

## Computer and Information Technology Tools in Signals & Systems

**Cheryl Xu, Florida State University**

Dr. Chengying Xu received the Ph.D. in 2006 in mechanical engineering from Purdue University, U.S.A., and the M.S. in 2001 in mechanical manufacturing and automation from Beijing University of Aeronautics and Astronautics, China. She currently is an associate professor at the Florida State University, Tallahassee, Florida. Her research interests include high temperature sensor design, intelligent systems and control theory, manufacturing of advanced materials. Dr. Xu has co-authored a textbook: *Intelligent Systems: Modeling, Optimization and Control* (CRC Press, 2008, 433 pages) and four book chapters. She has authored and coauthored more than 30 journal papers and 30 refereed conference proceedings. She has served as an organizing committee member and session co-chair for a number of national and international conferences. She also worked as an organizer for the Symposium Sensor Technology for the International Congress on Ceramics in Japan. She served as the Guest Editor for Transactions of the ASME, *Journal of Micro- and Nano- Manufacturing*, and has been an Associate Editor of the *International Journal of Nanomanufacturing* since 2008, and has been on the Board of Editor of *Journal of Aviation and Aerospace Industry Manufacturing* since 2010 and *International Journal of Computational Materials Science and Surface Engineering* since 2007.

**Dr. S. Hossein Mousavinezhad, Idaho State University**

Dr. Mousavinezhad was the principal investigator of the National Science Foundation's recent research grant, National Wireless Research Collaboration Symposium 2014; he has published a book (with Dr. Hu of University of North Dakota) on mobile computing in 2013. Professor Mousavinezhad is an active member of IEEE and ASEE having chaired sessions in national and regional conferences. He has been an ABET Program Evaluator for Electrical Engineering and Computer Engineering as well as Engineering Education. He is Founding General Chair of the IEEE International Electro Information Technology Conferences. Hossein served as 2002/2003 ASEE ECE Division Chair. He was IEEE Education Society Membership Development Chair and now serves as MGA Vice President (2013/2014) and Van Valkenburg Early Career Teaching Award Chair. Dr. Mousavinezhad received Michigan State University ECE Department's Distinguished Alumni Award, May 2009. He is recipient of ASEE ECE Division's 2007 Meritorious Service Award, ASEE/NCS Distinguished Service Award, April 6, 2002, for significant and sustained leadership. In 1994 he received ASEE Zone II Outstanding Campus Representative Award. He is also a Senior Member of IEEE, has been a reviewer for IEEE Transactions including the Transactions on Education. His teaching and research interests include digital signal processing (DSP) and Bioelectromagnetics. He has been a reviewer for engineering textbooks including *Essentials of Digital Signal Processing*, Cambridge University Press, 2014, "DSP First", published by Prentice Hall, 1998 and *Signal Processing First*, Prentice Hall, 2003. He is a member of the Editorial Advisory Board of the international research journal *Integrated Computer-Aided Engineering*.

Professor Mousavinezhad was EE/EECS Department Chair, 2007-2013 and teaches classes in circuits & systems, digital signal processing and communication systems. Before joining Idaho State University in 2007, Dr. Mousavinezhad served as Electrical/Computer Engineering Department Chair and Professor at Western Michigan University, Kalamazoo, Michigan. He has been an invited keynote speaker for national and international conferences. He has been a Program Evaluator for ABET Electrical/Computer Engineering, Computer Science and Engineering programs in the US and for international programs.

# Computer and Information Technology Tools in Signals & Systems

**ABSTRACT.** Signals and Systems is an upper division course offered in engineering programs including Electrical/Computer Engineering, Computer Science and Mechanical Engineering. There are several excellent textbooks available for the subject matter but students still have difficulty in grasping many seemingly abstract concepts like various transform methods (Fourier, Laplace and z), modeling of signals & systems in time/frequency domains, discrete power spectrum, energy spectral density, bandwidth, filter input/output relations, Parseval's theorem, convolution, signal-to-noise ratio, and transfer (system) function. Software packages like MATLAB, MATHCAD and WFilter are useful computer IT tools so problems, examples can be presented in the class and simulations discussed after analytical results are obtained for a given problem. Our experience has shown that use of these tools will enhance student learning and is an effective way of teaching the subject.

