

**NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY**

**Mobile Communication Systems (EE-451)**

Homework 3

**Submission Details**

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| Submitted to: | Dr. Syed Ali Hassan |
| Class: | BEE-12 |
| Semester: | 7th |
| Due: | 21/12/2023 |

**Problem 1 (CLO-1):**

Consider a linearly modulated signal of the form s(t) = Re{sl(t)ej2πfct}, where

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and where all pairs of symbols bn and bm are independent for n ≠m and each bn ε {-3, -1, 1, 3}, taking the values with equal probability. Furthermore, assume the pulse p(t) is rectangular with unit height and width Ts. Sketch the power spectral density (PSD), including labeling its peak height.

**Problem 2:**

Suppose the following constellation of 8 signals for a communication system is given:



1. Find the energy of each symbol and the average symbol energy of this constellation
2. Give a complete union bound for the probability of symbol error.
3. If the basis functions are the usual ones for QPSK, give the expression of the symbol waveform as a function of time for the symbol that is indicated by the arrow.

**Problem 3:**

Two signal points Sa and Sb are shown below:

**Chart, box and whisker chart

Description automatically generated**

1. Suppose the noise spectral height is N0/2=25/16. Evaluate the BER if these two signals are used in a wireless communication link.
2. Suppose the two basis functions are:

Text, letter

Description automatically generated

Construct an expression of signal labeled Sa in terms of t and Ts.

**Problem 4:**

Let the carrier frequency be 100 MHz and let the symbol period be 1 microsecond. Consider a transmitted BPSK signal that uses the 25% excess bandwidth Root Raised Cosine pulses (you can use the definition in Wikipedia, where beta = 0.25). Using MATLAB or your favorite programming language, plot the RF modulated BPSK signal,

Assume the symbol sequence be [1, -1, -1, 1, -1, -1, -1, 1].

**Problem 5:**

Using the same parameters as in Problem 4, plot the RF modulated QPSK waveform

Use the same sequence as in Problem 4, and let the quadrature symbols of the signal, , be [-1, -1, 1, 1, 1, -1, 1, -1].

**Problem 6:**

Consider the pulse below, plotted versus time in microseconds. Could this pulse be a Nyquist pulse for a binary transmission with a 10MHz data rate? Why or why not?



**Problem 4:**

Let the carrier frequency be 100 MHz and let the symbol period be 1 microsecond. Consider a transmitted BPSK signal that uses the 25% excess bandwidth Root Raised Cosine pulses (you can use the definition in Wikipedia, where beta = 0.25). Using MATLAB or your favorite programming language, plot the RF modulated BPSK signal,

Assume the symbol sequence be [1, -1, -1, 1, -1, -1, -1, 1].

We start by making the necessary imports, definitions, and important indices.

import numpy as np

import matplotlib.pyplot as plt

plt.rcParams["mathtext.fontset"] = "stix"

plt.rcParams["font.family"] = "STIXGeneral"

fc = 100e6

Ts = 1e-6

beta = 0.25

N = 8

t = np.arange(-2 \* N \* Ts, 2 \* N \* Ts, 1 / (2 \* fc))

x\_n = np.array([1, -1, -1, 1, -1, -1, -1, 1])

*# Zero crossing and shift for +-Ts/(4\*beta)*

zc = len(t) // 2

shift = len(np.arange(0, Ts / (4 \* beta), 1 / (2 \* fc))) + 1

Next, we define a function for Root Raised Cosine (RRC) pulse and substitute the zero crossing and shifts about the zero crossing with appropriate values.

