Alexandria University
Faculty of Engineering
Electrical and Electronics Engineering
Department

جامعة الإسكندرية
كلية الهندسة
قسم الهندسة الكهربية

# DIGITAL COMMUNICATIONS LAB

In the Digital Communications lab, you will investigate different aspects of digital communication systems.

## About the lab

The digital communications lab is a group-based lab, in which a group of students collaborate in completing the different aspects of the lab. The lab investigates **three** different aspects of digital communication systems. Each group of students should consist of 6-10 students (these limits are hard limits; no exceptions allowed). Each group would study the mentioned topics and provide the required outcomes for each of the parts as instructed below in this document.

## Goals and grading of the lab

The goal of the lab is to assess different important skills that a student should have. These aspects include

- **To learn new topics that are not necessarily covered (at all or in great depth) in class.** Therefore, the lab consists of different topics that the student should be able to follow and cover via self-learning and investigations.
- **To solve a new mathematical or engineering problem that the student may face.** In one part of the lab, a common digital communication problem will be explained in details and the student should pursue its solution. Various solutions may exist in the literature, and the student is advised to investigate many such solutions and compare if possible.
- **To assess the performance of the solutions that the student comes up with for problems related to digital communications.** This should be done by using the same BER simulation techniques.
- **To demonstrate their findings effectively and clearly.** This is covered by allowing groups of students to present their results and findings in a presentation.

Since this is a group lab, students are advised to be careful when forming their respective teams, taking into account the aspects mentioned above. It would be a good strategy to distribute the work among the students in the group according to what they do best. From that perspective, lab grading will not distinguish much between individuals in the same group. Therefore, it is perfectly okay (and in fact expected) for some students in a group to entirely work on presenting the findings of the group; other students focus on research aspects; others focus on coding aspects and so on.

The instructions to complete the lab will be different for each part of the lab. However, due to the open-ended nature of the lab, there are not going to be detailed instructions for finishing each part. Instead, general guidelines will be given in each part to help students approach the topic and provide meaningful results and findings.

Regarding aspects which require coding, please feel free to use any coding language that you may feel comfortable with. However, it is recommended to use MATLAB which is better suited to handle digital communication-related simulations.

# Lab submission

The outcomes of the lab should consist of the following:

- Presentation slides which describe the results and findings of the group for each aspect of the lab.
- The codes used to generate the results of the lab.

The details of these presentations will be announced at a later time. For now, you can prepare your presentations assuming that the total presentation time for each group will be 20 mins, with 10 mins for discussions.

# Collaborations between students and cheating

Each group of students is allowed to fully collaborate among themselves in discussing topics and writing codes. However, collaboration between groups is **only allowed as follows:**

- Students **can** discuss concepts and ideas related to the aspects they are studying in the lab.
- Students **cannot** share or discuss codes

Any sharing of codes (full codes or even parts of codes) will be considered as cheating, and the grades will be severely deducted from all collaborating groups.

Note that you have to implement all the required codes on your own. You cannot use built-in MATLAB functions. You cannot also find existing codes which do the tasks required in the lab. **Using existing codes is considered as a form of cheating and will also be severely penalized**. You can safely assume that, if you found a code online that does the job, chances are the instructors are aware of it as well!

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# Helpful hint

This will be an above average lab, so expect that it will require a lot of work. Please ask Eng. Hossam Mohammed for help whenever you are stuck in something or something is not clear. The instructor will try to help as much as possible.

No question is a dumb question, even if you are stuck with a MATLAB error that you cannot resolve. The only rule in asking a question is that you do your best finding the answer before you come with the question.

It would be much more appreciated by the instructors if you ask them many times for help as you take your project to completion, rather than remain struggling during the entire time until the project submission day and end up with very little to show.

