SSY121: Introduction to Communication Engineering

Computer-based exercises C_1-C_3*

August 31, 2021

- Document "Introduction to MATLAB 2021" has been uploaded to Canvas to help the beginners in MATLAB. Familiarize with MATLAB before the beginning of the course project. All the project members are required to contribute MATLAB code.
- Students are encouraged to try solving the problems before the exercise sessions.

Problems for Exercise C_1

1. **Sampling, Aliasing and Reconstruction**. [1]

   Consider the signal

$$p(t) = 6(\mathrm{sinc}(t/2T_s))^2 + (\mathrm{sinc}(t/6T_s))^6 + 6(\mathrm{sinc}(t/10T_s))^{10}, \tag{1}$$

$$\text{where } \mathrm{sinc}(t/T_s) = \frac{\sin(\pi t/\ T_\mathrm{s})}{\pi t/T_\mathrm{s}}, \tag{2}$$

   The pulse $p(t)$ has a onesided bandwidth of $B = 1/2T_\mathrm{s}$.

   (a) Generate a discrete signal $p(nT_\mathrm{samp})$ by sampling the signal $p(t)$ with $T_\mathrm{s} = 0.025$s and for $-6T_\mathrm{s} \leq t \leq 6T_\mathrm{s}$. Choose a suitable sampling rate that allows reconstruction of $p(t)$ from $p(nT_\mathrm{samp})$. (Hint: Use sampling frequency greater than Nyquist rate, $f_\mathrm{samp} = 1/T_\mathrm{samp} > 2B$).

   (b) Compute discrete Fourier transform (DFT) of the signal $p(nT_\mathrm{samp})$ and plot the magnitude and phase responses. Scale the frequency axes to indicate frequencies in Hz.

   (c) Repeat part(b) with different sampling frequencies. Do the magnitude and phase response change with the sampling frequency? What happens to the responses for $f_\mathrm{samp} < 2B$.

   (d) Reconstruction: If a bandlimited signal is sampled above its Nyquist rate, it can be reconstructed from its samples. The reconstruction can be described using an interpolating formula

$$p(t) = \sum_{n=-\infty}^{n=\infty} p(nT_\mathrm{samp})\,\mathrm{sinc}\left[f_\mathrm{samp}(t - nT_\mathrm{samp})\right]. \tag{3}$$

   Perform an approximate reconstruction of the signal $p(t)$ from $p(nT_\mathrm{samp})$ generated in part (a) using truncated sinc pulses. Repeat the reconstruction with a sampling rate below the Nyquist rate.

   (e) How does the width of the sinc pulse affect reconstruction?

2. Repeat Problem 1 with the signal

$$p(t) = \begin{cases} 0 & \text{if } |t| > \frac{T_s}{2} \\ 1 & \text{if } |t| \leq \frac{T_s}{2}. \end{cases} \tag{4}$$

   (a) What is the bandwidth of the signal?

   (b) Does the reconstructed signal resemble the continuous signal $p(t)$?

---

*With contributions by E. Agrell, K. Haghighi, A. Alvarado, H. Cao, J. Karout, L. Beygi, M. Reza Khanzadi, M. Ivanov, K. Nagalapur and J. Östman

[1] Refer to any standard textbook on digital signal processing for concepts

3. Repeat Problem 1 with the signal

$$p(t) = \frac{\sin(\pi t/\, T_{\mathrm{s}})}{\pi t/T_{\mathrm{s}}} \frac{\cos(\alpha \pi t/T_{\mathrm{s}})}{1 - 4\alpha^2 t^2/T_{\mathrm{s}}^2}, \tag{5}$$

where T_{s} is the symbol period of the pulse and α is the excess bandwidth factor. The pulse has an one sided bandwidth of $B = (1+\alpha)/(2T_{\mathrm{s}})$.
Generate the signal with $\alpha = 0.3$, $T_{\mathrm{s}} = 0.01$s and $-6T_{\mathrm{s}} \leq t \leq 6T_{\mathrm{s}}$.

4. **Power spectrum**:

In this problem, you will learn how to estimate and plot the power spectral density of a signal. The power spectral density is estimated using Welch's periodogram averaging method.

(a) Load and play the attached sound file, and plot the power spectrum of the sound.

(b) Add noise to the signal (using the awgn($\cdot$) function in MATLAB with 15 dB SNR).

