COURSE NAME: ECE 4531: Digital Signal Processing I

PREREQUISITES: ECE3511, ECE2214 and ECE2215

INSTRUCTOR: Dr. Maryhelen Stevenson (stevenso@unb.ca)

TEACHING ASSISTANT: Nick Kozma (nkozma@unb.ca)

CLASS MEETINGS AND MEANS OF COMMUNICATION: Email and MS Teams will be used to convey messages to the class. Please check both on a regular basis. MS Teams will be used for all class gatherings including: office hours/help sessions, labs, the midterm, and the final exam. The MS Teams class name is: **ECE 4531, WI21**

TIMES RESERVED FOR THE COURSE:
So as to allow for flexibility in the scheduling of office hours, the occasional live lecture or class meeting, and the midterm, students are expected to be available during the times reserved for this course. These times include: 10:30–11:20 on M,W,Th, and F; as well as Th (2:30–5:30) on designated lab weeks.

OFFICE HOURS: 10:30–11:00 on days when an assignment is due. starting next week.
I will be available for questions at 10:30 (via MS Teams) on days when assignments are due (this day will start off as Wednesday, but it may change throughout the term). You will be able to find a link to join these sessions on the General channel for this course in MS Teams as well as in the "Useful Links" folder under Content in D2L. If you do not have any questions, there is no need for you to attend; but, please feel free to come and hear what other students are asking. If you have specific questions you would like me to address during office hours, I would appreciate you sending me an email (preferably a day or more in advance) to let me know – this would allow me to find and open any necessary files ahead of time. When sending such emails, please be as specific as possible about what it is that you do not understand.

HOW TO ASK QUESTIONS: In addition to asking questions during office hours, you may post questions related to Assignments, Labs, and Lectures in the Questions Channel for this course on MS Teams. Please be sure to mention me (*i.e.,* type the @ symbol before my name) when you post a question and feel free to respond to other students' questions if you know the answer. I will try to respond to posted questions within 36 hours; please note that questions posted the night before a midterm or final exam are unlikely to be answered before the exam – so it's best to not wait until the last minute. Please do not email your questions (unless it is one you would like me to discuss during office hours) – I prefer to answer questions on MS Teams (or in the help session) so that all students have the opportunity to hear/see the response.

REFERENCE TEXT:
There is no required text book and most students are fine without a text book. However, for those who would like a text book, I have listed one below, and you can find many more in the library. Please be warned that the notation used in this text book differs from mine; and for assessment purposes (assignments, labs, and exams), you are expected to understand and use the notation, terminology, and approaches introduced in class.

- *Digital Signal Processing: Principles, Algorithms, and Applications,* John G. Proakis and Dimitris G. Manolakis, Pearson Prentice Hall, 3rd or 4th edition

WORKLOAD EXPECTATIONS: Depending on your background and capabilities, you should be prepared to spend between 6 and 12 hours per week on the course outside of the time you spend in the lab and watching the lecture videos. While most of this time will be spent working on assignment problems, some time should also be devoted to pre-lab exercises, reviewing class notes, reworking class examples (as needed), and determining how to correct any errors you may have made on the assignments or on the midterm. Please note that assignment and midterm solutions will generally not be provided; it will be up to you to review the appropriate course material in order to correct your marked work. If after making corrections, you still have doubts regarding the correctness of your work, I will be happy to provide feedback. You should not, however, wait until the night before the midterm or the final exam to do so, nor should you save up a pile of assessment corrections to ask about all at once.

DESIRE2LEARN (D2L): Course information, links to pre-recorded videos, handouts, and lecture slides, assignments, lab instructions, and student grades will all be posted on D2L.

A NOTE ON VIEWING THE DESCRIPTIONS OF CONTENT ITEMS ON D2L: I will occasionally include a short description of content items in D2L. Please note that you will not see these descriptions unless you are using the Content Tool; in particular, you will not see these descriptions when using the Content Browser Widget as opposed to the Content Tool. The best way to access the Content Tool is to click on the Content tab (located between the Course Home and Assessments tabs) at the top of the D2L page. Once you have opened the Content Tool, you will see a Table of Contents which includes various Content Modules (such as Assignments, Assignment Solutions, etc). If you click on one of the content modules, you will see the content items included in the module. If a description exists, the description will appear underneath the link to the item, but only if you are within the innermost folder containing the item. For example, you will not see the description of Assignment 1 (which says: "You should be able to complete this assignment after …") unless you are using the Content Tool and are inside the Assignments module.