# lab details

## Part 1: Inter-Symbol Interference due to band-limited channels

In this part, you will investigate another common channel in digital communication systems, which is the band-limited channel. As the name suggests, the channel only allows a limited range of frequency components to pass, while blocking frequency components outside this range. We investigate the simplest of such channels: a channel that has a flat response in the allowable range. Figure 1 shows the system that we will consider.

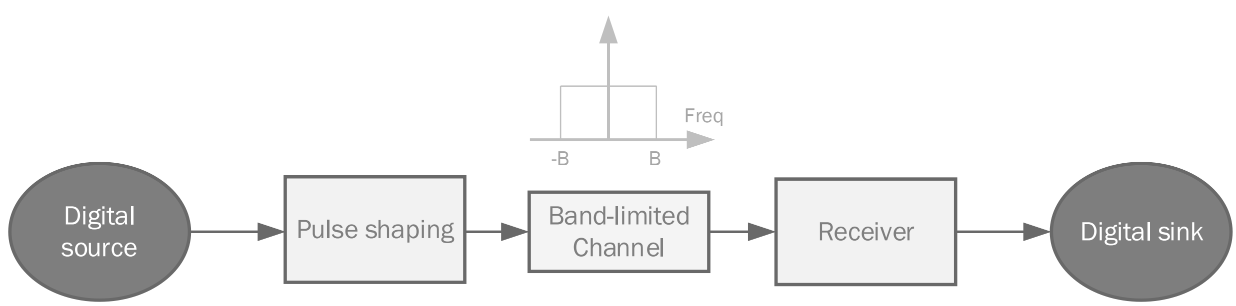


**Figure 1 Communication system with a band-limited channel with bandwidth B.**

The channel obviously limits the kind of signals that can pass unchanged through the channel, because if a signal has frequency components that are outside the allowable range of the channel, these components will not pass and therefore the output signal from the channel will be changed from the input signal. This issue will face the most common of signals that we use to represent bits: the square signal!

***Guidelines: The first thing you need to show here is the effect of a band-limited flat channel on the square signal. You need to create a band-limited channel such as the one in Figure 1, with a band $B = 100\ kHz$.***

***Then generate a square pulse of duration $T = 2/B$, pass it through the filter, and then look at the output. You need here to show the signal before and after the channel, both in time and in frequency.***

As you can see, the square signal is no longer a square signal coming out of the channel. In fact, the shape of the square signal out of the channel has "leaked" outside of the duration $T = 2/B$ that was intended at the beginning. If there are multiple square signals after each other (one square signal for each bit), these leaked parts will interfere with the signals of other bits. This phenomenon is called *Inter-Symbol Interference (ISI)*.

***Guidelines: The second thing you need to show is the effect of two consecutive square signals as they pass through the channel. Consider the same channel and the same square pulse duration as before. The plots you need to show here are in time domain only. Namely,***

1. ***Show two plots of the first square pulse: one before it passes through the channel, and one after.***
2. ***On top of the two previous plots, show similar plots for the second square pulse. Plot this pulse in the two plots using a different color, so that the shapes of the two pulses are distinguishable on the plots.***
3. ***Note that you will have to pass the two squares separately, i.e., you cannot create the two pulses together in the same vector and pass that into the channel. If you do it this way, you won't be able to clearly distinguish the two pulses.***