**I. Introduction.** In our schools we have offered a Signals & Systems course with pre-requisites of circuits I & II as well as differential equations (which is a co-requisite.) Since Matlab/Mathcad programs are available in our computer laboratory, these are used throughout the course. The textbook by Kamen & Heck [1] is used for the course and students can access the accompanying textbook website. It should be noted that some class examples use both Mathcad and Matlab but the textbook uses Matlab only. In our program we also have a senior-level elective course on filters using the software tool called WFilter accompanying the textbook [2]. As engineering educators teaching undergraduate, first year graduate courses we are all aware that these tools should be used at the **right time, right place** to help student understanding and learning. Usually a problem is worked out using the analytical approach (manual analysis) as much as possible, then software tools are used for presenting calculations, plots and extension of the problem using computer simulations. Since many advanced courses such as Control Systems, Analog and Digital Communication Systems, and Digital Signal Processing (for example [3]) use the Signals & Systems course as pre-requisite and background information, it is very critical that students have a good understanding of the basic concepts before doing the simulations and “number crunching” on the computer or their graphics calculators.

Computer-based education and introducing students to use IT tools when needed and appropriate especially in courses with complex mathematical concepts, e.g., Signals & Systems, are discussed by many engineering educators (for example see [4], [5] and [6].) Professor Fred W. DePiero of Cal Poly Electrical Engineering, [7], includes “Notes on Signals and Systems” where he presents IT tools examples and has a discussion of pedagogy.

Authors have broad backgrounds in Mechanical Engineering as well as Electrical/Computer Engineering and use practical examples in the class to discuss the difficult concepts. Many techniques learned in the Signals & Systems course are applicable to all engineering systems such as: Electrical, Mechanical, and Chemical. The course starts by presenting many different kinds of signals including analog, digital (discrete-time), energy, power, periodic, deterministic

and random signals. The linear, time invariant (LTI) systems are presented next. Signals are analyzed in the frequency domain by using transform tools of Fourier Analysis (integral and series), discrete-time Fourier series, discrete-time Fourier transform, discrete Fourier transform (also FFT algorithm), Laplace transform and z-transform. By using the system (transfer) function the response of a given system is computed in both time & frequency domains.

**II. Signals & Systems.** Signals can be represented mathematically as a function,  $x$ . When these signals are applied as input to a given system, the resulting output can be shown by function  $y$ . Signals can be analog (continuous-time) or digital (discrete-time.) At this time it is useful to point out to students that these are not just abstractions but have many practical applications. As shown in Figure 1 there are circuits, for example Digital Signal Processing, DSP board shown in Figure 1 that one can actually see the “input” and “output” pins on the circuit board.