*# Root Raised Cosine (Ts \* 1/Ts cancels); from Wikipedia*

p\_rrc = lambda t: (

    np.sin(np.pi \* t / Ts \* (1 - beta))

    + 4 \* beta \* t / Ts \* np.cos(np.pi \* t / Ts \* (1 + beta))

) / (np.pi \* t / Ts \* (1 - (4 \* beta \* t / Ts) \*\* 2))

p\_rrc\_zc = Ts \* 1 / Ts \* (1 + beta \* (4 / np.pi - 1))

p\_rrc\_shift = (beta / np.sqrt(2)) \* (

    (1 + 2 / np.pi) \* np.sin(np.pi / (4 \* beta))

    + (1 - 2 / np.pi) \* np.cos(np.pi / (4 \* beta))

)

p = p\_rrc(t)

p[zc] = p\_rrc\_zc

p[zc + shift] = p\_rrc\_shift

p[zc - shift] = p\_rrc\_shift

*# Plot*

plt.figure(figsize=(8, 4)), plt.tight\_layout()

plt.plot(t, p, "k-", linewidth=1.5)

plt.xlabel("Time (s)")

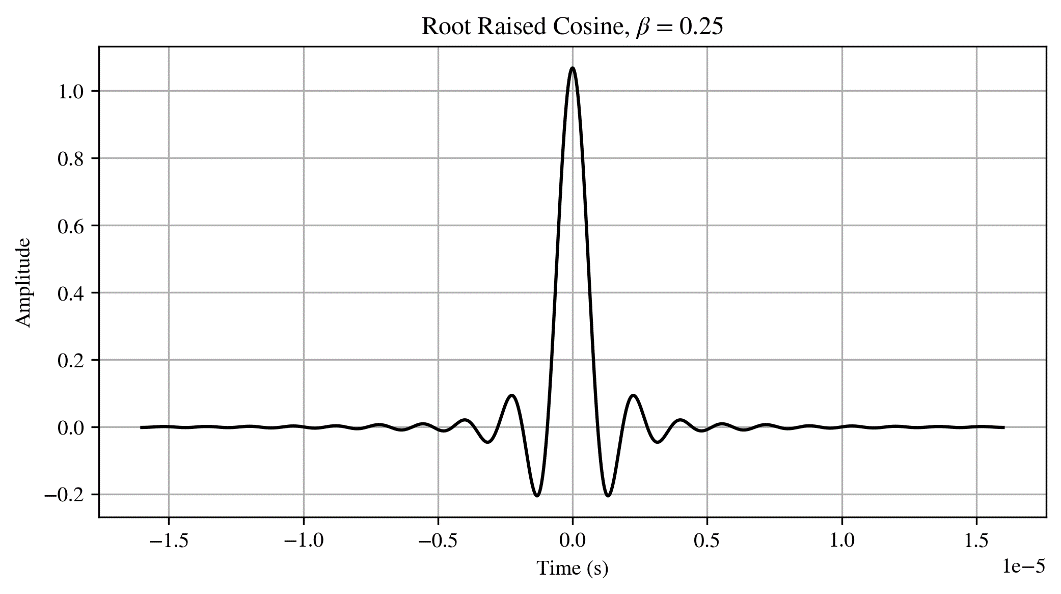
plt.ylabel("Amplitude")

plt.title(r"Root Raised Cosine, $\beta$ = 0.25")

plt.grid()

plt.savefig("p4a.png", dpi=300)

plt.show()



Now, we just define and plot the aggregated BPSK waveform, i.e., the complex envelope.

shifted\_p = np.zeros(len(t))

interval = len(np.arange(0, Ts, 1 / (2 \* fc))) + 1

x\_t = np.zeros(len(t))

plt.figure(figsize=(8, 4))

plt.tight\_layout()

for i in range(N):

    shifted\_p[interval \* i : len(p)] = p[0 : len(p) - interval \* i]

    x\_t += x\_n[i] \* shifted\_p

    plt.plot(t, x\_n[i] \* shifted\_p, linewidth=1.5)

plt.xlabel("Time (s)")

plt.ylabel("Amplitude")

plt.title(r"BPSK Waveform for Each Symbol $x\_n \in \{-1, 1\}$")

plt.grid()

plt.savefig("p4b.png", dpi=300)

plt.show()

plt.figure(figsize=(8, 4))

plt.plot(t, x\_t, "k-", linewidth=1.5)

plt.xlabel("Time (s)")

