Discrete-Time Signals and Systems
EE 3353-002, CRN-20248
Fall 2022

Syllabus
Department of Electrical & Computer Engineering
The University of Texas at El Paso, El Paso, Texas 79968, USA
Ricardo von Borries
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Contents

Discrete-Time
Signals and Systems

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Monday, August 22, 2022

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1 General Information

- **Course ID:** Discrete-Time Signals and Systems, EE 3353-002, CRN-20248
- **Time:** Monday and Wednesday, 4:30 pm – 5:50 pm
- **Lecture Room:** Liberal Arts Building 209
- **Prerequisites:** EE 2350 and CS 1320 both with a grade "C" or better. Topics required include: calculus and differential equations, complex numbers and functions, basic time-domain and steady-state circuit analysis, familiarity with `Matlab`® software.
- **Textbook:** J. H. McClellan, R. W. Schafer, and M. A. Yoder. *DSP First*. Pearson, New York, NY, 2nd edition, 2016 [1] and the companion website `https://dspfirst.gatech.edu` [2]
- **Computational Software:** `Matlab`® [3] [4]
- **Instructor:** von Borries – `rvonborries@utep.edu`
- **Office:** Engineering Building 313
- **Office Hours:** MW 6:00 pm to 7:00 pm (room 313 or Blackboard)
  F 4:00 pm to 5:00 pm (room 313 or Blackboard)
- **Version:** Monday, August 22, 2022

2 Description

DSP First [1] starts with the mathematical representation of signals and systems in both the continuous-time and in the discrete-time.

In Chapter 2, we concentrate the initial discussion on continuous-time sinusoidal signals and their representations by complex exponentials and phasors.

In Chapter 3, continuous-time sinusoids are used to introduce the concept of spectrum of a continuous-time periodic signal. Graphical plots illustrate the relationship between representations of signals in the time- and frequency-domains (spectrum, dc-component, bandwidth, time-shifting, frequency-shifting, chirp signals, time-frequency spectrum).

After this introduction, Chapter 4 introduces the conversion of bandlimited continuous-time signals to discrete-time signals (sampling, aliasing, and the sampling theorem). The conversion of discrete-time signals back to continuous-time and the ideal bandlimited interpolation with the *sinc* function close the study on sampling and aliasing.

After getting familiar with discrete-time signals and their representations in the time- and frequency-domains, Chapter 5 applies these concepts to describe discrete-time systems, particularly, the finite impulse response (FIR) filters (moving-average filters, difference equation, impulse response, convolution, polynomial multiplication, block diagrams, and properties of linear time-invariant (LTI) systems).

Chapter 6, introduces the concept of frequency response. We express the sinusoidal response of FIR filters in terms of its impulse response, apply the principle of superposition to the frequency response, and analyze the steady-state and the transient responses of FIR filters. Properties and graphical representation of the frequency response are also investigated. We also study the cascade of FIR filters (LTI systems) and conclude that the time domain convolution corresponds to the frequency domain multiplication. The chapter closes with a practical example of FIR filtering, a system for FIR filtering of bandlimited continuous-time signals, and a `Matlab`® graphical user interface (GUI) to illustrate the characteristics of FIR filters.

In Chapter 7, we investigate the frequency-domain representation of discrete-time signals and systems using the discrete-time Fourier transform (DTFT). At this point, we analyze the Fourier transform of finite- and infinite-length discrete-time sequences (we learn that the spectrum representation using the DTFT corresponds to a continuous and periodic function of the frequency variable). We also investigate properties of the DTFT and apply it to study the characteristics of both ideal and practical FIR filters, including linear-phase filters.