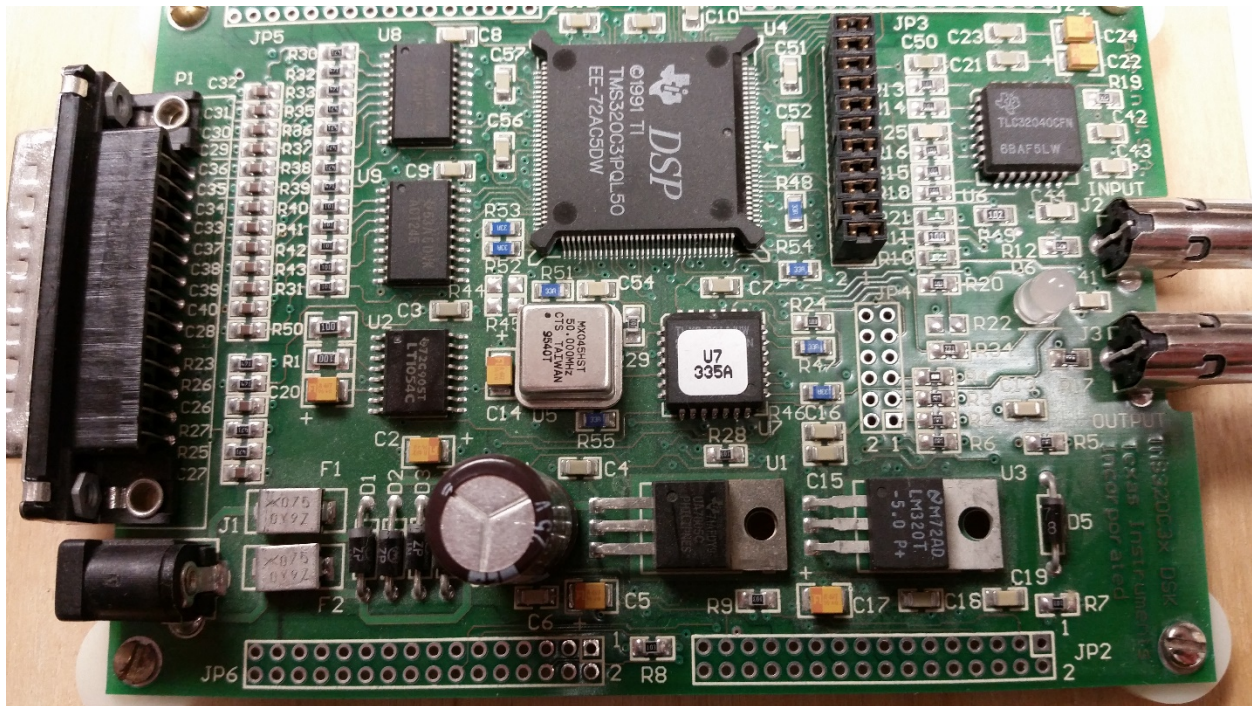


Figure 1. An example of a DSP board showing input/output pins.

The problem, from student point of view, is when one starts analyzing signals/systems in time/frequency domains and applying various transformations (for example Laplace, Fourier and  $z$ .) Since this is a required course for their senior-level course involving, for example, design of digital filters or control systems, it is critical that students understand the main concepts in the course before trying to use software tools for simulations/modeling. For modeling engineering systems, students need the background in differential equations, in our programs the differential equations (math) course is a co-requisite. For discrete-time systems they need the model of difference equations where (continuous) time is replaced by  $t = nT$  ( $n$  is an integer and  $T$  is sampling time with sampling frequency given by  $f_s = 1 / T$ ), with derivatives being replaced by differences. Of course it is discussed in the course that, for example solution of a difference

equation is very similar to solution of a differential equation. Laplace transform can be used to solve the differential equation as z-transform is used to solve difference equation. This is again seen as difficult by students who need to understand reason for having different domains and transforms. In Section III we present some examples and simulations that are typically used in the class to help student understanding and learning of important concepts in signals & systems. Figure 2 shows notations used for continuous-time (CT) and discrete-time (DT) systems.

