digital transmission.

Instruction User Guide

The line coding generates transmitted signal to be sent through communication channel from a stream of bit 0 and bit 1. There are seven types of line coding included in this experiment which are unipolar NRZ, unipolar RZ, polar NRZ, polar RZ,

bipolar NRZ, bipolar RZ, and Manchester line coding. In addition, the input bit can be set to be either fixed or random mode as seen in figure 19. Users can put the initial values in the boxes below the graph either by manually or randomly after that users press either on the Fix or Random button on GUI for processing in manual or random mode respectively.

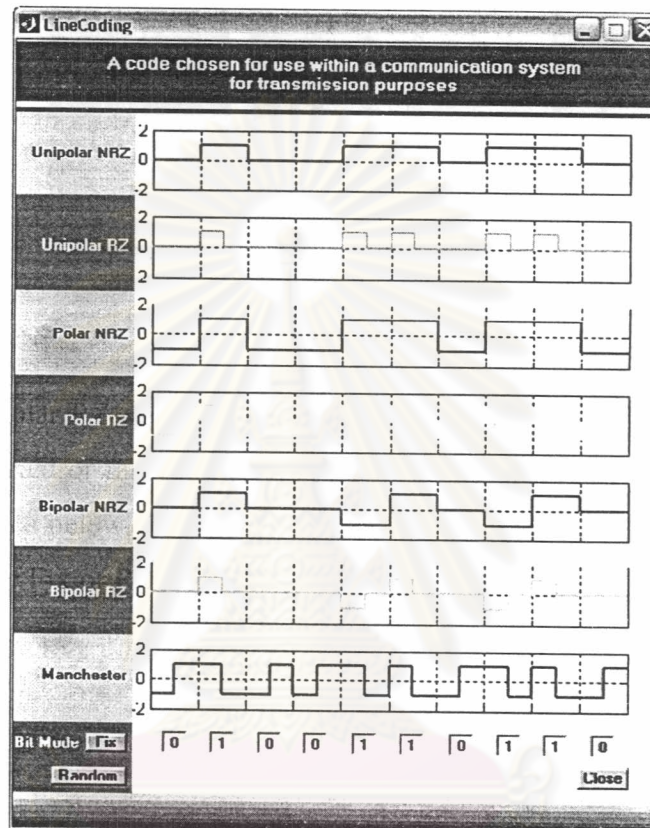


Figure 19 Linecoding windows.

For power spectrum density analysis, it includes all of the seven types of line coding mentioned above. In this section, graphs of power spectrum density are presented in figure 20. Users can see the power spectrum density for comparing the performance of each line code type and can click on the equation button to see the derivation of power spectrum density.

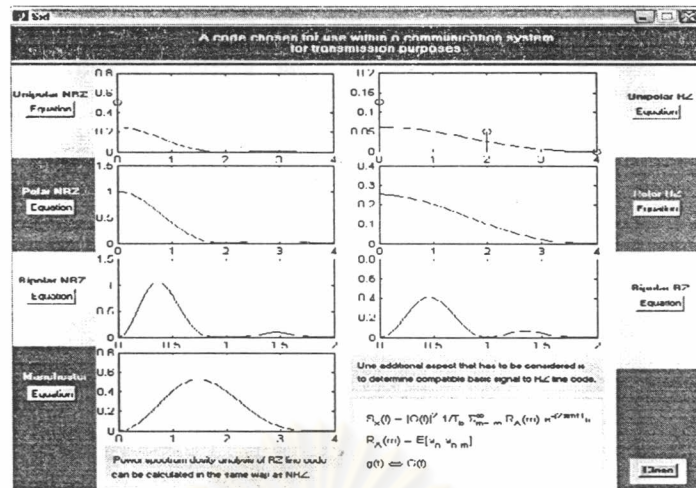


Figure 20 Power spectrum density windows.

3.4 Pulse Shaping

In the third part of GUI, two main experiments about pulse shaping is provided so as to give understanding about digital transmission through bandlimited channels.

The impulse response $g_T(t)$ of the transmit filter determines the spectral characteristics of the transmitted signal. Impulses that are limited in the time domain are infinite in the frequency domain. On the other hand, bandlimited pulses are infinite in the time domain. Consequently, in order to avoid intersymbol interface (ISI) after sampling, the cascade of the transmit and receive filter $g(t) = g_T(t) * g_R(t)$ needs to meet the first Nyquist condition, which was discussed in chapter 2.

Instruction User Guide

Firstly, the pulse shaping and the Fourier spectrum of an NRZ rectangular pulse is displayed in figure 21.

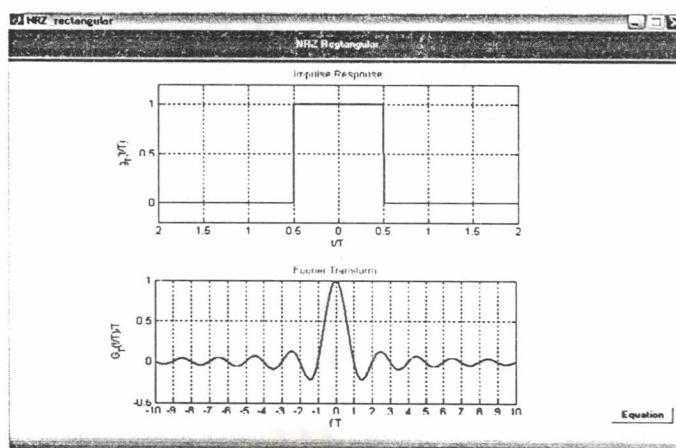


Figure 21 NRZ Rectangular windows.

In figure 22, there are raised-cosine pulses with different roll off factors $0 \leq \alpha \leq 1$. The roll off factor can be varied using a scrollbar. The green pulse (dot line) included in the plot is the impulse response of the next bit that is transmitted at time T .

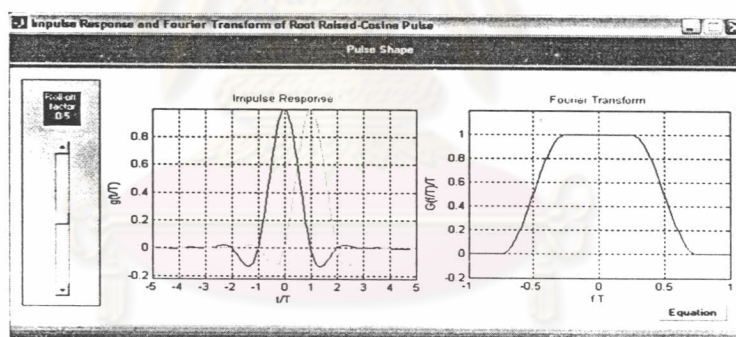


Figure 22 Raised-Cosine Pulses windows

In figure 23 square-root raised-cosine pulses with various roll off factors is displayed.