LECTURES: Videos of pre-recorded lectures will be made available in the Lecture Video and Handouts folder on D2L. In addition to pre-recorded videos, and depending on how the term evolves, it's possible that some lectures will be delivered live. In the past, I have found it useful to use some of the lecture time to do examples that might otherwise be done in a tutorial and have, thus, used part of the tutorial time as extra lecture time. That will likely be the case this year as well. On average, you should expect approximately 7 lectures every two weeks (perhaps 3 lectures on weeks with labs and 4 lectures on the weeks without labs). Based on my experience from last term, it may take me longer to cover the same material when writing on my iPad as opposed to writing on a chalk board – if you find this to be the case, please feel free to compensate by watching the video at a faster-than-normal playback speed. While watching the videos, it is important that you remain actively engaged in what is being taught. I recommend that you take notes as you would during a normal in-person lecture – you may even want to pause the video to try working class examples on your own before I do them on the video.

LECTURE SCHEDULE: So that you have an idea of which videos you should be watching on which days, I will label the videos according to the lecture number in which I usually cover the same material. For example, a video whose name begins with L01 includes content that is usually covered in the first lecture. When the content of a lecture is chunked into multiple videos, the fourth character of the video's name will indicate the order in which the videos should be watched; thus, a video beginning with L01b should be watched before a video whose name begins with L01c. I may also put in the video's description the date on which I would be delivering the lecture assuming in-person classes.

LECTURE SLIDES AND HANDOUTS: Handouts and/or lecture slides used as a basis for pre-recorded lectures will also be posted in the Lecture Videos and Handouts folder in D2L. Please note that the version of the lecture slides that I post will normally correspond to what I start with at the beginning of the video. Any annotations that I add, or any examples that I do during the video will not be included. This means that you should be taking notes as you watch the videos. Feel free to post any lecture-related questions in the Questions channel on MS Teams.

CLASS RECORDINGS AND COPYRIGHT

Distribution of course materials (*e.g.*, lecture videos, lecture slides, handouts, assignments, tests, lab documents, *etc.*) is prohibited without the prior written consent of the instructor. In addition, anyone who wishes to video or audio record lecture presentations must obtain the instructor's written consent beforehand. Without the instructor's written consent, all such distribution and reproduction is an infringement of copyright and is absolutely prohibited and subject to academic penalties.

ASSIGNMENTS: Assignments will be posted on D2L. There will be approximately one assignment per week. You are advised to start working on assignments well before their due dates (which will be indicated on D2L). Students are entrusted to write their solutions on their own. If you do not know how to work a problem, you should first review your course notes to make sure you understand the relevant background material and to review similar examples that may have been done in class. You may post questions regarding assignment problems on the Questions channel of MS Teams and you may also ask assignment related questions in the help sessions. Various requirements and expectations regarding your submitted work are detailed in the section below entitled *Assignment Submissions.*

ASSIGNMENT SUBMISSIONS:

Expectations regarding write-up of solutions: Rather than simply writing the answer to a question, you must *provide context* so that someone who reads your submission can figure out what you are doing without necessarily having access to the question. You should *always show your work,* providing enough detail that it is easy to follow and providing justification where appropriate. *Points may be deducted if your solution lacks detail, lacks justification, or is hard to follow.* Your assignment submissions should be neatly written and well organized. With the goal of obtainining a high-quality scanned version of your work, please consider using an eraseable pen on white paper for high contrast. For submission purposes, you should start each question and sometimes each part of a question on a new piece of paper; consult the Crowdmark template to determine if individual parts of a question should be written on separate pages. It is also recommended that you leave lots of space on the sides for comments to be added by the marker; otherwise, the marker's comments will cover up your work making it more difficult to understand the added comments.