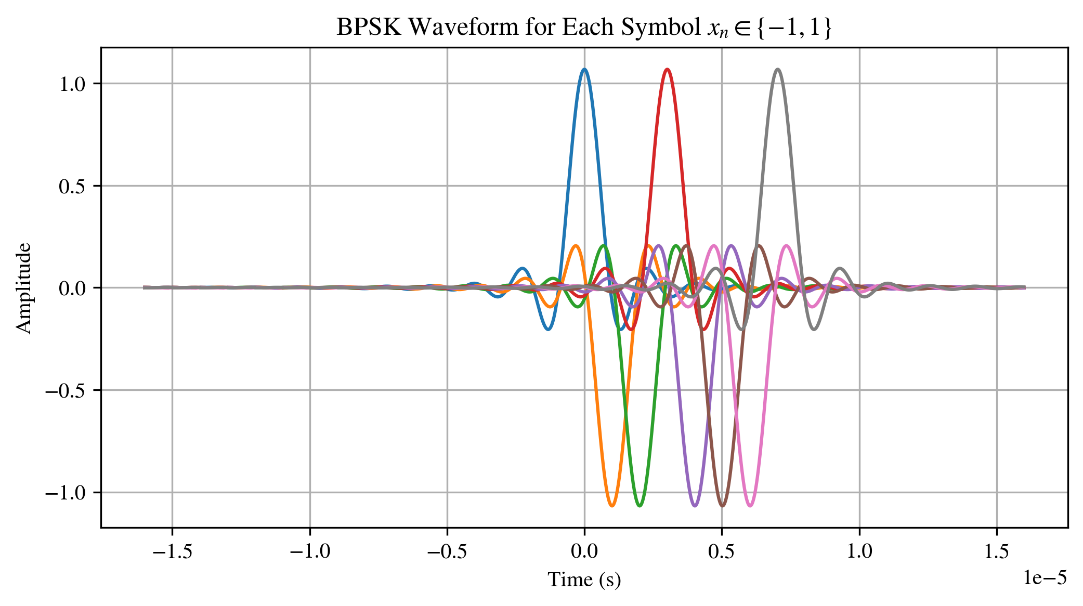
plt.ylabel("Amplitude")

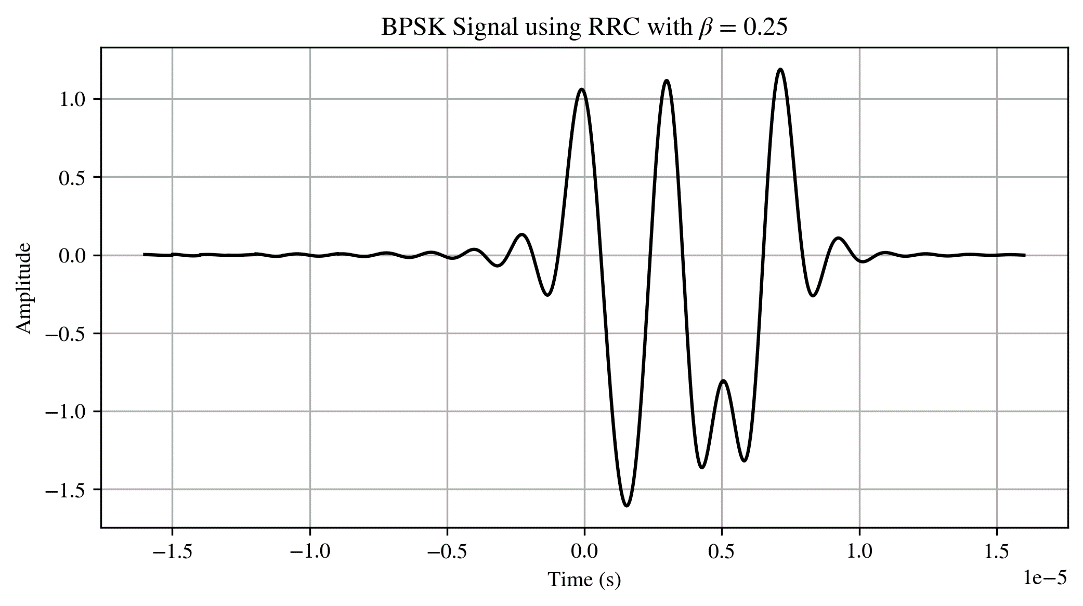
plt.title("BPSK Signal using RRC with $\\beta$ = 0.25")

plt.grid()

plt.savefig("p4c.png", dpi=300)

plt.show()