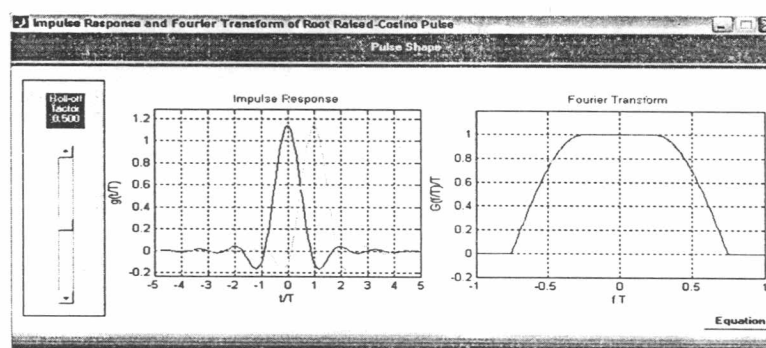


Figure 23 Square-Root Raised-Cosine Pulses windows

3.5 Introduction to Simulink

In this section, we learn how to use Simulink to help explain the digital communication system using BPSK and QPSK modulation. Simulink is, in short, a program for simulating dynamic systems and also providing a graphical interface. Within the MATLAB environment it is a toolbox. Dynamical systems are often represented using block diagrams. The graphical interface allows us to use such a block diagram directly for programming Simulink. The dynamical system in this thesis is the digital modulation scheme with time-varying data.

Simulink is started by the command “simulink” from the MATLAB workspace. The *Block Library Browser* will open and provide the blocks available in the Simulink library as seen in figure 24.

The library is divided according to the functions of the blocks, such as Sources or Sinks. You can open a library by double-clicking on the respective button.

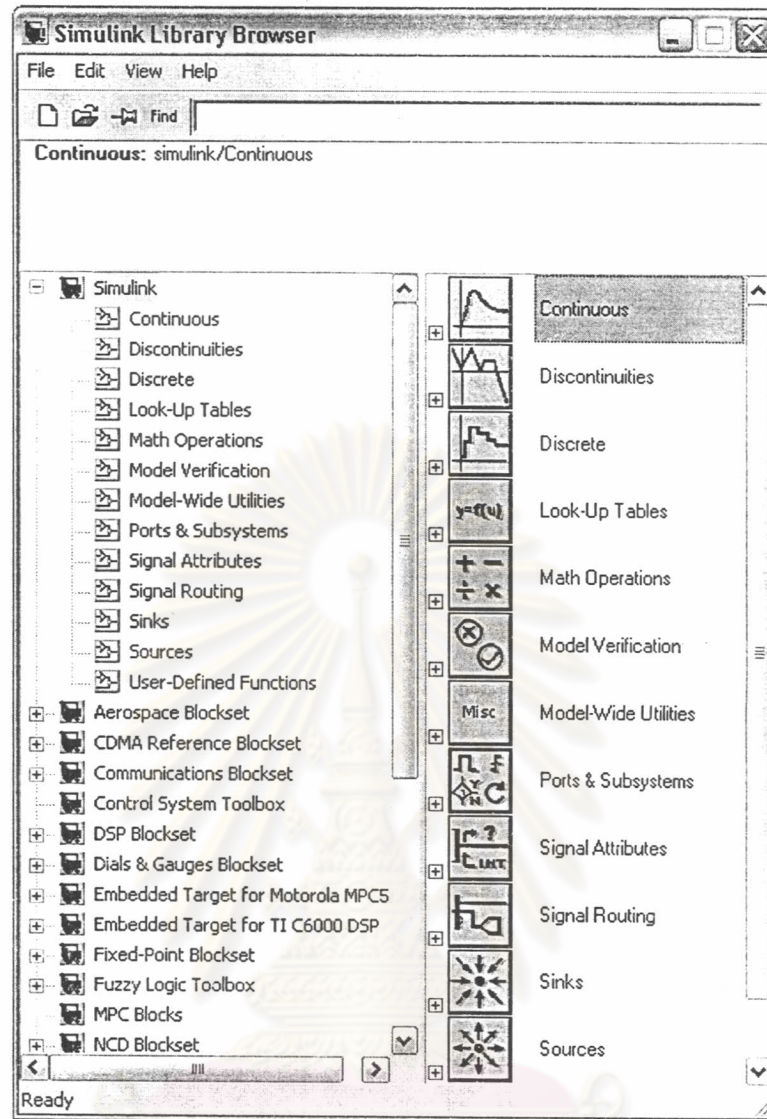


Figure 24 Simulink Block Library Browser.

3.6 BPSK Simulink

BPSK simulation is presented by the help of Simulink. The structure of BPSK model consists of transmitter, AWGN channel, and receiver as shown in figure 25. The model includes a meter to measure the signal in eye pattern, scatter plot (signal-space constellation), and the time domain signal measurement.

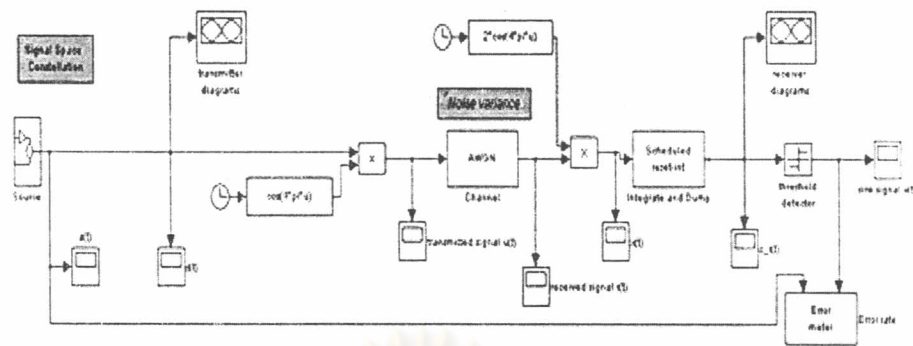


Figure 25 The structure of BPSK model.

This experiment show the whole BPSK transmitter and receiver by looking at the time domain signals such as source signal $a(t)$, transmitted signal $u(t)$, and signal $x(t)$ at matched filter input, etc. We can observe each step of signal processing from source to sink. It is useful for understanding the digital communication system as we can easily practice what we learn from theories. There are three experiments in BPSK Simulink which is NRZ rectangular pulses with matched filter, raised-cosine pulses, and square-root raised-cosine pulses.

Instruction User Guide

There are three main menus in simulation tool as seen in figure 26(a), (b), (c). First of all, choose either BPSK or QPSK Simulink on the main controlling menu. Secondly, choose a type of transmit filter to be either NRZ rectangular, Raised-Cosine, or Root-RC filter on the pulse shape menu. Lastly, choose a type of receive filter to be either Matched filter or Butterworth on the receive filter menu.

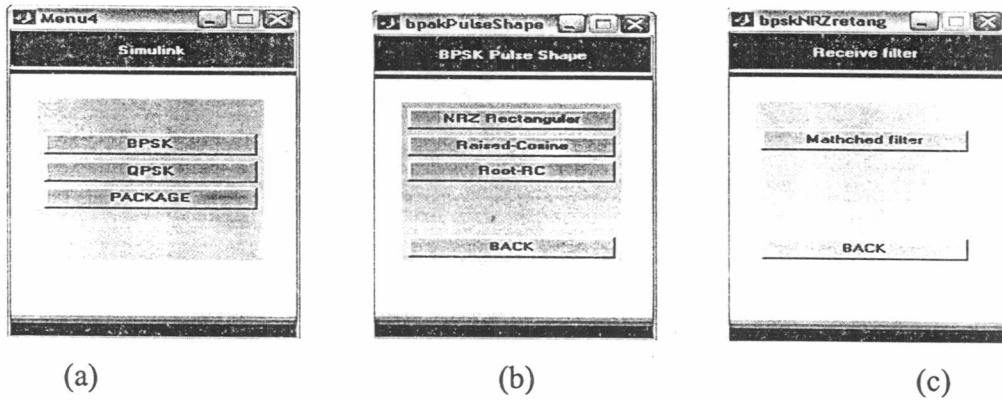


Figure 26 (a) Main controlling menu, (b) Transmit filter menu, and (c) Receive filter menu

3.6.1 BPSK > NRZ Rectangular > Matched Filter

Instruction User Guide

Choosing BPSK experiment, NRZ rectangular pulse as a transmit filter, and Matched Filter as a receive filter.