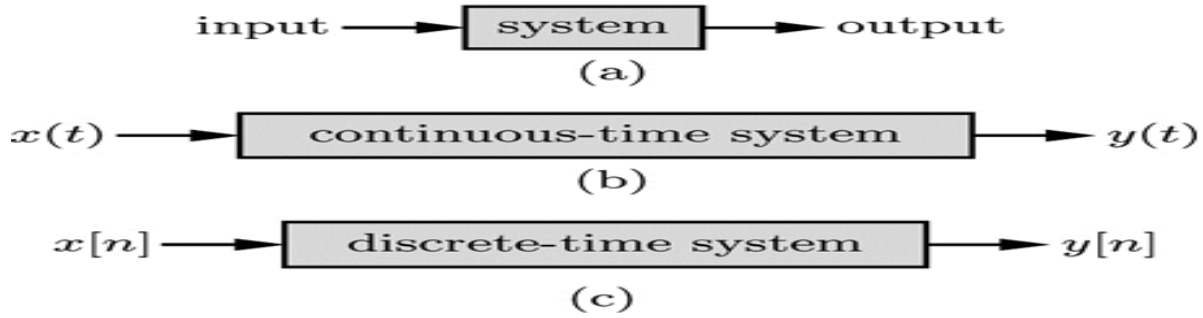


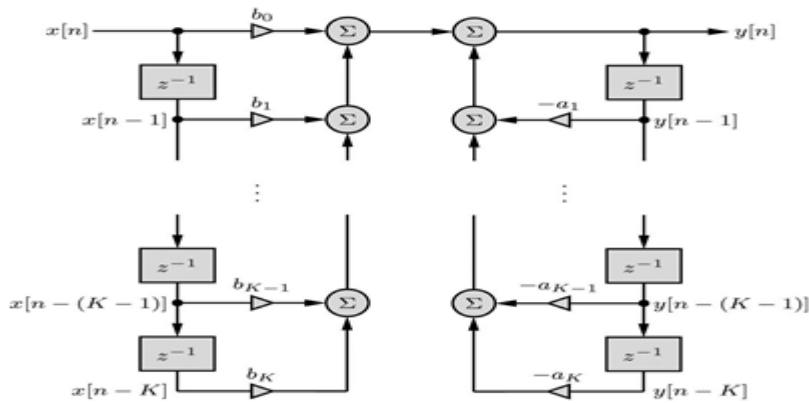
Figure 2. Notation used for representation of CT/DT Systems.

CT systems are described mathematically in the form of differential equations:

$$\sum_{k=0}^K a_k \frac{d^k}{dt^k} y(t) = \sum_{l=0}^L b_l \frac{d^l}{dt^l} x(t)$$

While DT systems are represented by linear, constant-coefficient difference equations (LCCDEs) and block diagram (signal flow graph, SFG):

$$\sum_{k=0}^K a_k y[n - k] = \sum_{l=0}^L b_l x[n - l]$$



**III. Examples, Simulations.** Here we discuss some signals & systems problems using software tools available and show selected simulation results. More examples will be presented during the Annual Conference together with some student data.

**Example 1. Difference Equation.** Since students are familiar with (ordinary) differential equations, it is emphasized in the course importance of using differential equations to model physical systems. The course covers both CT & DT systems, here we present an example of a difference equation which is usually obtained by “digitizing” the CT differential equation.

Let’s consider the following second order difference equation with step function input:

$$6y[n] - y[n - 1] - y[n - 2] = 24x[n], \text{ input } x[n] = u[n],$$

initial conditions are given as:  $y[-1] = 0, y[-2] = 12$ .

Solution is obtained analytically in the time domain by computing homogeneous and particular responses (similar to solution of differential equations.) Later students solve the problem in the frequency domain using the z-transform. Here we present the solution using MATHCAD:

$$\mathbf{n := 0, 1 .. 10} \quad \mathbf{y(n) := -1.2 \cdot (0.5)^n + 1.2 \cdot \left(\frac{-1}{3}\right)^n + 6}$$