ASSIGNMENT SUBMISSIONS (continued on next page).

ASSIGNMENT SUBMISSIONS: (continued from previous page)

Submission Logistics: To submit your assignment solutions, you will need to scan them to a PDF file and then upload the PDF file to CrowdMark. There will generally be a designated location in the CrowdMark template for each question and sometimes for individual parts of a question. You can either upload a single PDF file containing all pages of your submission to a single location in the CrowdMark template and then drag the individual pages to their appropriate locations or you may upload a different PDF file for each question straight to its designated location in the CrowdMark template. You may submit as many times as you want until the due time. Before pressing submit for the final time, you should ensure that all pages are properly oriented and in the correct location of the CrowdMark template. *In addition to losing points if your work is difficult to read or follow (either due to bad handwriting, poor organization, or low contrast), you will also lose points if your solutions are uploaded to the wrong location in the CrowdMark template, oriented/rotated incorrectly, or submitted late.*

Certification that the work you submit is your own: Along with each submitted assignment, you must include a signed statement attesting that the work you have submitted is your own. While it is acceptable to have high-level discussions with your classmates, regarding assignment questions, these discussions should not involve a detailed line-by-line written or verbal description of anyone's solutions or portions thereof. *Provided that you restrict yourselves to high-level discussions with your classmates(or others) and that you write your solutions on your own, it is highly unlikely that you will make the same mistake(s) as a classmate with whom you discussed the assignment; it is also unlikely that you would use the exact same notation and simplification steps, etc.*

Under no circumstance** is it acceptable to share your solutions with another student – nor is it acceptable to look at, copy, or borrow someone else's solutions (this includes solutions of students who took the course in previous years). **Either of these actions could result in all parties involved receiving an academic offense.

ASSIGNMENT SOLUTIONS ARE USUALLY NOT PROVIDED: Once your assignment has been marked and returned, I strongly recommend that you look it over to understand the reason for any lost points as well as to make sure that you are able to correct your solutions to problems that were marked as incorrect. If, after reviewing the feedback provided in your marked assignment and correcting your solutions, you still have doubts as regarding your corrected solutions, I will be happy to provide feedback (provided your corrected solutions are neatly written and well organized). So as to encourage students to rework assignment problems in a timely manner, your request for feedback should be limited to questions from one assignment per week. Please ask only about corrections for which you are uncertain; depending on the number of requests it may take several days for me to get back to you.

ISSUES WITH ASSIGNMENT MARKING: Questions about assignment marking should first be discussed with the TA; if after consulting with the TA, you still have questions or unresolved marking issues, please feel free to discuss them with me.

LABS: A total of five matlab-based labs will be held virtually on MS Teams on the following six Thursday afternoons from 2:30−5:30. (note that two afternoons will be devoted to Lab 5.)

LAB DATES: Jan 21, Feb 4, Feb 18, Mar 11, Mar 25, Apr 8

Attendance at all labs is compulsory (*any student who fails to successfully complete one or more labs will not receive a passing grade for the course*). To attend labs, students will join the Lab Meeting on MS Teams at 2:30 on lab days. After some introductory remarks from the TA, students will move into the break-out room created for their lab group, where the group will meet to work on the lab and prepare the lab report. Within the break-out rooms, students will be able to talk to their lab partners, use the chat function, share screens, and share files. Both the instructor and the TA will be able to drop into your break-out room to monitor your progress and answer any questions you may have. The labs are intended to help you understand course concepts. Please take advantage of your time in the lab to clear up any questions you may have about the associated concepts taught in the lectures. ***When applicable, prelab exercises should be completed prior to attending labs.***

LAB GROUPS: Labs will be performed in groups of two or three. Lab groups will be established prior to the first lab and will remain the same for the entire term. All students in the group are expected to play an active role in performing the lab and writing/proofreading the report, which is due at the end of the lab session.

LAB SUBMISSIONS: In general, it is expected that each group will submit their lab report before leaving the lab. In some cases, students may be given extra time to submit their work. For example, if the lab session is held before the associated theory is covered in class and if the lab requires a discussion relating the lab observations to the underlying theory, students will be able to hold onto their work until the theory has been covered in class.