Lastly, we multiply the complex envelope with the necessary carrier wave as follows:

modulated\_p4 = x\_t \* np.cos(2 \* np.pi \* fc \* t)

plt.figure(figsize=(8, 4))

plt.plot(t, modulated\_p4, "k-", linewidth=1.5)

plt.xlabel("Time (s)")

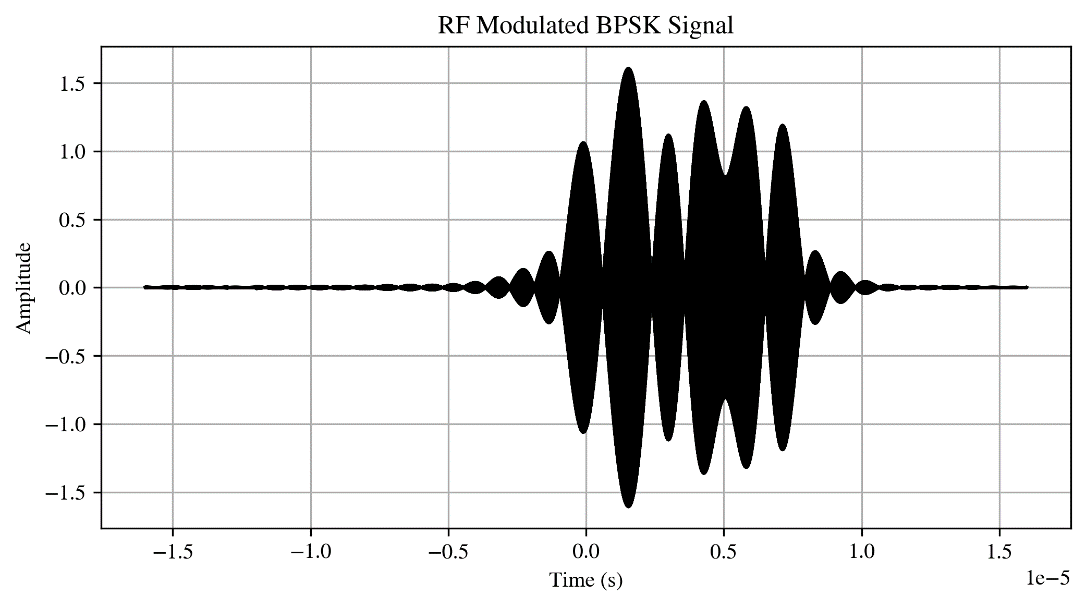
plt.ylabel("Amplitude")

plt.title("RF Modulated BPSK Signal")

plt.grid()

plt.savefig("p4d.png", dpi=300)

plt.show()



**Problem 5:**

Using the same parameters as in Problem 4, plot the RF modulated QPSK waveform

Use the same sequence as in Problem 4, and let the quadrature symbols of the signal, , be [-1, -1, 1, 1, 1, -1, 1, -1].