(c) Play the noisy signal, and plot the power spectrum. Observe the level of the noise power in the power spectrum.

(d) Change the SNR variable the awgn function, then play the noisy sound again, and plot the spectrum. What do you see from these spectrum figures? Is there any relationship between what you see and what you hear?

5. **Signal space and Constellation**

A simplified modulator can be formed by three blocks (as shown in Figure. 1): bits to messages, messages to symbols and symbols to signals. Write a MATLAB program to implement these three blocks and perform the following tasks.
Design requirements for the modulator: Sampling frequency $f_{\text{samp}} = 1/T_{\text{samp}} = 44\text{kHz}$, data rate $R_{\text{b}} = 440\text{bits/s}$, dimension of the signal space $N = 2$. Note, $\mathbf{a}$ is the transmitted bits vector.

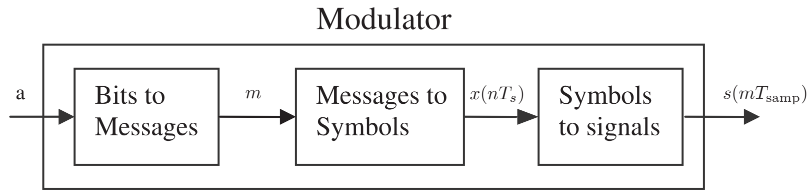

Figure 1: Block diagram of the modulator

(a) In the first block, map bits into messages. If we use two bits per symbol, how many different messages M can we transmit?

(b) In the second block, choose a two-dimensional constellation for transmission of the messages and map the messages to the constellation symbols.

(c) Every symbol is associated with a pulse to restrict the bandwidth of the transmitted signal. The sampled transmitted signal is given by

$$s(mT_{\text{samp}}) = \sum_{n=0}^{N} x(nT_{\text{s}})p(mT_{\text{samp}} - nT_{\text{s}}), \tag{6}$$

where $p(mT_{\text{samp}})$ is the sampled pulse and T_{s} is the symbol period.

In the third block, create the transmitted signal using a rectangular pulse.

(d) Draw your symbols in a constellation plot. Plot your transmitted signal.

(e) Solve the problem in case of using RC pulse with $\alpha = 0.35$ instead of using rectangular pulse. (Hint: Take the help of the function `rcpuls.m` provided.)

(f) Solve the problem in case of using RRC pulse with $\alpha = 0.4$ instead of using rectangular pulse. (Hint: Take the help of the function `rtrcpuls.m` provided.)

Problems for Exercise C_3

6. **Matched filter**

   In this problem, we transmit the signals you created in Prob. 5 (c) and (f) through an AWGN channel (use the awgn($\cdot$) function in MATLAB, and set SNR = 20dB). Implement the matched filter type demodulator in the receiver.

   (a) Design the matched filter, and plot it in MATLAB.

   (b) Plot the received signal before and after the matched filter, and constellation plot of the received signal after the matched filter.

   (c) Use ML decision rule to detect the received symbols and transform the symbols into information bits. How many error bits do you receive?

7. **Eye diagram**

   Write a program in MATLAB to plot an eye diagram for the signals generated in 5(f) and the signal obtained after matched filtering.

   (a) Repeat 5(f) with different roll-off factors $\alpha = 0.3, 0.5$ and widths.

   (b) Plot eye diagrams for the pulse trains generated in part (a) and the pulse trains filtered through corresponding matched filter.

   (c) Repeat parts (a) and (b) by adding noise with awgn($\cdot$) function in MATLAB to have 10 dB SNR.

8. **Sequences for Frame detection**

   (Prob. 4-22, Book) A length-7 sequence is to be used in the acquisition of a timing epoch. We are to locate the epoch by correlating what is received with a copy of the length-7 sequence at the receiver. The transmitted symbols are the antipodal values ± 1, henceforth denoted by + and -. Immediately before and after the sequence, nothing is transmitted, which the receiver interprets as the value 0.

   (a) Find the correlation that will be observed if the sequence + - + - + - + is employed, and compare your answer to what would happen if the PN sequence + + + - + - - in Example 4.8-1 were used instead. (Hint: use autocorrelation)

   (b) Now suppose the first and seventh digits are received in error (i.e., inverted). Compare the two correlations.