Lab reports should be neat and well organized; you may produce your report using Matlab's desktop publishing or any other word processing software − it may even be handwritten as long as it is neat and easy to read. A CrowdMark template, allowing a group submission, will be distributed near the beginning of the lab. The report should include: prelab exercises (if any); a brief discussion of what was done (*e.g.*, matlab code that was executed, etc.), results that were obtained (include print outs obtained while performing the lab), and a clear concise discussion of your results. Your discussion should include answers to questions posed in the lab manual and, where applicable, you should discuss how your lab observations relate to underlying theory. Answers to questions posed in the lab manual should be written in complete sentences and in such a way that the reader does not need the question to make sense of your answer. All plots should be clearly labelled and included in the report at the point where you refer to the Figure as opposed to an appendix; when appropriate, you are encouraged to add handwritten annotations/explanations/discussions to your plots.

All students in the group are responsible for the content of the submission. Lab submissions should not include the names of students who leave the lab before the work is completed. *Groups receiving a mark less than 45% must improve and resubmit their work; the resubmitted work will be marked as acceptable or not acceptable; despite an acceptable resubmission, students will retain the mark received on their original submission.* ***A student will not receive a passing grade in the course until all lab submissions have been deemed acceptable.***

ADMINISTRATION OF TIMED IN-CLASS ASSESSMENTS (MIDTERM AND FINAL EXAM)

Timed in-class assessments will be administered using CrowdMark in conjunction with MS Teams. For each timed assessment, students should join the designated meeting on MS Teams. Following some initial comments, the assessment will be distributed via CrowdMark. Students should be prepared to download and print the assessment. Students are expected to remain in the MS Teams meeting while working on the assessment; this will enable students to ask questions by typing them into the meeting chat as well as to hear any announcements I might make regarding clarifications and/or typos in the assessment. Students will write their answers, as instructed, either on blank pieces of paper or on the printed assessment. After finishing the assessment, or when time is up, students will scan their work, and upload their solutions to the appropriate location in the CrowdMark template. It is important that students allow sufficient time for the uploading process. In addition to a penalty for late submission, penalties will also be imposed for uploading work to the wrong location in the CrowdMark template and for failing to orient/rotate work appropriately – both of which complicate the marking process.
These timed in-class assessments will be *closed-book. Calculators and/or other electronic devices for computational purposes will not be permitted.*

EXPECTATION OF ACADEMIC HONESTY FOR TIMED IN-CLASS ASSESSMENTS:

Students will complete the Midterm and Final Exam entirely on their own (neither giving or receiving aid from others) and without consulting class notes, assignments, labs, or any other resources besides the formula sheet (if one is provided). Electronic devices are not permitted for any use other than communicating with the instructor, printing the assessment (when required), or scanning and uploading your work.

MIDTERM: The midterm exam will be held at 10:30 on Thursday, Feb 25, ~~2020~~ 2021. A make-up midterm will not be offered; if you have a registrar-approved excuse for missing the midterm, the weight of the midterm will be shifted to the final exam. *The midterm will be closed-book and will be administered as described above. Calculators and/or other electronic devices for computational purposes are not permitted.*
When writing the midterm, students are entrusted to adhere to the *Expectation of Academic Honesty* (as stated above) and are reminded that cheating is a serious academic offense.

FINAL EXAM: The final exam will be held at the time scheduled by the registrar. It will be closed-book. A formula sheet for use in the Final Exam will be posted on D2L. *Calculators and/or other electronic devices for computational purposes are not permitted.*
While writing the final exam, students are entrusted to adhere to the *Expectation of Academic Honesty* (as stated above) and are reminded that cheating is a serious academic offense.