Continuing from the previous problem, we define and perform the same steps as before.

y\_n = np.array([-1, -1, 1, 1, 1, -1, 1, -1])

shifted\_p = np.zeros(len(t))

interval = len(np.arange(0, Ts, 1 / (2 \* fc))) + 1

x\_t = np.zeros(len(t))

y\_t = np.zeros(len(t))

ax, fig = plt.subplots(2, 1, figsize=(7, 8))

for i in range(N):

    shifted\_p[interval \* i : len(p)] = p[0 : len(p) - interval \* i]

    x\_t += x\_n[i] \* shifted\_p

    y\_t += y\_n[i] \* shifted\_p

    fig[0].plot(t, x\_n[i] \* shifted\_p, linewidth=1.5)

    fig[1].plot(t, y\_n[i] \* shifted\_p, linewidth=1.5)

fig[0].set\_xlabel("Time (s)")

fig[0].set\_ylabel("Amplitude")

fig[0].set\_title(r"BPSK Waveform for Each Symbol $x\_n \in \{-1, 1\}$")

fig[0].grid()

fig[1].set\_xlabel("Time (s)")

fig[1].set\_ylabel("Amplitude")

fig[1].set\_title(r"QPSK Waveform for Each Symbol $y\_n \in \{-1, 1\}$")

fig[1].grid()

plt.tight\_layout()

plt.savefig("p5a.png", dpi=300)

plt.show()

plt.figure(figsize=(8, 4))

plt.plot(t, x\_t, "k-", linewidth=1.5)

plt.xlabel("Time (s)")