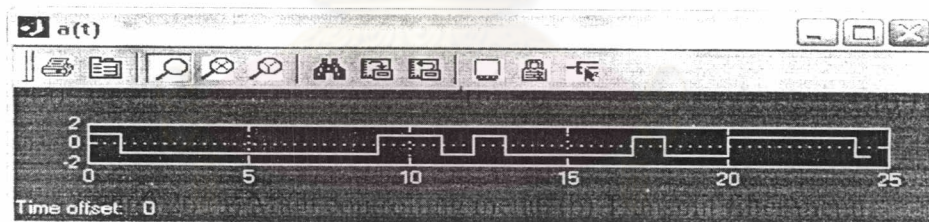


Figure 27 Signal $a(t)$ of BPSK > NRZ Rectangular > Matched Filter.

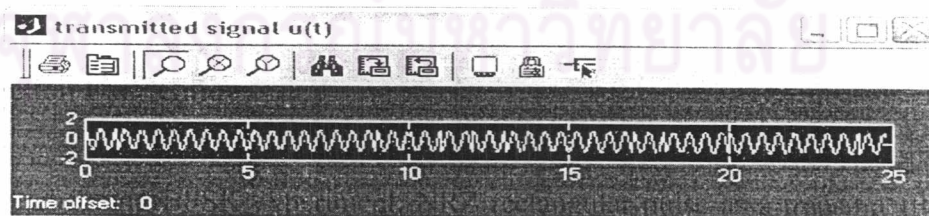


Figure 28 Transmitted Signal $u(t)$ of BPSK > NRZ Rectangular > Matched Filter.

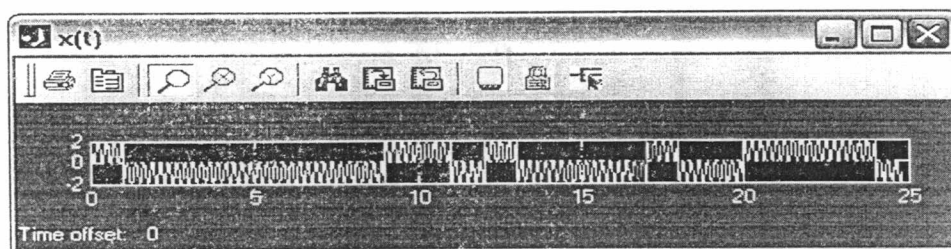


Figure 29 Signal $x(t)$ At Matched Filter Input of BPSK > NRZ Rectangular > Matched Filter.

In addition, we can look at the eye patterns and signal-space plots (see in figure 30-35).

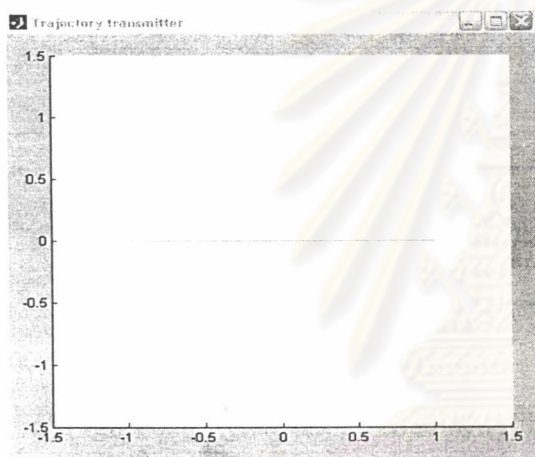


Figure 30 Transmitter trajectory for BPSK with NRZ rectangular pulses.

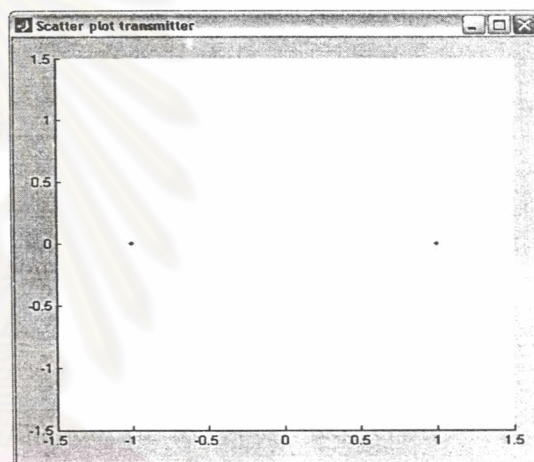


Figure 31 Transmitter scatter plot for BPSK with NRZ rectangular pulses.

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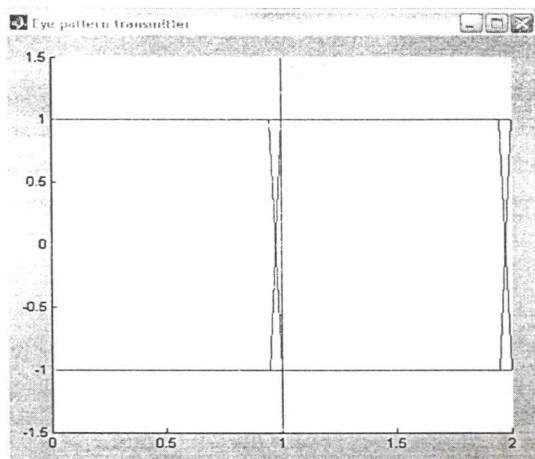


Figure 32 Eye pattern at transmitter for BPSK with NRZ rectangular pulses.

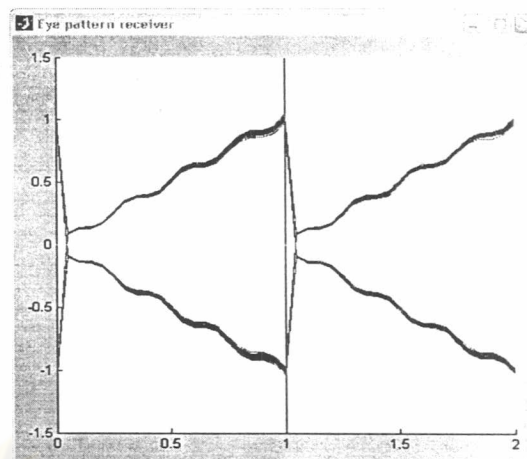


Figure 33 Eye pattern at receiver for BPSK with NRZ rectangular pulses and matched filter.