GRADES: *A minimum grade of C is required to credit this course towards the B.Sc.E. degree.*

Decomposition[†]:

midterm	10%
final exam	50%
assignments	30%
labs	10%

Numerical to Letter Grade Conversion[‡]:

A+	94–100	B+	75–79	C+	60–64
A	85–93	B	70–74	C	53–59
A–	80–84	B–	65–69	D	45–52
				F	0–44

DEFERRED FINAL EXAMS:

University regulations on deferred exams can be found in the section entitled *University Wide Academic Regulations* of the 2020-21 UNB undergraduate calendar (see Regulation III-E). Please also note the following ECE policy on deferred exams:
All deferred exams in courses offered by the Department of Electrical and Computer Engineering are scheduled to be written on the fourth day of classes in the following term. There are no exceptions.

Students requiring deferred exams must apply for registrar approval as soon as possible. It is also important that you contact Denise in the ECE office to let her know that you will be writing a deferred exam as well as to find out the time and location of the deferred exam.

PLAGIARISM:

As taken from Regulation III.A.3.*iii* in the section of the 2020-21 UNB undergraduate calendar entitled *University Wide Academic Regulations*, please note the following.

> *The University of New Brunswick places a high value on academic integrity and has a policy on plagiarism, cheating and other academic offences.*
>
> *Plagiarism includes:*
> • *quoting verbatim or almost verbatim from any source, including all electronic sources, without acknowledgement;*
> • *adopting someone else's line of thought, argument, arrangement, or supporting evidence without acknowledgement;*
> • *submitting someone else's work, in whatever form without acknowledgement;*
> • *knowingly representing as one's own work any idea of another.*
>
> *Examples of other academic offences include: cheating on exams, tests, assignments or reports; impersonating somebody at a test or exam; obtaining an exam, test or other course materials through theft, collusion, purchase or other improper manner, submitting course work that is identical or substantially similar to work that has been submitted for another course; and more as set out in the academic regulations found in the Undergraduate Calendar.*
>
> *Penalties for plagiarism and other academic offences range from a minimum of F (zero) in the assignment, exam or test to a maximum of suspension or expulsion from the University, plus a notation of the academic offence on the student's transcript.*

For more information, please see Regulation VIII.A in the section of the 2020-21 UNB undergraduate calendar entitled *University Wide Academic Regulations*, or visit

http://nocheating.unb.ca.

It is the student's responsibility to know the regulations.

PURPOSE OF COURSE:

To introduce mathematical methods and tools which are useful in the analysis of discrete-time signals and systems.

COURSE CONTENT

I. Fundamentals of discrete-time (d.t.) signals: representation of d.t. signals, commonly used discrete-time signals (unit step, unit impulse, exponentials, sinusoids), discrete-time frequency and its relationship to continuous-time frequency and the sampling frequency, classification of discrete-time signals (power signals vs. energy signals, periodic vs. aperiodic, symmetric vs. antisymmetric, causal vs. noncausal), simple manipulation of discrete-time signals, various approaches to convolution of discrete-time signals. Autocorrelation and cross-correlation of d.t. signals.

II. Characterization of discrete-time systems: static vs. dynamic, linear vs. nonlinear, time-invariant vs. time-varying, causal vs. noncausal, stable vs. unstable, FIR vs. IIR. Characterization of linear time-invariant (LTI) systems by their impulse responses. Conditions on impulse response for stability and causality of LTI systems.

III. LTI systems described by linear constant coefficient difference equations (LCCDE): Solution of LCCDEs (homogeneous solution, natural/forced responses, zero-state/zero-input responses); conditions on the roots of the characteristic equantion for system stability. Block diagram representation of systems described by LCCDEs, properties of convolution and implications regarding block diagram manipulations of interconnected LTI systems. Implementation structures: direct forms I and II, transposed direct form II, and translation of initial conditions for LCCDE into initial state values for direct form II structures.

IV. The Z transform: definition and region of convergence (ROC), properties of the Z transform. Signals with rational Z transforms: poles and zeros; behaviour of time-domain signal as determined by pole location of signal's Z transform. Inversion of the Z transform (power series expansion, partial fraction expansion). Transfer function of an LCCDE. Application of Z transform to the analysis of systems described by LCCDEs.

V. Frequency Analysis of signals and systems: the discrete Fourier Series and its properties, the Discrete-time Fourier Transform (DTFT) and its properties, Frequency Response Function of a d.t. LTI system and its relation to the system transfer function, steady-state response to sinusoidal signals, cross-correlations of input and output signals, energy/power spectral densities of input and output signals.