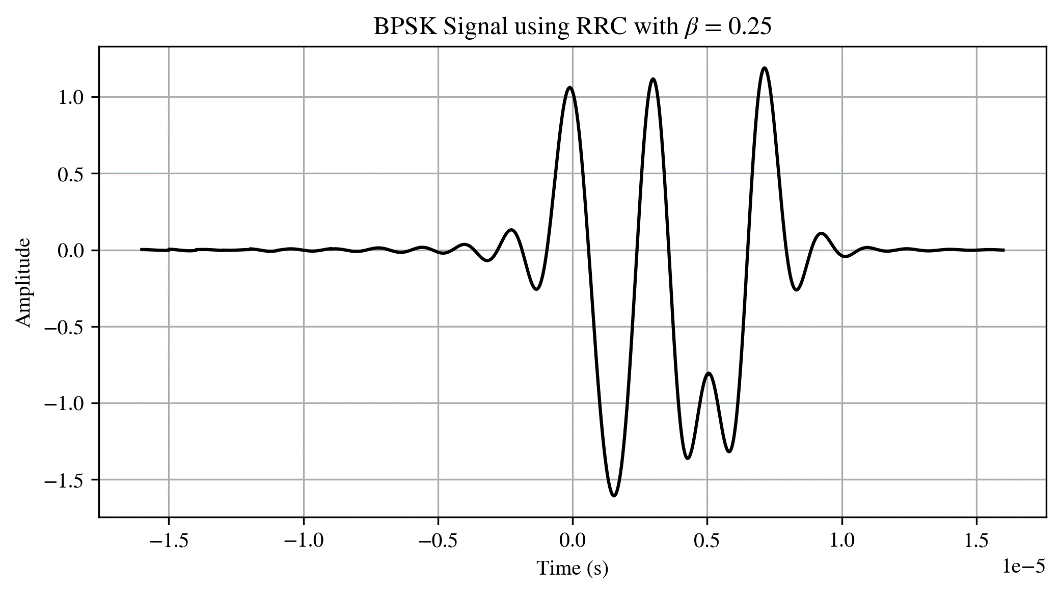
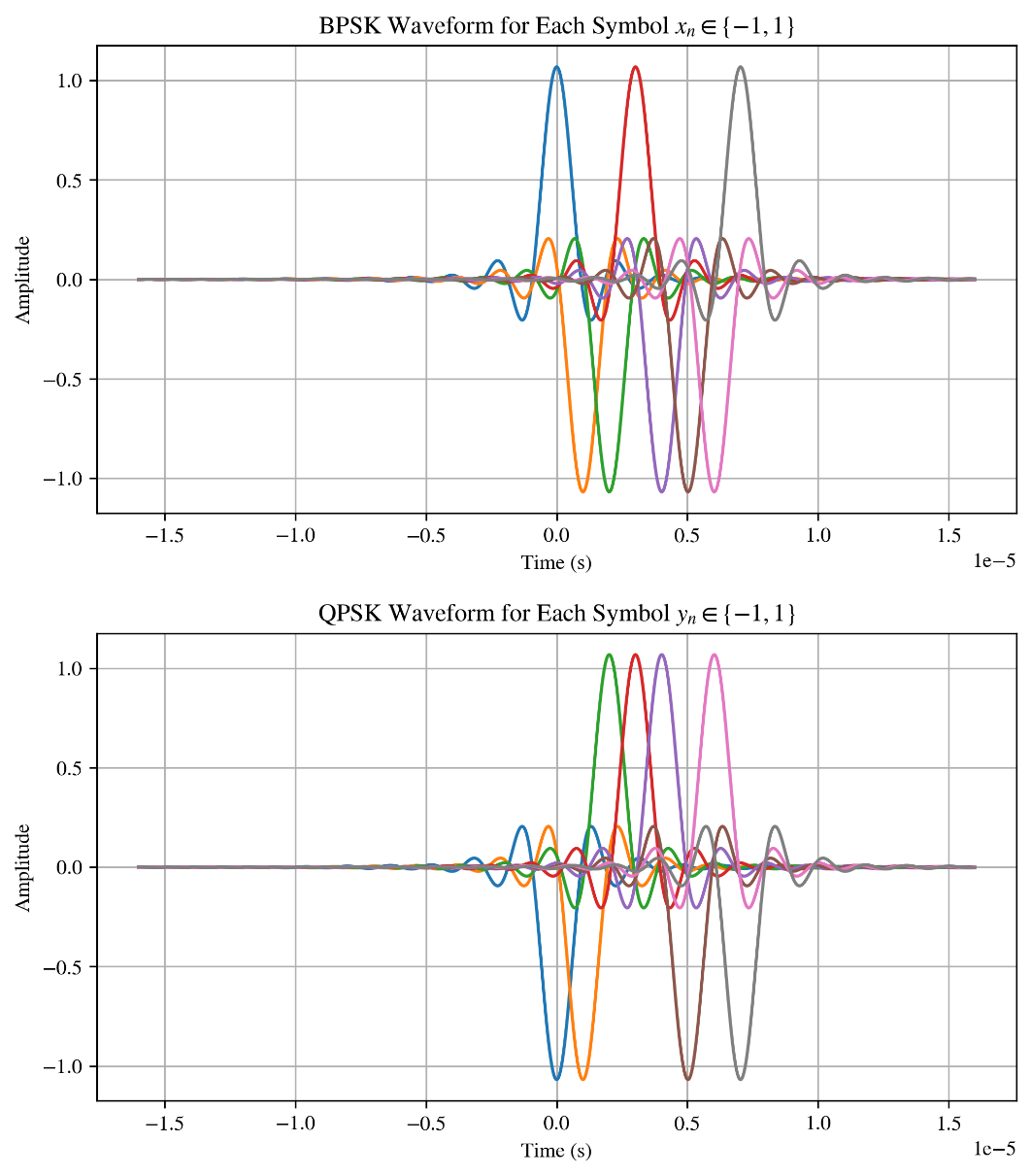
plt.ylabel("Amplitude")

plt.title("BPSK Signal using RRC with $\\beta$ = 0.25")

plt.grid()

plt.savefig("p5b.png", dpi=300)

plt.show()



Now, we can define the modulated signal in accordance with the following formula, and visualize it:

modulated\_i = x\_t \* np.cos(2 \* np.pi \* fc \* t)

modulated\_q = y\_t \* np.sin(2 \* np.pi \* fc \* t)

modulated\_p5 = modulated\_i - modulated\_q

plt.figure(figsize=(8, 4))

plt.plot(t, modulated\_p5, "k-", linewidth=1.5)

plt.xlabel("Time (s)")

plt.ylabel("Amplitude")

plt.title("RF Modulated QPSK Signal")

plt.grid()

plt.savefig("p5c.png", dpi=300)

plt.show()