***The procedure that you need to follow to generate the plots required above are shown in Figure 2.***

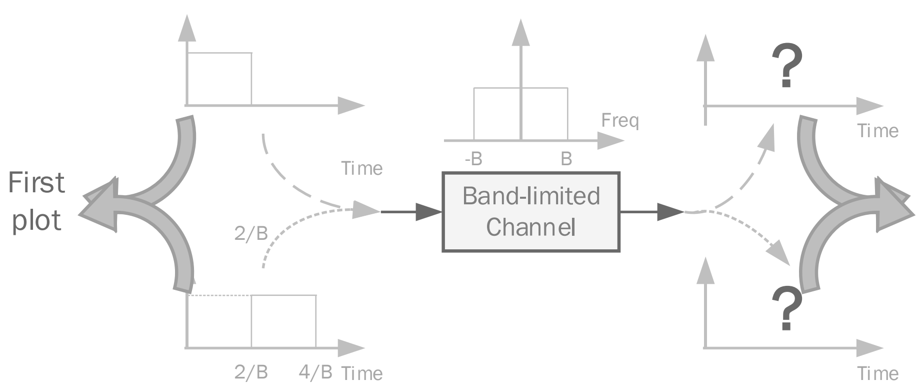


**Figure 2 How to generate the two plots described above.**

ISI can negatively affect the detection performance of multiple consecutive signals. To combat the effect of ISI in band-limited channels, one cannot use square pulses anymore. Instead, there are other pulse shapes that are better suited for such channels. You need to investigate such solutions.

***Guidelines: the following aspects can be useful in investigate these solutions***

1. ***Explain what is the mathematical criterion that ensures no ISI.***
2. ***Describe one or more pulse shapes that ensure that such condition is met.***
    a. ***For one or more of these pulse shapes, show (at least for one of those pulse shapes) plots of the pulse shape before and after the channel, both in time and frequency.***
3. ***(Optional) show the BER performance of using these pulse shapes in AWGN channels.***

# Part 2: Inter-Symbol Interference due to multi-path channels

In this part, we consider another form of ISI that happens in channels that we face in wireless communication systems. The channel considered here is referred to as the *multipath channel*. To understand the effect of this channel, we refer to Figure 3.

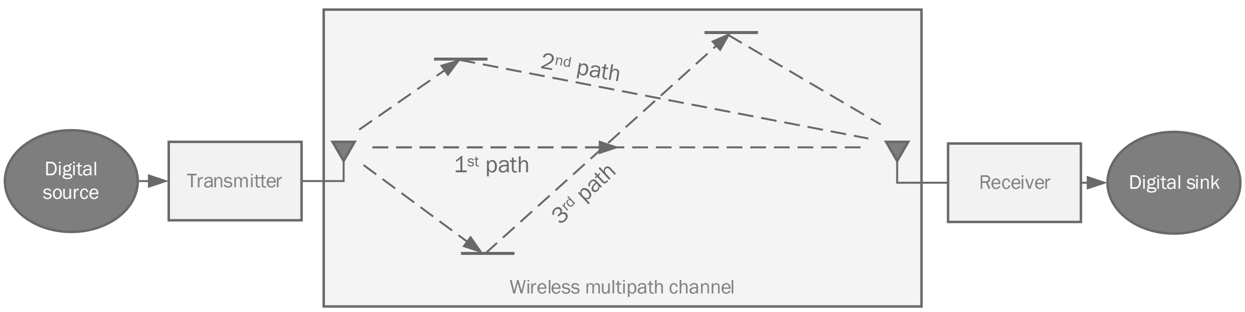


**Figure 3 Signal propagation in a wireless multipath channel.**

In wireless channels, signals are transmitted via electromagnetic waves which propagate through the air until it reaches the receiver. However, the nature of electromagnetic waves allow that multiple copies of the signal would travel around and reach the receiver at different times, such as is shown in Figure 3. This effect is what is known as the multipath effect. As is shown in the figure, a symbol transmitted by the transmitter would traverse multiple paths until it reaches the receiver. Therefore, the receiver is expected to receiver multiple copies of the same transmitted signal. Each of these copies would arrive at a different time (based on how long the path that the signal travelled through is) and with a different magnitude (based on how much attenuation that the signal suffered from during the transmission across the path).

This behavior of receiving multiple copies of the same signal is mathematically captured as follows. Let the first symbol transmitted by the transmitter be labeled as $x[0]$. Then, the receiver would receive a first copy of that symbol as

$$y[0] = h_0 x[0] + n[0]$$

where $y[0]$ is the received signal, $h_0$ is the channel effect of the first path on the transmitted signal $x[0]$, and $n[0]$ is the noise component.