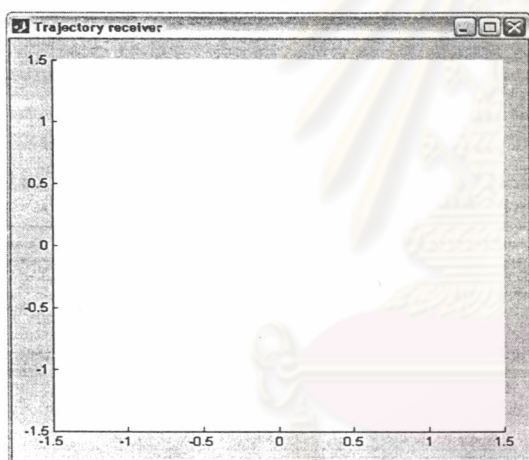


Figure 34 Receiver trajectory for BPSK with NRZ rectangular pulses and matched filter.

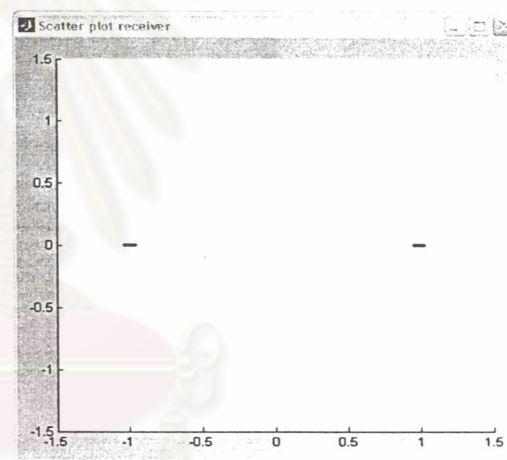


Figure 35 Receiver scatter plot for BPSK with NRZ rectangular pulses and matched filter.

3.6.2 BPSK > Raised-Cosine

Instruction User Guide

In this section we investigate BPSK with raised-cosine pulse. We choose BPSK > Raised-Cosine from the menu tool for simulation. In figure 36, the model of BPSK with raised-cosine pulses is shown.

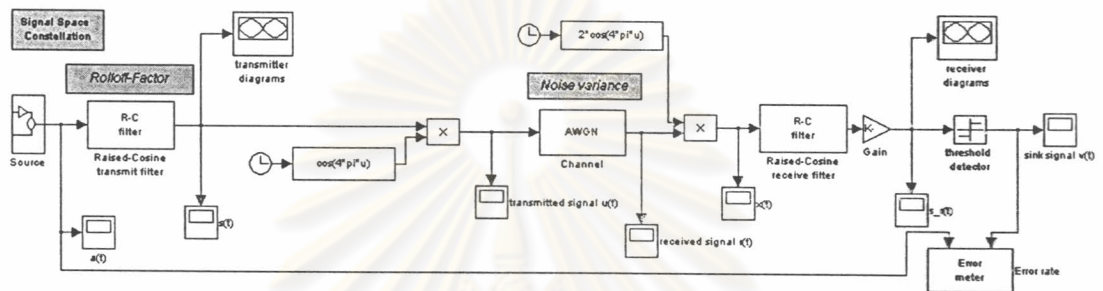


Figure 36 Simulink model for BPSK with Raised-Cosine Pulses and Matched Filter.

Users can double click on meter building boxes for observing the characteristics of time domain signals, eye patterns, and scatter plots (in figure 37-46).

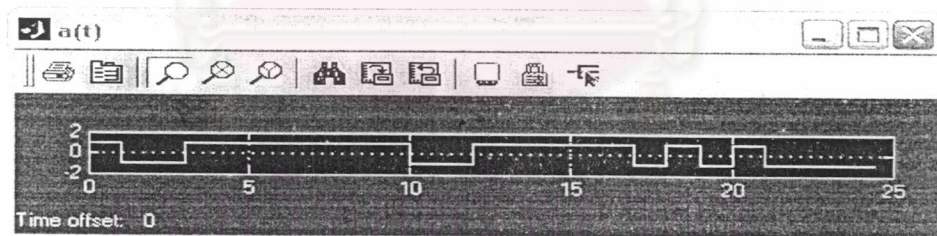


Figure 37 Source signal $a(t)$ of BPSK > Raised-Cosine.

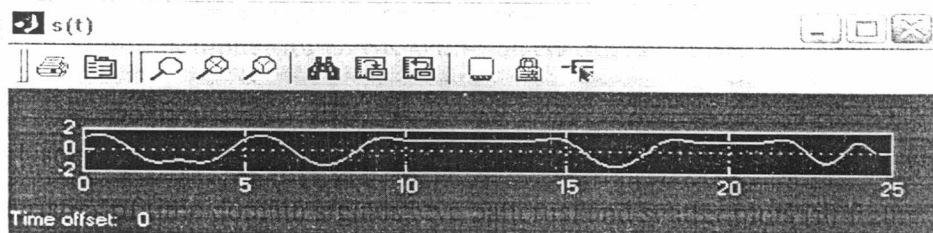


Figure 38 Basedband signal $s(t)$ of BPSK > Raised-Cosine.

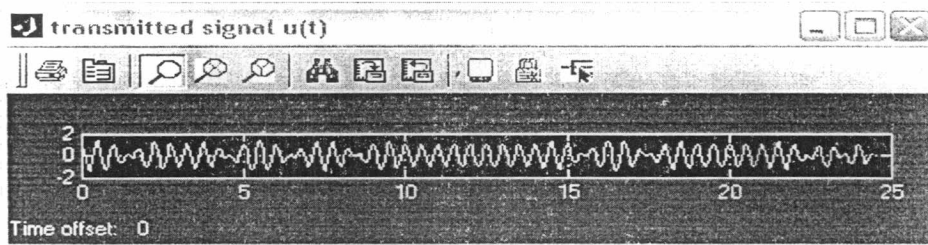


Figure 39 Transmitted signal $u(t)$ of BPSK > Raised-Cosine.

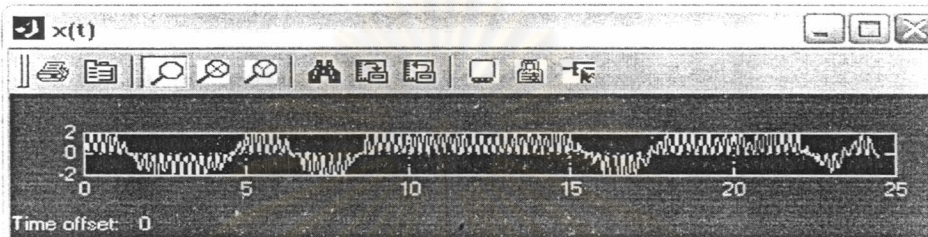


Figure 40 Signal $x(t)$ at Matched Filter Input of BPSK > Raised-Cosine.

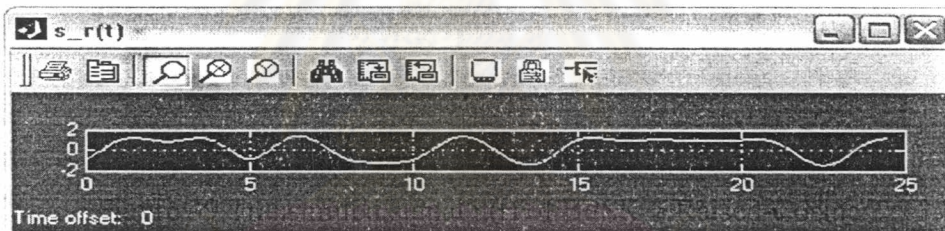


Figure 41 Demodulated baseband signals $s_r(t)$ at Matched Filter Output of BPSK > Raised-Cosine.