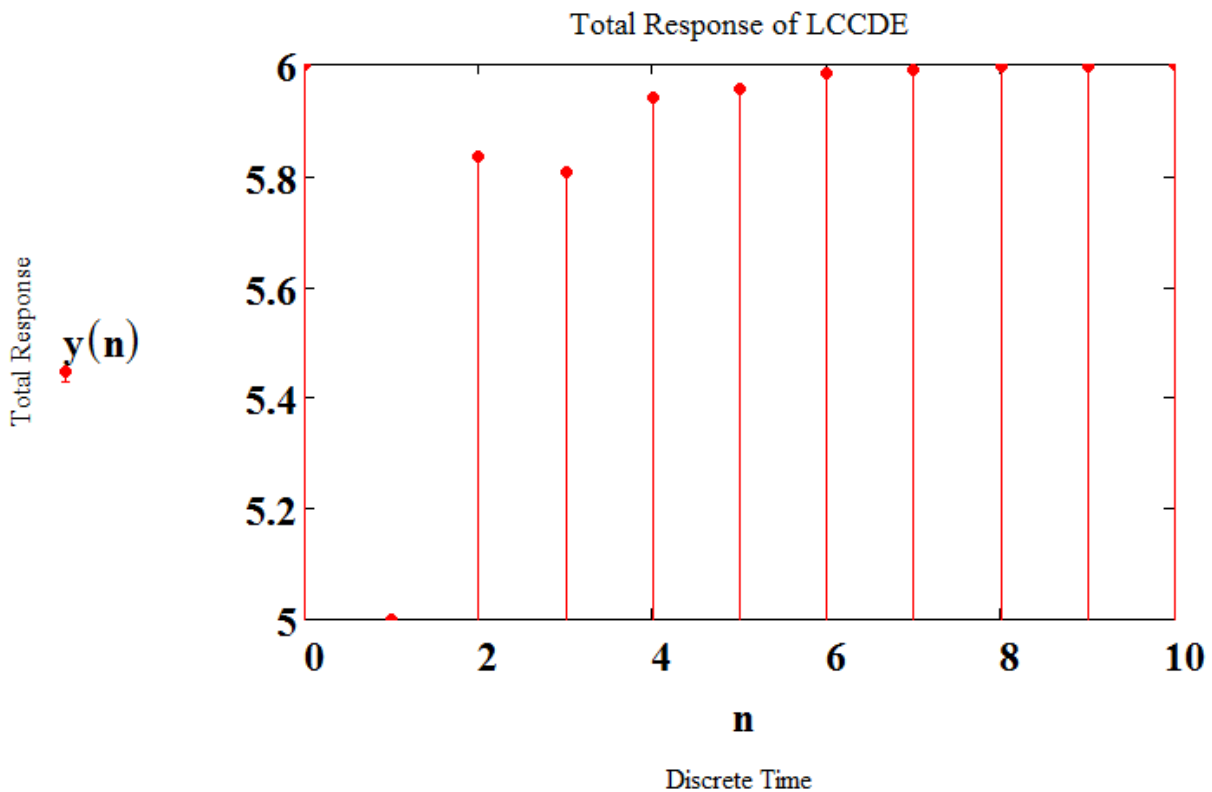


Figure 3. Total Response  $y[n] = y_h[n] + y_p[n]$  of the given LCCDE.

**Example 2. Convolution in Signals & Systems.** The concept of convolution is another difficult operation for most students. Starting with graphical convolution student can learn finding the response to the given excitation and the system's impulse response (assuming zero initial conditions.) They have briefly encountered convolution when using Laplace Transform to solve differential equations and taking inverse transformation.

Consider the following CT signals in evaluating convolution integral:

$$y(t) = x(t)*h(t) = \int x(t - \tau) h(\tau) d\tau, \text{ where integration is from } \tau = 0 \text{ to } \tau = t :$$

$$x(t) = 3 ; 0 \leq t \leq 2 \text{ sec. , } x(t) = 0 ; \text{ otherwise}$$

$$h(t) = t ; 0 \leq t \leq 2 \text{ sec. , } h(t) = -1 ; 2 \text{ sec.} \leq t \leq 4 \text{ sec. , } h(t) = 0 ; \text{ otherwise.}$$

The analytical (manual analysis) solution is found as:

$$y(t) = 0 ; t \leq 0, \quad y(t) = 1.5t^2 ; 0 \leq t \leq 2 \text{ sec. , } y(t) = -1.5t^2 + 3t + 6 ; 2 \text{ sec.} \leq t \leq 4 \text{ sec. ,}$$

$$y(t) = 3t - 18 ; 4 \text{ sec.} \leq t \leq 6 \text{ sec. , } y(t) = 0 ; t \geq 6.$$

We present MATLAB solution next.

```
% CONVOLUTION of two finite energy signals, sampling time T = 0.01 sec.
>> x=[1.5,3*ones(size(1:199)),1.5];
>> n=0:1:199;
>> h=[(ones(size(n))).*n*0.01, 0.5,-1*ones(size(201:1:399)),-0.5];
>> y=0.01*conv(x,h);
>> plot(y)
>>
```