After the DTFT, we are then prepared to apply sampling also in the frequency domain. In Chapter 8, we learn a Fourier transform that is computationally efficient. The discrete Fourier transform (DFT) works with discrete finite length sequences in both the time-domain and the frequency domain. The chapter introduces the DFT definition using both finite sum and matrix forms (linearity, periodicity, symmetry, sampling, interpolation, convolution, Parseval's theorem). We are then able to compute the spectrum representation of any finite-length sequence using a fast Fourier transform (FFT) algorithm. We also apply the DFT and the concept of windowing to compute the time-frequency spectrum (also known as the short-time discrete Fourier transform).

In Chapter 9, we learn a generalization of the Fourier transform: the polynomial z-transform enhances our understanding of discrete-time signals and systems. We define the z-transform of a discrete-time sequence, and investigate its basic properties and applications (its use in block diagrams, convolution as polynomial multiplication, representation of poles and zeros of FIR filters in the z-plane and the corresponding frequency response, linear-phase FIR filters).

Finally, In Chapter 10 we study a class of LTI systems that have infinite length impulse response, the infinite impulse response (IIR) filters. The IIR filters are examples of the general class of feedback systems. We study their general difference equations, block diagrams, impulse response, transfer function, frequency response, and stability.

3 Course Topics

1. Introduction
   a. Mathematical representation of signals
   b. Mathematical representation of systems
   c. Block diagram representation of systems
2. Sinusoids
   a. Review of sine and cosine functions
   b. Sinusoidal signals: period, frequency, time shift, phase
   c. Complex exponentials and phasors: complex numbers, Euler's formula, multiplication, addition
3. Spectrum Representation
   a. The spectrum of a sum of sinusoids: graphical plot
   b. Sinusoidal amplitude modulation: AM spectrum, bandwidth
   c. Operations: scaling, adding, shifting, time-differentiating
   d. Periodic and non-periodic signals
   e. Fourier series: analysis, synthesis
   f. Time-frequency spectrum
4. Sampling and Aliasing
   a. Sampling: sinusoids, reconstruction
   b. Spectrum: aliasing, over-sampling, under-sampling
   c. Discrete-to-Continuous conversion: interpolation
   d. Sampling theorem

5. Finite Impulse Response (FIR) Filters
   a. Moving-average filters
   b. Unit impulse response
   c. Convolution
   d. Block diagrams
   e. Linear time invariant (LTI) systems
   f. Example of FIR filtering
6. Frequency Response of FIR Filters
   a. Sinusoidal response
   b. Superposition
   c. Steady-state and transient responses
   d. Properties of the frequency response: graphical representation
   e. Cascade of LTI systems
   f. Smoothing an image
   g. Discrete-time filtering of bandlimited continuous-time signals
7. Discrete-Time Fourier Transform (DTFT)
   a. Forward and inverse transforms
   b. Properties of the DTFT
   c. Ideal and practical filters
8. Discrete Fourier Transform (DFT)
   a. Forward and inverse transforms: summation and matrix forms
   b. Properties of the DFT
   c. Convolution: periodicity of $x[n]$ and $X[k]$
   d. Windows
   e. Spectrogram
   f. Fast Fourier transform (FFT)
9. z-Transform
   a. Definition: n-domain, z-domain, properties
   b. Linear systems: block diagrams
   c. Convolution and polynomial multiplication

    d. z-Transform, DTFT, and DFT
    e. Poles and zeros of z-polynomials

10. Infinite Impulse Response (IIR) Filters
    a. Difference equation with feedback
    b. Impulse response
    c. Transfer function $H(z)$: poles and zeros, diagrams, stability, plots in the z-domain
    d. Block diagrams
    e. Example of IIR filtering

4 Student Outcomes

Ability to

- determine the parameters amplitude, frequency, period, and phase of sinusoids.
- sketch continuous-time and discrete-time sinusoids and vector diagrams of phasors.
- analyze and manipulate continuous-time and discrete-time sinusoids using sine and cosine functions, trigonometric identities, complex exponentials, and phasors.
- identify and sketch the spectrum of a sum of sinusoids, and the spectrogram of chirp signals.
- apply the spectrum representation and the sampling theorem to implement an ideal converter of bandlimited continuous-time signals to discrete-time signals.
- apply the spectrum representation and the ideal bandlimited interpolation to implement ideal discrete-to-continuous conversion.
- determine the unit impulse response of FIR filters.
- compute the discrete-time convolution to find the output response of FIR and IIR filters.
- represent FIR and IIR filters using basic building blocks in the time-domain, frequency-domain, and z-domain.
- apply numerical simulations to solve problems in discrete-time signals and systems.