Now let $x[1]$ be the second symbol transmitted by the transmitter. Ideally, the receiver would receive a signal $y[1]$ which corresponds to this signal (plus noise). However, the effect of multipath is that $y[1]$ will also include a copy of $x[0]$ which have passed through a longer path and therefore have arrived at a delayed time. Therefore, the second received signal can be written as

$$y[1] = h_0 x[1] + h_1 x[0] + n[1]$$

where $h_1$ is the channel effect of the second path on the transmitted signal. Note that we assume here that any symbol which travels through a particular path would have the same channel effect.

Assume we have a total of $L$ paths in our channel. Then, the $L$th received signal can be expressed as

$$y[L-1] = h_0 x[L-1] + h_1 x[L-2] + h_2 x[L-3] + \cdots + h_{L-2} x[1] + h_{L-1}\, x[0] + n[L-1]$$

where $h_i$ corresponds to the channel effect of the $(i+1)$th path, and $x[i]$ is the $(i+1)$th transmitted symbol.

Let’s write this set of equations on top of each other

$$\begin{aligned}
&y[0] = h_0 x[0] + n[0] \\
&y[1] = h_0 x[1] + h_1 x[0] + n[1] \\
&y[2] = h_0 x[2] + h_1 x[1] + h_2 x[0] + n[2] \\
&\vdots \\
&y[L-1] = h_0 x[L-1] + h_1 x[L-2] + h_2 x[L-3] + \cdots + h_{L-2} x[1] + h_{L-1} x[0] + n[L-1]
\end{aligned}$$

This can be written in a matrix form

$$\underbrace{\begin{bmatrix} y[0] \\ y[1] \\ y[2] \\ \vdots \\ y[L-1] \end{bmatrix}}_{Y} = \underbrace{\begin{bmatrix} h_0 & & & & & & \\ h_1 & h_0 & & & & & \\ h_2 & h_1 & h_0 & & & & \\ \vdots & & & \ddots & h_1 & h_0 & \\ h_{L-1} & h_{L-2} & h_{L-3} & \cdots & h_2 & h_1 & h_0 \end{bmatrix}}_{H} \underbrace{\begin{bmatrix} x[0] \\ x[1] \\ x[2] \\ \vdots \\ x[L-3] \\ x[L-2] \\ x[L-1] \end{bmatrix}}_{X} + \underbrace{\begin{bmatrix} n[0] \\ n[1] \\ n[2] \\ \vdots \\ n[L-1] \end{bmatrix}}_{N}$$

So this set of equations results in the simple matrix equation $Y = HX + N$. From the receiver perspective, the terms of the equation are as follows:

1. The transmitted signal is $X$. This is what the receiver wants to know or estimate.
2. The received signal is $Y$. This is what the receiver measures from the channel, and is the main observation from which the receiver can figure out what $X$ is.
3. The noise component $N$. This corresponds to the AWGN noise which corrupts $Y$.

4. The channel coefficients $H$. This term captures the effect of the channel on the transmitted symbols passing through different paths. There are mechanisms which allow the receiver to estimate the value of $H$. So we can safely assume that $H$ is known at the receiver.

So, your goal is to answer the following question:

***Knowing $Y$, $H$, and the statistics of the AWGN noise (i.e., mean and variance), what is the best way of estimating the transmitted symbols $X$?***

***Guidelines: The goal here is to give an answer to the previous question. Note that there are several techniques to solve this equation in the literature. You can investigate one or more of these solutions. Please perform simulations to show the BER vs $E_b/N_o$ performance of the techniques you consider for estimating $X$. In doing these simulations, you can assume that the transmitted symbols are BPSK symbols with energy $E_b = 1$. You can also assume that the coefficients of the channel are Complex Gaussian with zero mean and variance 1.***