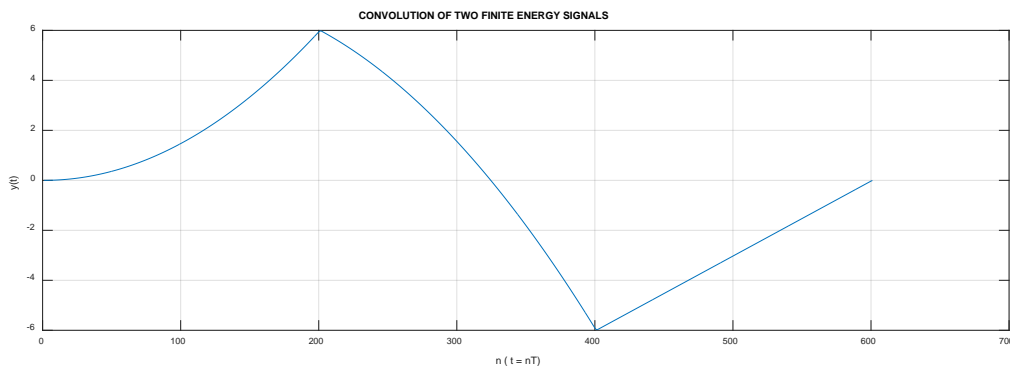


Figure 4. Convolution of two finite-energy signals.

**Example 3. Spectrum Computation.** One useful example from the field of communication is the computation of signal spectrum, transmission bandwidth and related parameters. In addition to Laplace transform and its usefulness in studying system's transfer function and solution of differential equations, students are introduced to the important Fourier methods (series, various

transforms including discrete Fourier transform when dealing with digital signals & systems.) Many tools allow students to use the fast Fourier transform (FFT) in