

AC 2007-1429: STUDIO-BASED INSTRUCTION IN SIGNALS AND SYSTEMS

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Studio-Based Signals and Systems

Abstract

One of the more challenging aspects of most undergraduate electrical engineering programs is the Signals and Systems (SS) course, taught in virtually every EE program. The traditional lecture/exam format is, for many students, not effective at instilling the key concepts such that the students truly understand. They frequently fail at making the connections between mathematical results and physical results and lack the ability to gain engineering insights from mathematical results.

Various programs have approached these challenges by adding a lab, or augmenting their classes with web-based or computer demonstrations. Because of other pressures in the curriculum, we sought an alternative approach that did not increase laboratory time but obtained the goals of hands-on learning. In order to obtain the increases in comprehension we are seeking, our focus has been on inquiry-based methodologies. In this project, the Signals and Systems class is being totally redesigned. Using Microsoft Excel® and Matlab®, in-class exercises have been developed to motivate and demonstrate key concepts in Signals and Systems. This process has been incremental with some changes made every year and was first described in “Studio-Based Signals and Systems”. The current paper reports on the status of this transition and, most importantly, concentrates on an assessment of the effectiveness of the changes based on the Signals and Systems Concept Inventory (SSCI) published by Buck et al. Using the SSCI in a pre- post-test format, we quantified the gain in concept understanding that the students get from this new classroom format. It also contains examples of in-class exercises applying signal generation, convolution, filtering, modulation, frequency analysis and other areas to help students better understand the concepts. This new approach has now been used for two years (offered once per year) and the results from each year are compared. In addition, the gains from this method are compared to ‘typical’ results reported in the literature.

Introduction

Signals and Systems is a course traditionally taught early in most electrical engineering programs. A review of textbooks typically used shows a strong mathematical prerequisite. Although most texts have started to incorporate Web based and/or Matlab® exercises, they seem to be intended to supplement the class and not be the focus of lessons. For example, Hanselman³ has an excellent series of demonstrations. Most texts today offer similar tools either on the web or on a CD^{4,5}.

However, many students learn best through problem-based learning exercises. As a result, they struggle with the traditional lecture format, even when supplemented by demonstrations. In 2004, was decided to convert the class from lecture format to more of a problem-based learning format. Since this class is only offered in the fall, this transition will take several years.

In order to support these changes, a studio format was implemented for the class in which a computer laboratory was used for real-time computer instruction as part of the content of every

lecture. In this way, every student had his/her own station with MS Office (for Excel) and Matlab. In this way, in-class exercises could be included in every class.

This paper presents the evolution of the class and the assessment of the results.

Background

The University of St. Thomas is a moderate size liberal arts university with a new electrical engineering program. Our program includes one class in Signals and Systems typically taken in the Junior year that covers both continuous and discrete time systems and is a prerequisite for Controls as well as a class in embedded systems. No lab is included and, because of constraints on the program, it would be difficult to add one. Early offerings of this course used a fairly traditional lecture-test format. Although student assessment of the class was fairly good (the major criticism was that this class was too much like a math class), in subsequent classes it was clear that the material had not 'sunk in'.

One of the first steps was to investigate references on teaching Signals and Systems. This included attending the 2004 ASEE national conference, reviewing the proceedings of previous ASEE conferences and the IEEE Education society journal. There is very little available information on this specific subject. Two specific ones that were found useful^{3,5}. However, there is significant information on the general topics of student learning that is applicable. Most of this research resulted in refreshment of well-known lessons. For example, see Chickering¹. Also, the Learning Pyramid from the National Training Laboratories, Bethel, ME emphasizes the importance of hands-on experimentation.

Guidelines for Course Development

The major results, somewhat obvious after the fact, were reflected in the objectives used in redesigning the course. These are:

- A hands-on exercise in Matlab, Simulink or Excel should be included as part of class sessions.
- Attempts should be made to have the exercise done BEFORE the material is explained. In this way, these were used to motivate the material rather than demonstrate the material after the fact.
- Frequent opportunities for questions, discussions and interactions on the material should be provided.

Facilities

In order to support this new approach to teaching Signals and Systems, we used a computer lab that was otherwise used to teach CAD. This lab included seventeen Dell Personal Computers equipped with the following software: MS Office including Excel, Matlab®, the Controls Toolbox for Matlab. This room also included a projector that can display the instructor's screen. We support sixteen students at one time in and are currently expanding to allow twenty-four students at one time. Although the approach being presented here would work with students

working in pairs, we felt that it was important to have the flexibility of allowing the students to each have their own computer.

Experiments

In order to provide a module that supported most of the concepts in Signals and Systems, many small problems were developed in Excel and Matlab. A sample of these is provided below. The goal was to have one small exercise in each 65-minute period. In a few classes, the exercise was extended in a subsequent period, for example when the AM modulation exercise was extended to demonstrate quadrature modulation.