5 Textbook and Numerical Computation Software

Discrete-Time Signals and Systems has two required resources: (1) the textbook by J. H. McClellan, R. W. Schafer, and M. A. Yoder. *DSP First.* Pearson, New York, NY, 2nd edition, 2016 (available at UTEP's bookstore); and (2) the software `Matlab`® for numerical computation and visualization developed by The MathWorks, Inc. [3, `Matlab`® on MathWorks]. If you don't have `Matlab`® installed in your computer, you can get `Matlab`® from the Engineering Technology Center (ETC) at the Engineering building E351D, College of Engineering, located between the Engineering and Classroom buildings on the 3rd floor, `http://etc.utep.edu`, e-mail: `etchelpdesk@utep.edu`. Alternatively, you can have access to `Matlab`® at `https://my.apps.utep.edu/vpn/index.html`.

The numerical data simulation and graphic visualization in `Matlab`® software can enhance both teaching and learning of new ideas and concepts in EE 3353.

6 Evaluation

Activity	**Content**	**%**
Quizzes	Chapters 1 to 10	20
Participation	(classroom, office hours, Blackboard, e-mail)	10
Exam I	Chapters 1 to 4	20
Exam II	Chapters 5 to 7	25
Comprehensive Final	Chapters 7, 8, 9, 10, and 1 to 6	25

Exams I, II and the Comprehensive Final taken in the classroom.

Formulas are part of the material assessed in EE 3353 and formula sheets are not allowed during EE 3353 exams and quizzes. Two important rules for the exams and quizzes are: (1) closed textbook, notes and homework solutions; and (2) turned off electronic devices: calculator, computer, cell phone, smart watch, headphone, etc.

7 Grading

$A = 100 - 90\%$, $B = 90 - 80\%$, $C = 80 - 70\%$, $D = 70 - 60\%$ and $F = 60 - 0\%$.

8 Missed Exams

If you miss Exam I or Exam II without an acceptable excuse you will receive zero points for the missed exam. You may be excused from a scheduled exam time due to serious illness, funeral attendance, courtroom appearance, or a UTEP athletic participation. In the case of a missed exam, you must communicate and submit the appropriate documentation to me no later than ten days after the date of the missed exam. The make-up exam for either Exam I or Exam II is comprehensive (all the material for Exams I, II, and III) on the Friday of the finals' week (tentatively, December 10, 4:00 pm to 6:45 pm). Note that there is no make-up exam for the Comprehensive Final or for more than one missed exam.

9 Grade Assignment for Drops and Withdrawals

If you drop the course before the drop deadline, the grade is "W." However, please note the following regulation stated in the UTEP academic catalog (http://catalog.utep.edu/grad/academic-regulations/registration-and-records/): "... if the student drops after the student-initiated course drop deadline, instructors will determine a grade of "W" or "F" for each course. A grade of W will be considered only under exceptional circumstances and must be approved by the instructor and department chair for the course. A student may need to petition the instructor for a grade of "W" in writing with the necessary supporting documentation."