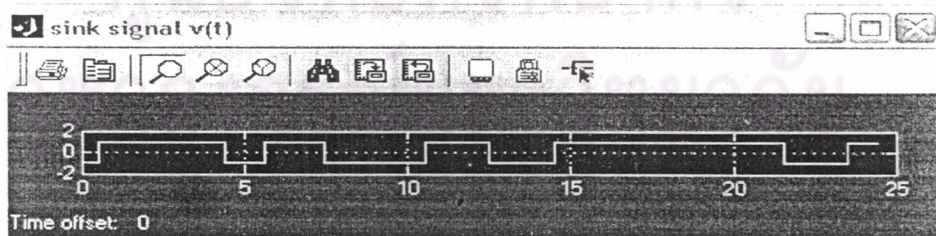


Figure 42 Sink signal $v(t)$ of BPSK > Raised-Cosine.

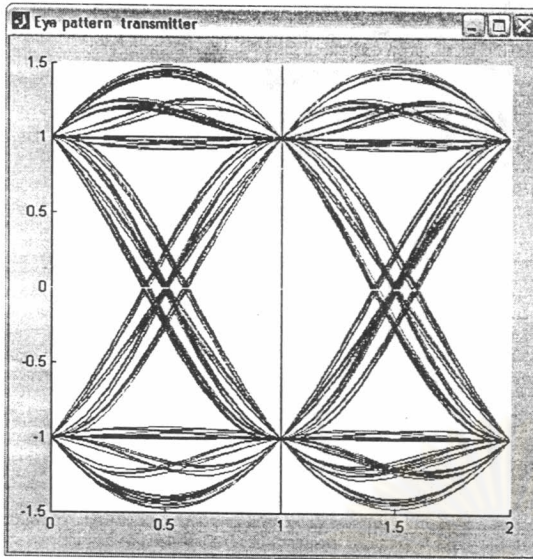


Figure 43 Eye pattern at the transmitter for BPSK with raised-cosine pulses.

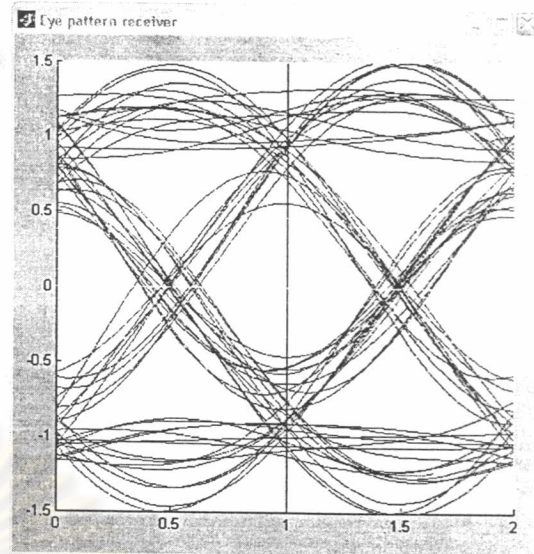


Figure 44 Eye pattern at the receiver for BPSK with raised-cosine pulses.

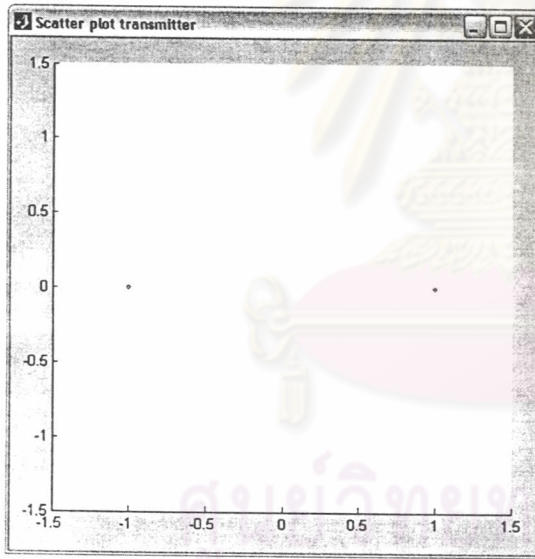


Figure 45 Transmitter scatter plot for BPSK with raised-cosine pulses.

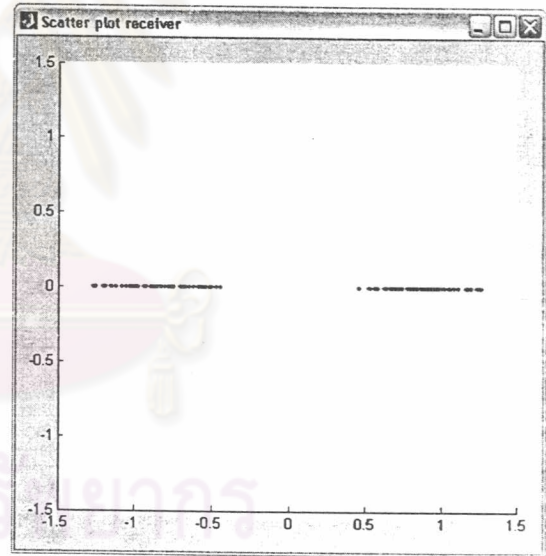


Figure 46 Receiver scatter plot for BPSK with raised-cosine pulses.

3.6.3 BPSK > Root-RC

Instruction User Guide

Choosing BPSK > Root-RC in order to investigate BPSK with square-root raised-cosine pulses. The time domain signals, eye patterns, and scatter plots are depicted in figure 47-56.

Carry out the experiment in the same way that is conducted in the previous section for raised-cosine pulses. Note that now the zero ISI condition is met at the matched filter output. Therefore, in the sequel we will only consider the relevant case of a square-root raised-cosine transmit filter.

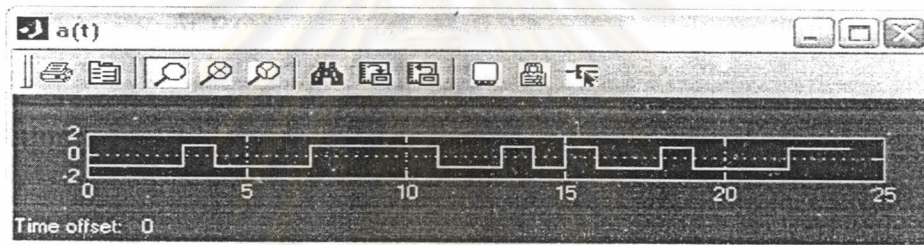


Figure 47 Source signal $a(t)$ of BPSK > Root-RC.

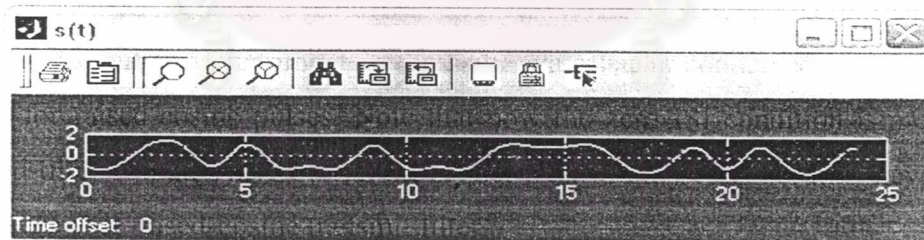


Figure 48 Basedband signal $s(t)$ of BPSK > Root-RC.