VI. The Discrete Fourier Transform (DFT). Frequency-domain sampling and reconstruction, relationship between the DTFT and the DFT, properties of the DFT, implementation of the DFT via the Fast Fourier Transform. Convolution via multiplication of two DFTs; circular convolution. Windowing, frequency resolution, and spectral leakage.

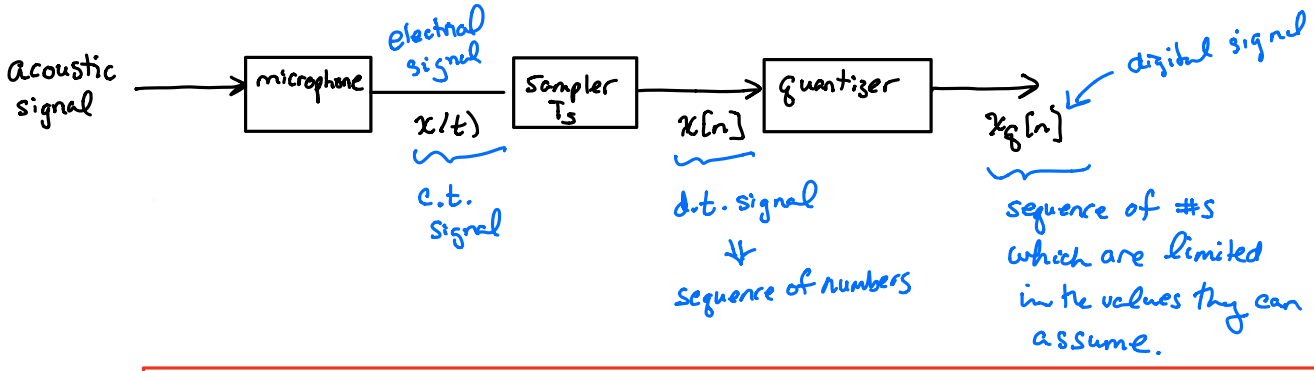
VII. Introduction to Filter Design. Frequency response as determined from pole-zero placement. Pole-zero placement for lowpass, highpass, bandpass, notch, comb, and allpass filters. The Bilinear Transform: conversion of continuous-time filters to discrete-time filters via the Bilinear Transform.

A signal is a set of information that is indexed by an independent variable. If the index has a continuous domain, the signal is a continuous-domain signal. If the indices can be put in one-to-one correspondence with the set of integers, it is a discrete-domain signal.

A system manipulates a signal to produce another signal.

Discrete-time systems operate on discrete-time signals to produce other discrete-time signals.

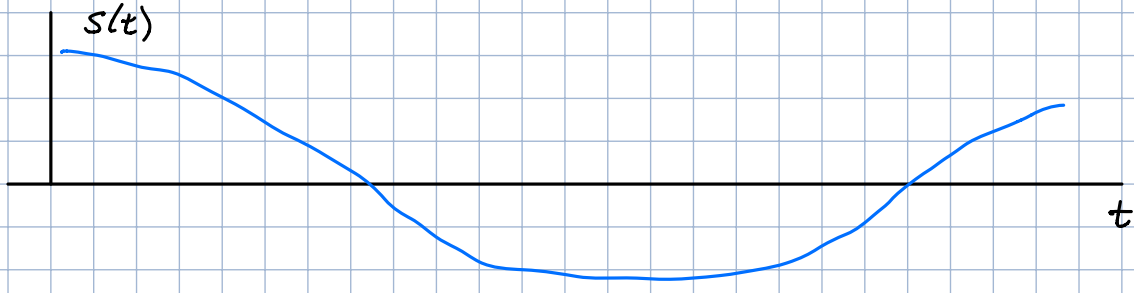
Consider various versions of a speech signal as related by the systems below.