10 Office Hours

In addition to attending the lectures, plan to use office hours to get most out of EE 3353. Feel encouraged to attend office hours and work with me on the textbook concepts and problems, `Matlab`® simulations, and preparing for the exams and quizzes. I can help you to learn "Discrete-Time Signals and Systems." You can use office hours to get more information on anything you are struggling with in class. During office hours, I can provide you with an opportunity (1) to carefully walk through an idea and (2) to get answered lots of questions that are specific to your needs, helping you to effectively learn the material. You can also use office hours to get more information on anything covered in class that triggered your interest, that you enjoyed. I will not collect or grade the recommended exercises from the textbook and from past exams; however, note that you should work on all them as part of your study for EE 3353. I can work with you on the recommended exercises using my office's chalkboard and laptop computer (on `Matlab`® simulations). In addition to regular office hours, you can contact me by email 24/7 with questions on the EE 3353 material and I will try to reply and help you as soon as possible.

11 Academic Integrity

Review and comply with the policy on academic integrity available at https://www.utep.edu/student-affairs/osccr/student-conduct/academic-integrity.html.

12 Attendance

Class attendance is mandatory and will be monitored. Any student with more than two unexcused absences will be dropped out of the EE 3353. It is student's responsibility to sign the attendance sheet provided by the instructor for each class.

13 UTEP E-mail Account

To communicate with me, make sure your UTEP e-mail account is working fine. It is your responsibility to have a UTEP e-mail account working properly. By the end of the first week of classes, every student should have received at least one e-mail message from EE 3353. If you detect an e-mail problem (no EE 3353 e-mail message received by the end of the first week of classes), you should request UTEP's Help Desk assistance to fix the problem with your UTEP's e-mail account.

14 Accommodations and Support Services

If you have a disability and need classroom accommodations, please contact *The Center for Accommodations and Support Services (CASS)* at 747-5148, or by email at `cassutep.edu`, or visit their office located in UTEP Union East, Room 106. For additional information, visit the CASS website at `www.sa.utep.edu/cass`.

15 Use of Electronic Devices

The use of cell phones or electronic devices may pose a negative distraction (social media, internet, email) and disrupt classroom discussions. Phones must be silenced during classes, exams, or quizzes, and if you need to answer a call during a class, please step out of the classroom. You can use an electronic notepad for note taking only [5].

16 Copyright Statement for Course Materials

Materials in this course, unless otherwise indicated, are protected by the United States copyright law. Materials are presented in an educational context for personal use and study and should not be shared, distributed, or sold in print or digitally, outside the course without permission.

17 References Sorted by Order of Appearance

[1] J. H. McClellan, R. W. Schafer, and M. A. Yoder. *DSP First*. Pearson, New York, NY, 2nd edition, 2016.

[2] J. H. McClellan, R. W. Schafer, and M. A. Yoder. DSP First 2e. `https://dspfirst.gatech.edu`.

[3] `https://www.mathworks.com/help/matlab/getting-started-with-matlab.html`. `Matlab`® documentation.

[4] `https://www.youtube.com/user/MATLAB?feature=watch`. `Matlab`® tutorials.

[5] P. A. Mueller and D. M. Oppenheimer. The pen is mightier than the keyboard: Advantages of longhand over laptop note taking. *Psychological Science*, 25(6):1159–1168, April 2014.

A Calendar

EE 3353, MW 4:30 pm to 5:50 pm

August 2022

M	T	W	R	F	S	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

September 2022

M	T	W	R	F	S	S
			1	2	3	4
	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

October 2022

M	T	W	R	F	S	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

November 2022

M	T	W	R	F	S	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23			26	27
28	29	30				

December 2022

M	T	W	R	F	S	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

- ☐ **Labor Day, UTEP Closed**
  September 5, Monday
- ☐ **Exam I**: September 26, Monday
  Chapters 1, 2, 3, and 4
- ☐ **Course Drop/Withdrawal Deadline**
  October 28
- ☐ **Exam II**: October 31, Monday
  Chapters 5, 6, and 7
- ☐ **Thanksgiving, UTEP closed**
  November 24 to 25
- ☐ **Comprehensive Final**: December 5
  Monday, 4:00 pm to 6:45 pm
  Chapters 7, 8, 9, 10, and 1 to 6