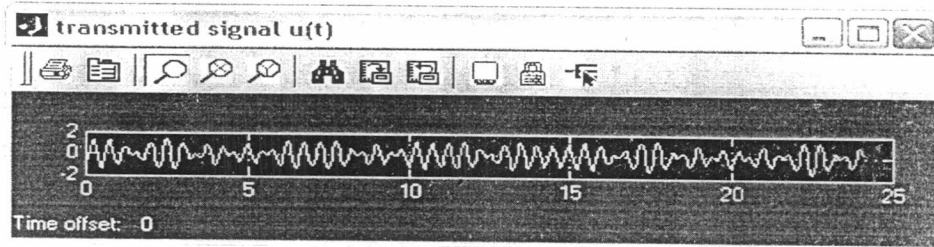


Figure 49 Transmitted signal $u(t)$ of BPSK > Root-RC.

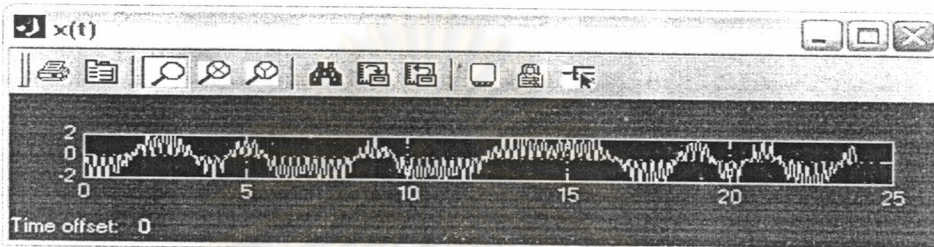


Figure 50 Signal $x(t)$ at Matched Filter Input of BPSK > Root-RC.

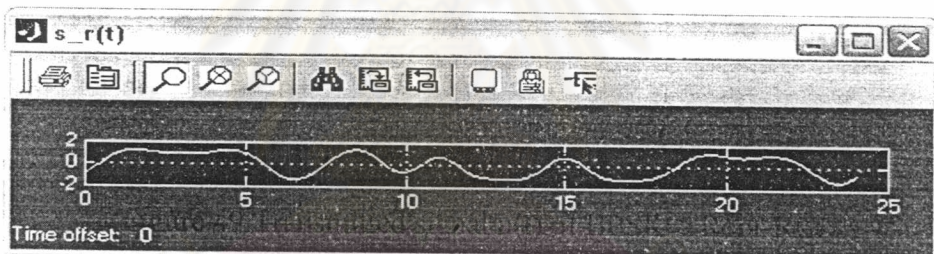


Figure 51 Demodulated baseband signal $s_r(t)$ of BPSK > Root-RC.

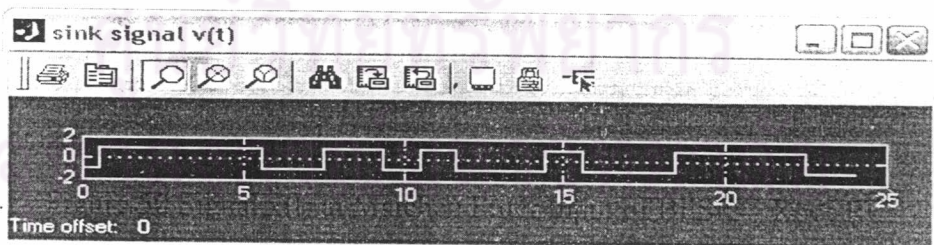


Figure 52 Sink signal $v(t)$ of BPSK > Root-RC.

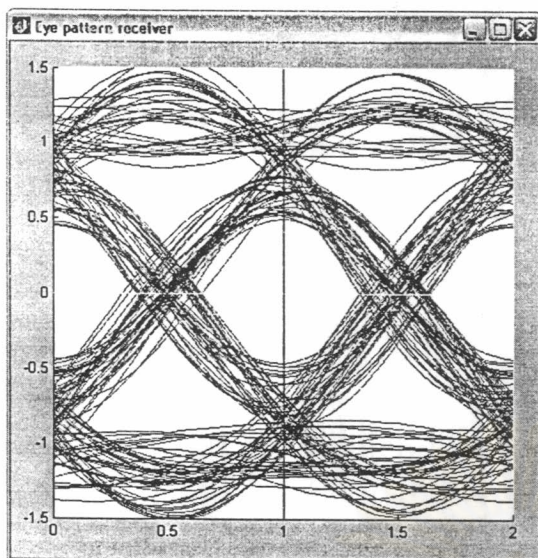


Figure 53 Eye pattern at the transmitter for BPSK with square-root raised-cosine pluses.

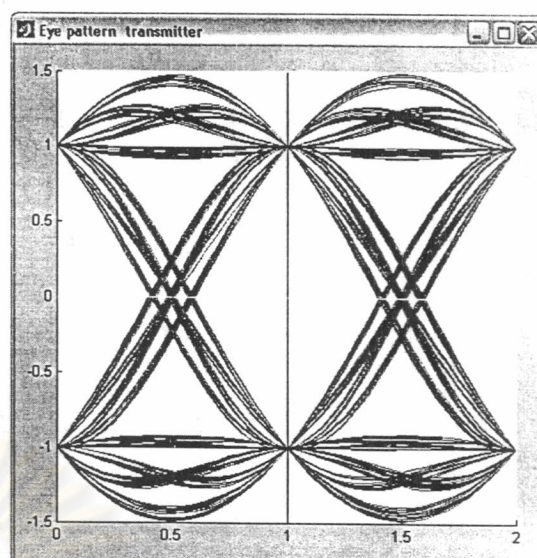


Figure 54 Eye pattern at the receiver for BPSK with square-root raised-cosine pluses.

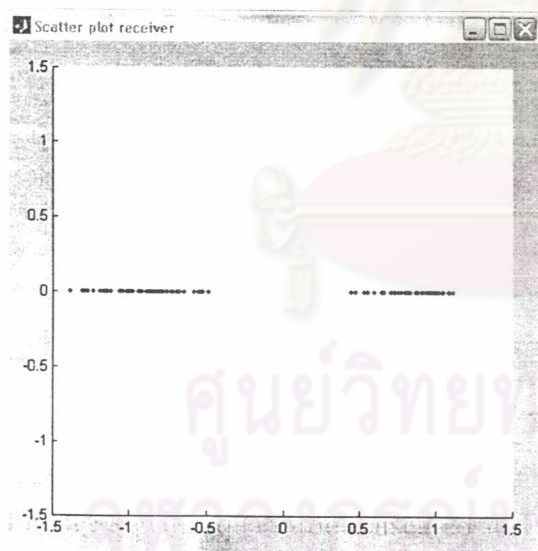


Figure 55 Transmitter scatter plot for BPSK with square-root raised-cosine pluses.