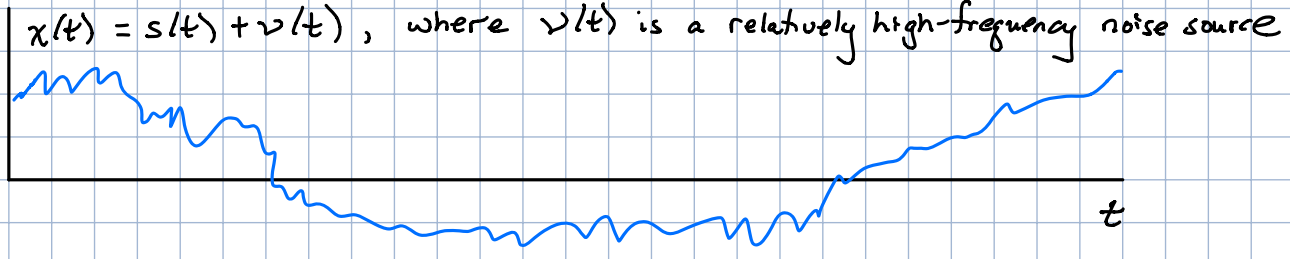


note: $x[n] = x(nT_s) \Longrightarrow$ This is shorthand notation for: $x[n] = \begin{cases} x(nT_s) & \text{if } n \in \mathbb{Z} \\ \text{undefined,} & \text{if } n \notin \mathbb{Z} \end{cases}$

The microphone, the sampler, and the quantizer are all examples of systems.

Let $x(t)$ denote a noisy version of a signal $s(t)$





Given $x(t)$, how might you recover the desired signal, $s(t)$?

Answer:

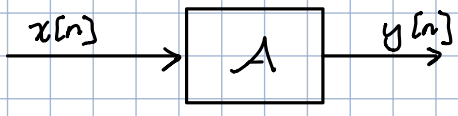
Mathematically what does a lowpass filter do?

Let $x[n]$ be a noisy version of $s[n]$.

Assuming the noise corrupting $s[n]$ is relatively high-frequency compared to the signal $s[n]$, what might we do to $x[n]$ to attenuate the noise?

One way we might attempt to suppress the high-freq. noise corrupting $x[n]$ is to replace each element of the sequence $x[n]$ by the average of the element and its two neighbors.

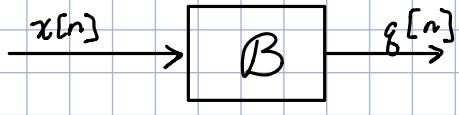
The averaging operation can be viewed as a d.t. system, $\mathcal{A}$, with the input-output equation shown below.



where: $y[n] = \frac{1}{3}\left(x[n-1] + x[n] + x[n+1]\right)$

note: The system $\mathcal{A}$ is noncausal because its output at time n cannot be computed until time $n+1$.

If we don't like the noncausal system, we might consider a slightly different system $\mathcal{B}$.