solving these computational problems. Here we use an example of the computation of Fourier transform.

Consider the finite-energy signal:

$$x(t) = t - 1 ; 0 \leq t \leq 2 \text{ sec. } , x(t) = 0; \text{ otherwise.}$$

The analytical expression for the Fourier transform is obtained as follows:

$X(\omega) = 2j \exp(-j\omega) [\omega \cos(\omega) - \sin(\omega)] / \omega^2 ; \omega \neq 0 , X(\omega = 0) = 0$ . First we show computation of the exact (actual) spectrum using MATHCAD:

# Fourier Transform of Finite Energy Signal

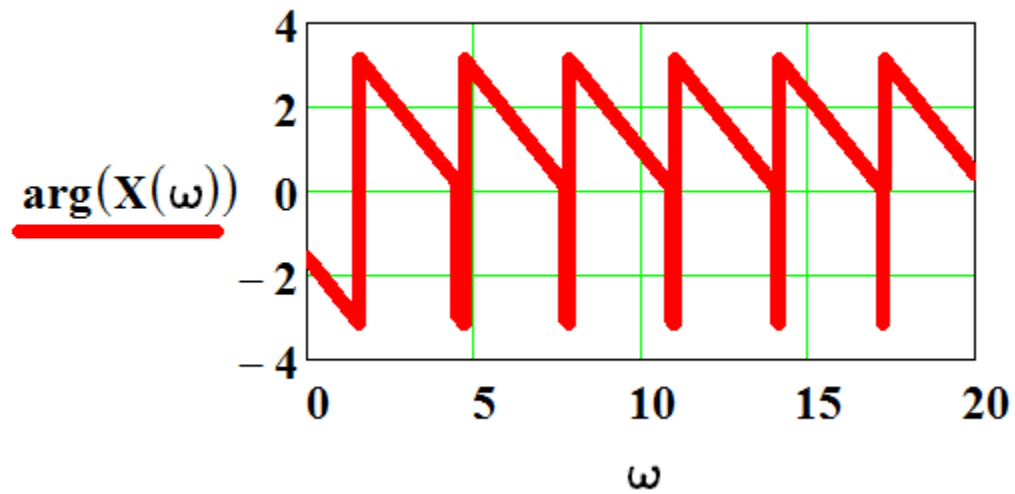
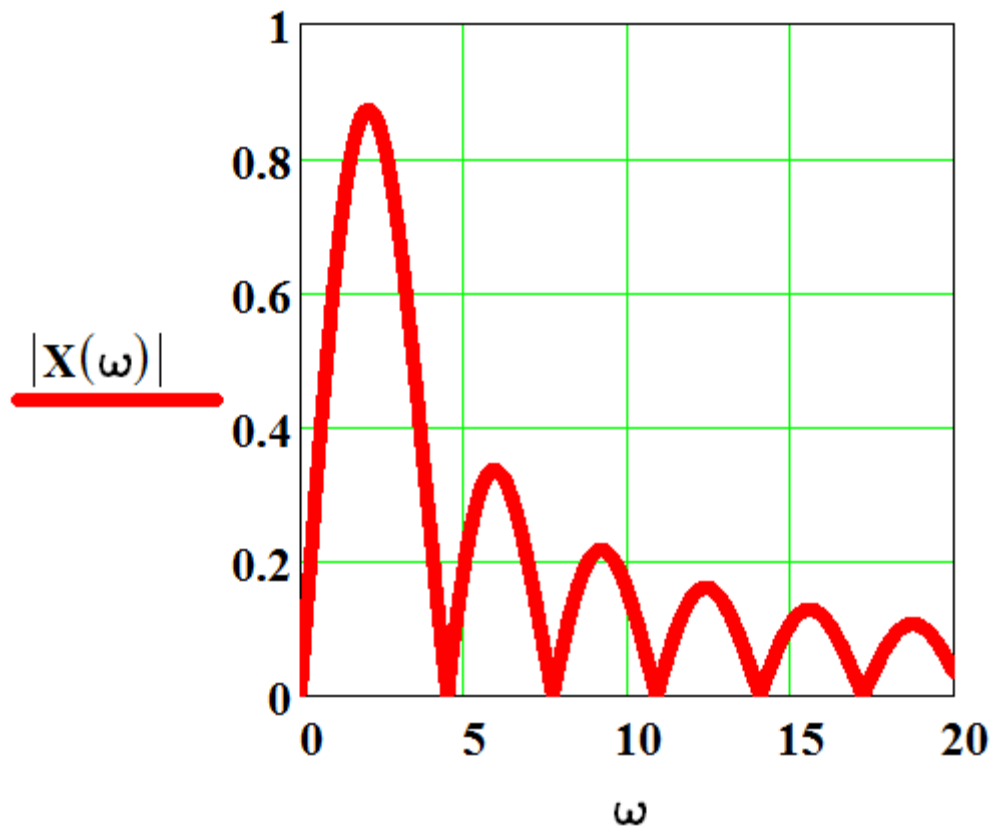
$$x(t) = t - 1 ; 0 < t < 2$$