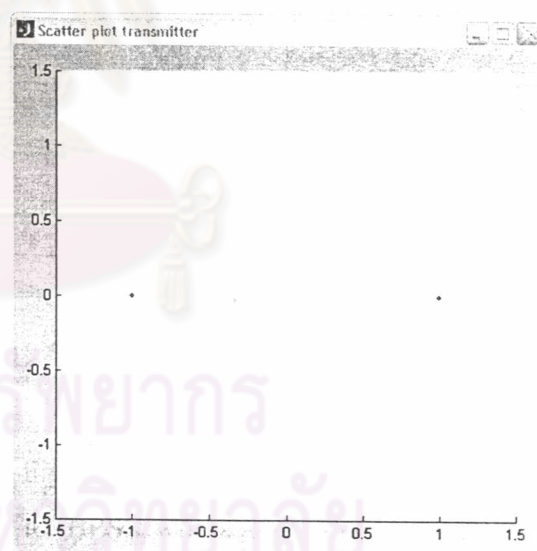


Figure 56 Receiver scatter plot for BPSK with square-root raised-cosine pluses.

3.7 QPSK Simulink

Instruction User Guide

Choose to experiment on QPSK with square-root raised-cosine pulses: QPSK > Root-RC. The Simulink model is shown in figure 57. The transmitter and receiver models depicted in figure 58 and figure 59 are opened by a double-click on the blue box *Transmitter* or *Receiver*, respectively.

Open the transmitter and start the simulation. Note that now separate eye patterns are displayed for both quadrature components that are identical to the respective BPSK eye patterns in figure 53 and 54. The time domain signals in both quadrature components look like the respective BPSK signals. The QPSK signals are shown in figures 60-68 for noiseless transmission. The scatter plot observed at the receiver in noisy channels looks similar to figure 68. Inspect the envelope of the modulated signals in the quadrature components and the transmitted signal $u(t)$.

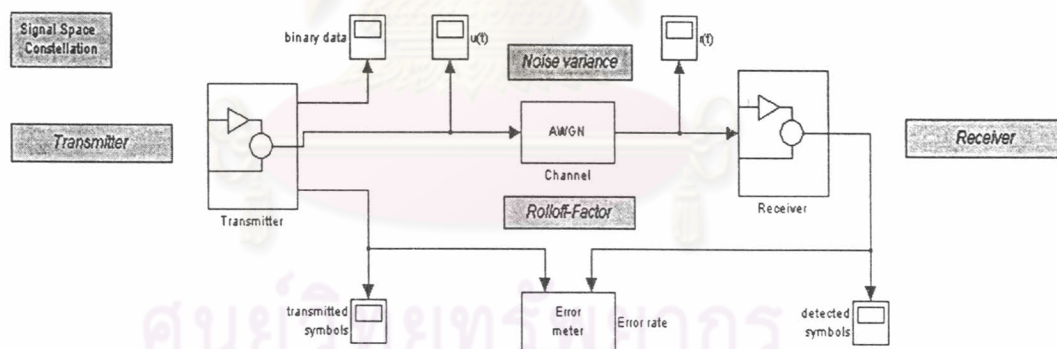


Figure 57 Simulink model for QPSK with Square-Root RC Pulses.

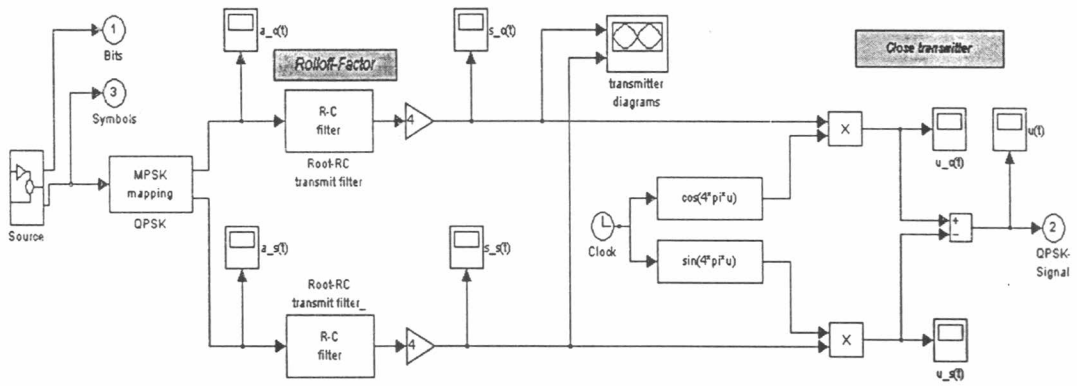


Figure 58 Simulink model for QPSK Transmitter with Square-Root RC Pulses.

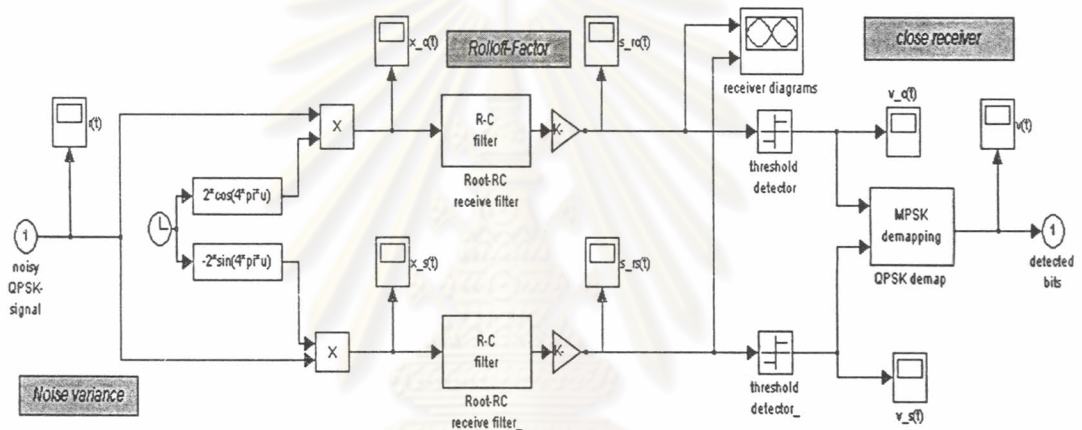


Figure 59 Simulink model for QPSK Receiver with Square-Root RC Pulses.