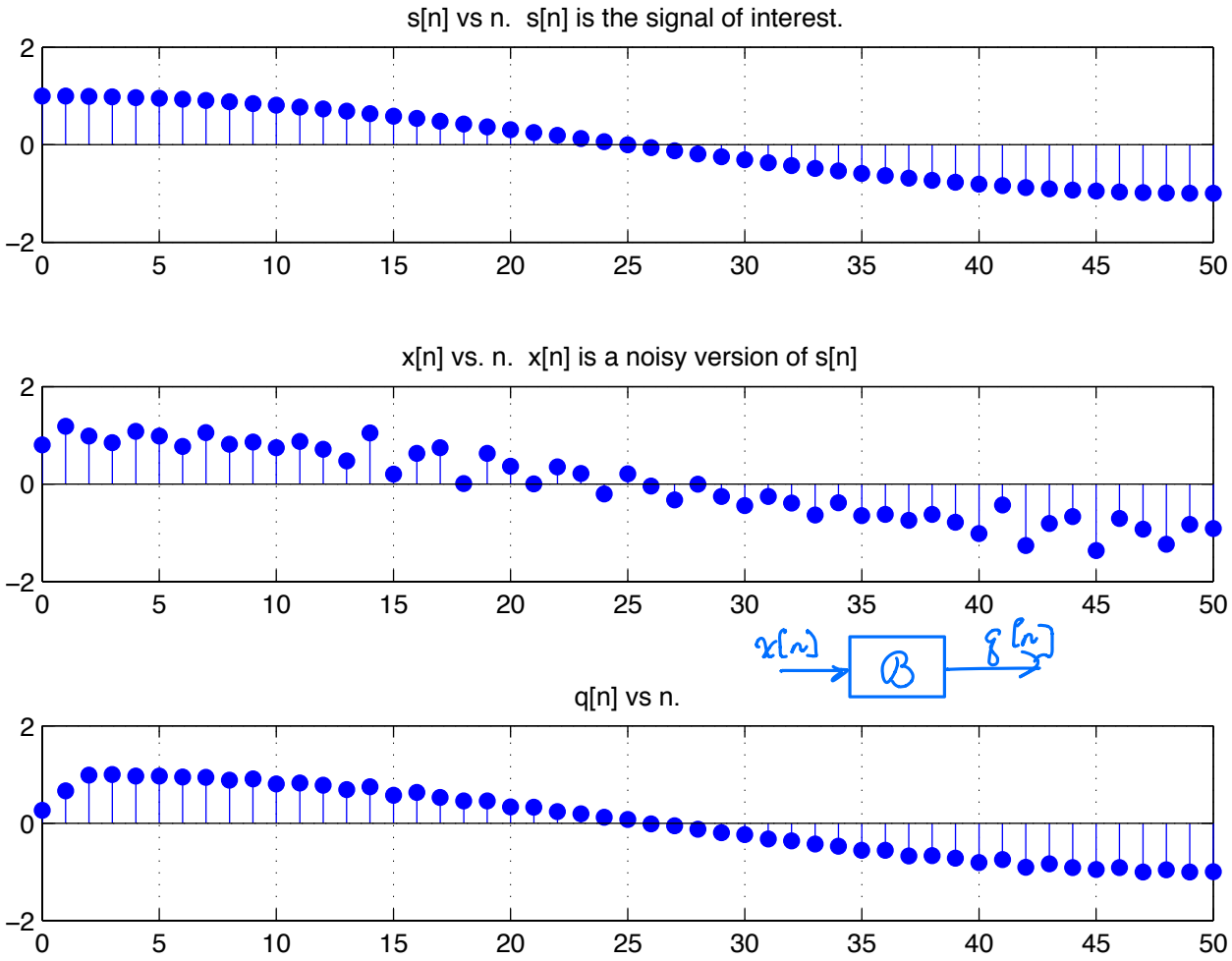
where: $q[n] = \frac{1}{3}\left(x[n-2] + x[n-1] + x[n]\right)$

note that $\mathcal{B}$ is causal, and that the output of system $\mathcal{B}$ is simply a delayed-by-one-sample version of the output of system $\mathcal{A}$.

$$q[n] = y[\ ?\ ]$$

Noncausal systems can be implemented as long as a real-time implementation is not required.

$\mathcal{B}$ is a LTI system and is therefore characterized by its impulse response, $h[n]$, and its frequency response, $H_{DTFT}(F)$.


s[n] vs n. s[n] is the signal of interest.
x[n] vs. n. x[n] is a noisy version of s[n]
x[n]
B
q[n]
q[n] vs n.
q[n] is a lowpass−filtered version of x[n]: q[n] = (x[n] + x[n−1] + x[n−2])/3

In this class, we are especially interested in the analysis of discrete-time systems whose input-output relationship can be expressed as a Linear Constant Coefficient Difference Equation (LCCDE).

General form of LCCDE

$$y[n] + a_1 y[n-1] + \cdots + a_N y[n-N] = b_0 x[n] + b_1 x[n-1] + \cdots + b_M x[n-M]$$

Systems described by LCCDEs are linear and time-invariant.

- they can be characterized by their impulse response and frequency response.

The Z-transform is a useful tool for solving such equations.

Typical Analysis problem:

Given initial conditions at $n=0$ and given $x[n]$, $n \geq 0$, find $y[n]$, $n \geq 0$.

How can we find the frequency response of a system described by a LCCDE?