$$x(t) = 0 ; \text{ otherwise.}$$

$$\omega := 0, 0.01 .. 20$$

$$j := \sqrt{-1}$$

$$X(\omega) := 2 \cdot j \cdot \exp(-j \cdot \omega) \cdot \frac{(\omega \cdot \cos(\omega) - \sin(\omega))}{\omega^2}$$



Next we show computation of the spectrum using MATLAB FFT function (approximation) and compare the magnitude spectrum of approximation and actual spectrum obtained analytically.

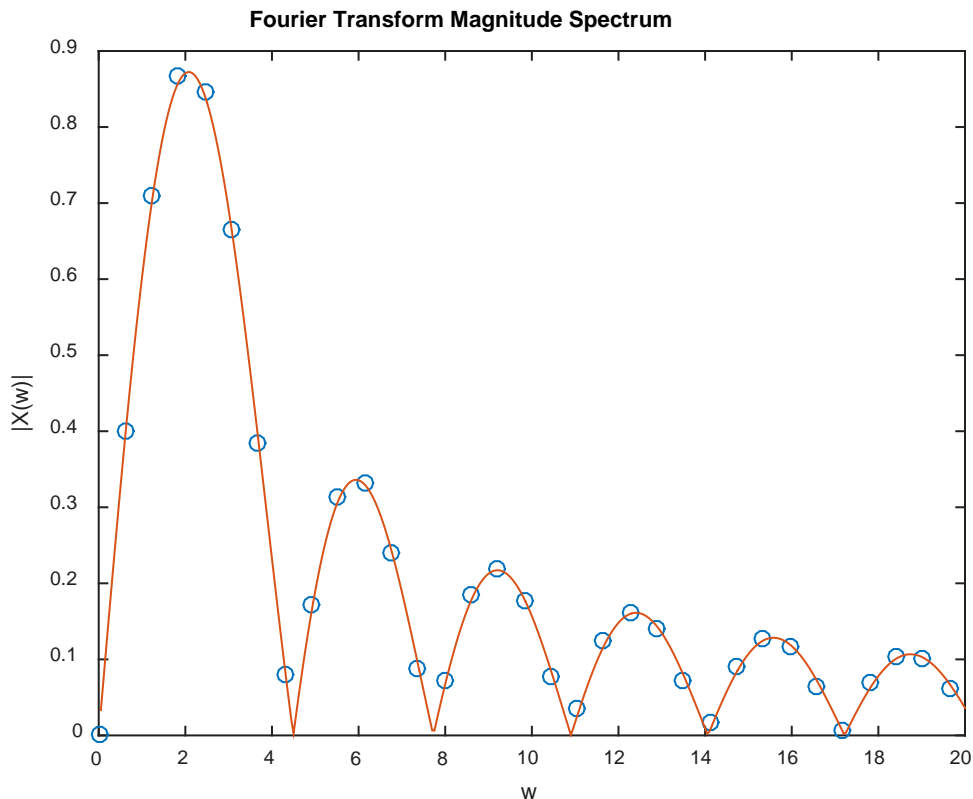
```
>> % Computation of the Fourier Transform
>> T=0.01;
>> N=2^10;
```



```

>> t=0:0.01:2;
>> x=[t-1 zeros(1,N-length(t))];
>> Xk=fft(x);
>> gam=2*pi/(N*T);
>> k=0:20/gam;
>> Xapp=(1-exp(-j*k*gam*T))/j/k/gam*Xk;
>> w=0.05:0.05:20;
>> Xact=2*j*exp(-j*w).*(w.*cos(w)-sin(w))./(w.*w);
>> plot(k*gam,abs(Xapp(1:length(k))),'o',w,abs(Xact))
>>

```



**IV. CONCLUSIONS.** In this paper we have discussed the use of modern tools in teaching engineering classes with high mathematical content. Specifically we considered the course on Signals & Systems taken by engineering and some science students. One question raised by engineering educators using Computer and Information Technology (CIT) tools is that when/where these powerful tools and software packages should be used. Our experience has been that for certain topics and abstract concepts students should know the fundamentals and make sure they understand/learn the logic, basic theory before doing calculations, simulations/modeling. Some problem solutions may require use of calculators, more advanced problems will require the use of software packages such as MATLAB and MATHCAD used in our courses. The signals & systems course in many programs is a lecture-only class, in our schools this course is followed by advanced courses in controls, digital/analog communication systems and digital signal processing (DSP). We also have an elective course on advanced

circuits & systems. In these senior-level, first-year graduate courses students can use the computer Lab which includes the needed software packages. In the elective course they also use the filter analysis/design tool called WFilter as the software companion to the textbook [2].

As for student response/perceptions we have found that students like to use the CIT tools but they are also frustrated by “too much math” involved in these courses. Examples, demos used in the class can help them understand the materials once they see applications, for example in smartphones (filters, DSP), or sensors, and control, communication systems. The signals & systems course includes the following student outcomes as specified by ABET:

- (a). an ability to apply knowledge of mathematics, science, and engineering
- (e). an ability to identify, formulate, and solve engineering problems
- (k). an ability to use techniques, skills, and modern engineering tools necessary for engineering practice.

Outcome (k) is partially achieved by utilizing IT tools introduced in this paper.

## **R E F E R E C E S**

[1]. Fundamentals of Signals and Systems, Third Edition, by Kamen & Heck, Prentice Hall, 2007.

[2]. Practical Analog and Digital Filter Design, by Les Thede, Artech House, 2005.

[3]. Fundamentals of Digital Signal Processing, by Lathi & Green, Cambridge, 2014.

[4]. DSP First, second edition, by McClellan, Schafer, and Yoder, Person, 2016.

[5]. Signals and Systems Using MATLAB, Sturm and Gibson, Frontiers in Education (FIE) Conference, October 19-22, 2005, Indianapolis, IN.

[6]. Signals and Systems, a MATLAB Integrate Approach, by Oktay Alkin, CRC Press, 2014.

[7]. <http://www.ee.calpoly.edu/faculty/fdepiero/>.