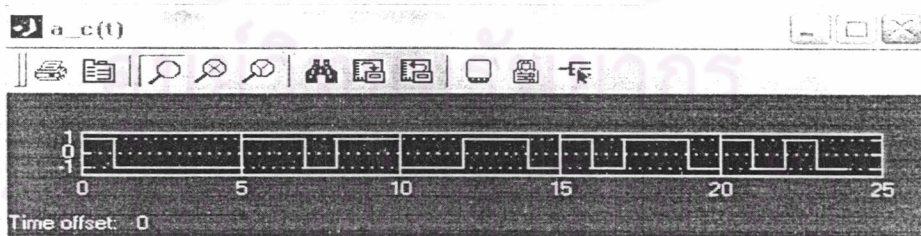
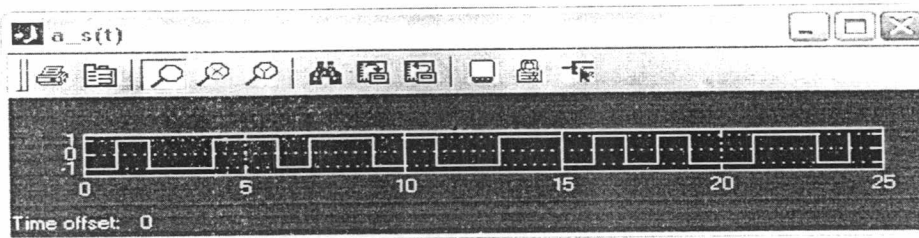
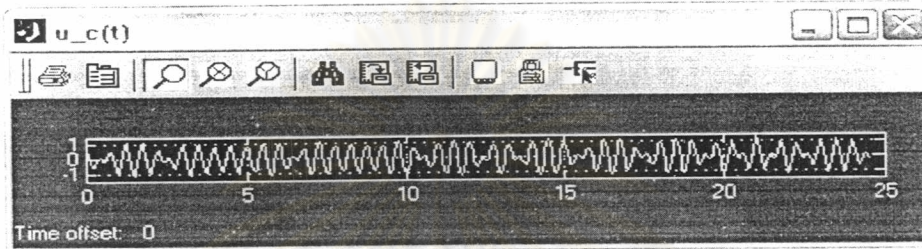
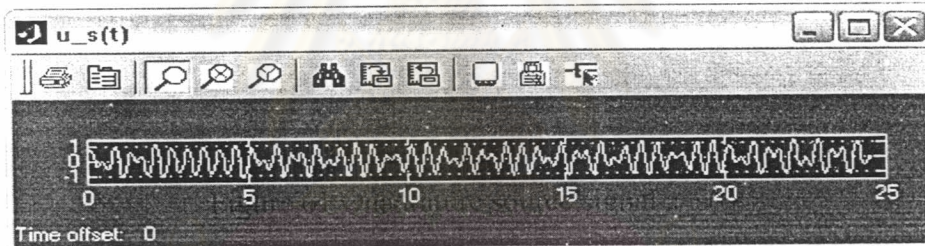
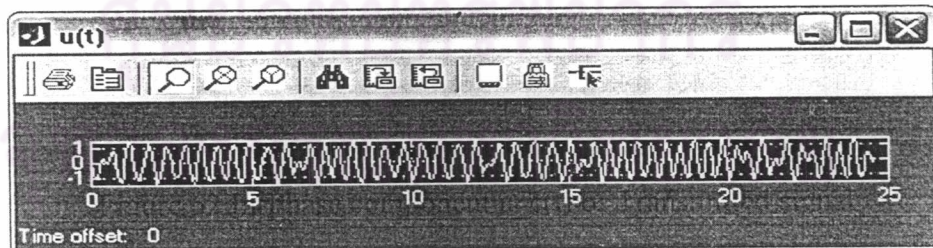


Figure 60 In-Phase source signal a_c(t)

Figure 61 Quadrature source signal $a_s(t)$ Figure 62 In-Phase component $u_c(t)$ of Transmitted signalFigure 63 Quadrature component $u_s(t)$ of Transmitted signalFigure 64 Transmitted signal $u(t)$

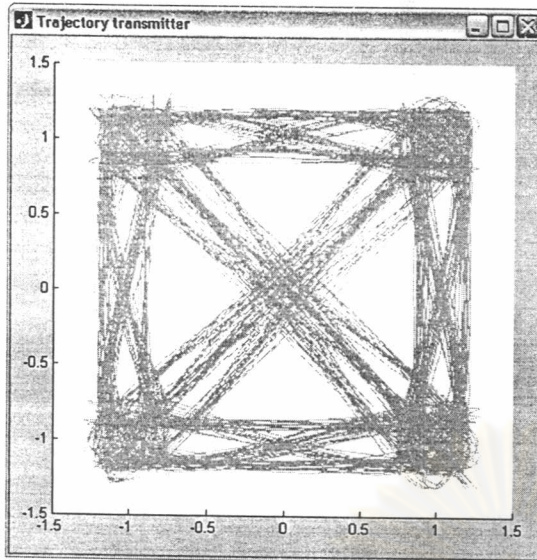


Figure 65 Transmitter trajectory for QPSK.

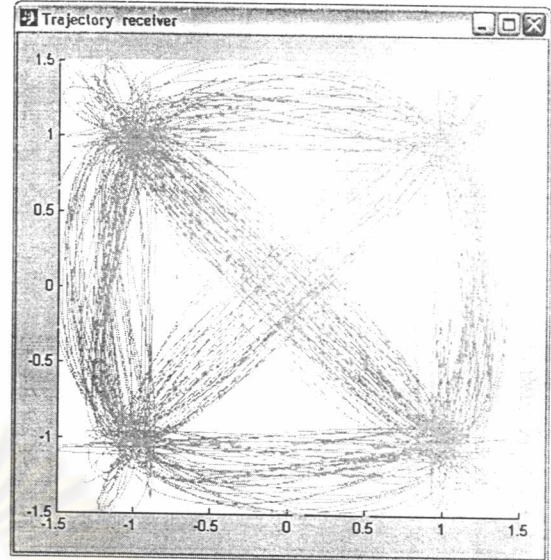


Figure 66 Receiver trajectory for QPSK.

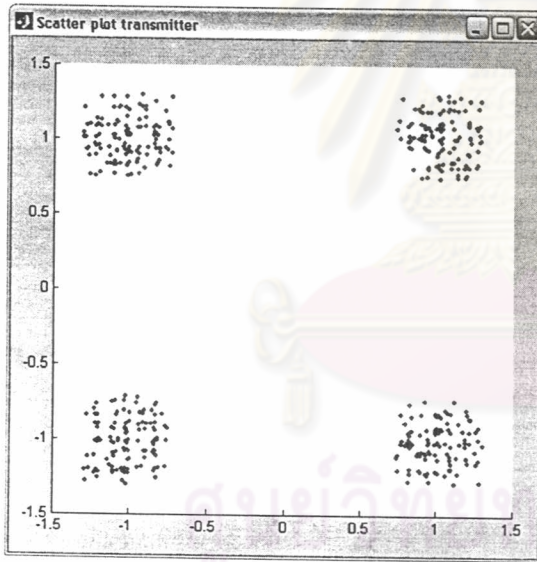


Figure 67 Transmitter scatter plot for QPSK.

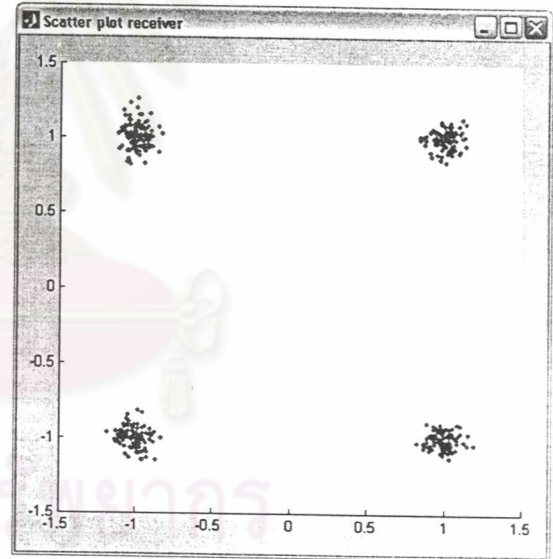


Figure 68 Receiver scatter plot for QPSK.

The next chapter deals with implementation on C6711 DSK. The experiments in the next chapter are designed to help students become familiar with C6711 DSK and acquire sufficient skills to use C6711 DSK according to their own interests.