One important distinction between the experiments developed here and more traditional ‘demonstrations’ (even when run by each individual student) is that each was built up by the students themselves with minimal guidance from the instructor. As such, they lacked many of the flashy aspects of these demos. However, since the students built the experiments themselves using common or industry standard tools such as Matlab®, they were better able to see what was going on ‘behind the curtain’.

Sample Excel Exercises

Excel can be an excellent tool to bring some concepts to life in the classroom⁶, especially for discrete time systems. Spreadsheets were developed by the students in class to represent step and impulse functions. This had the added advantage of improving their skill at using a spreadsheet – something not generally taught but very useful for an engineer. Several other exercises were developed to demonstrate convolution, filter and discrete Fourier Transform.

Convolution

In one exercise, the students used Excel to compute the convolution of two signals. This provides a direct connection between the algebraic formula for convolution

$$y[n] = x[n] * h[n] = \sum_{k=-\infty}^{\infty} h[k]x[n-k]$$

and the corresponding spreadsheet that the students construct themselves. Columns were constructed to represent the time index, n , the two signals being convolved, x and h , and the result, y .

Filtering

We use Excel to demonstrate FIR and IIR filtering. One column is the index, one is the input and the third is filter output. Using Excel’s @Average function is a very physical way for students to visualize what an N-point moving average filter does, as well as the differences between a trailing and mid-point filters. It also reinforces the meaning of causality.

Discrete Fourier Transform

In another session, the Discrete Fourier Transform (DFT) of a signal is calculated. This helped the students understand the DFT and helped the math become accessible. Modern PC's are fast enough to calculate the DFT directly for short and even moderately long signals. By doing this directly in Excel, the some of the mystery is removed and the connections between the math and the results are reinforced.

Matlab/Simulink Exercises

Many of the exercises developed demonstrated the direct use of Matlab® and Simulink® to solve engineering problems. System simulations, step and impulse responses, convolution integrals, and later in the course the DFT were all used. This approach has the added advantage of introducing the students to actual industrial tools that they may be asked about in future employment.

Modulation

Several Simulink models were developed during the class. Figure 1A shows one used to introduce the concepts of modulation. The details of the modulator and demodulator are shown in Figures 1B and 1C respectively.

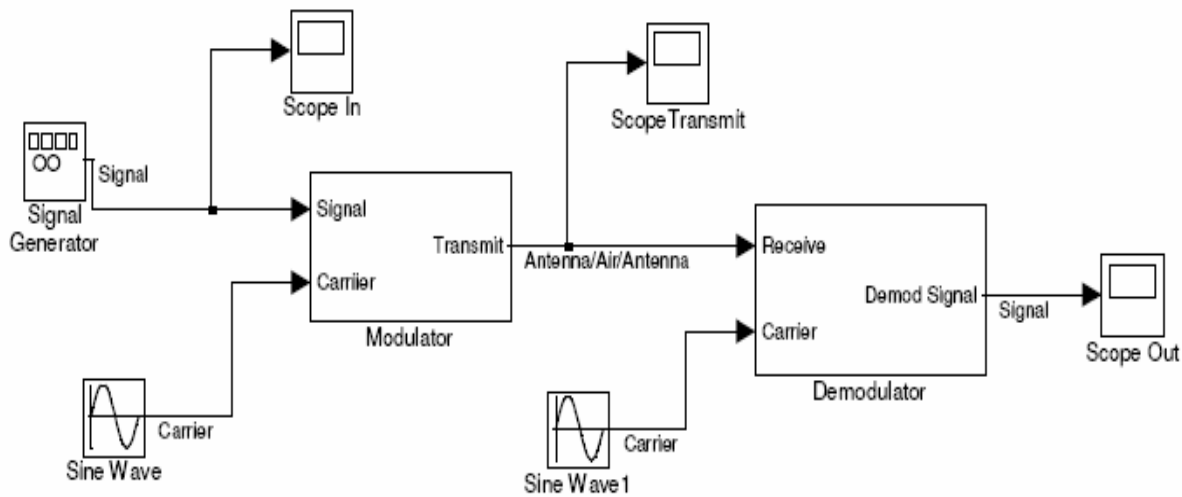


FIGURE 1 EXAMPLE SIMULINK EXPLORATION OF AM MODULATION

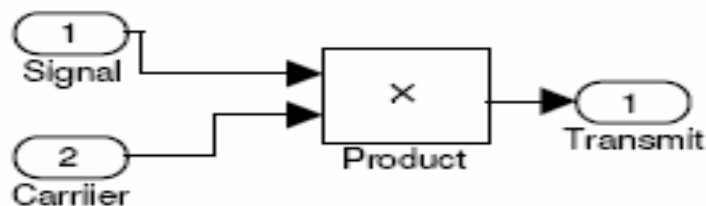


FIGURE 2 MODULATOR

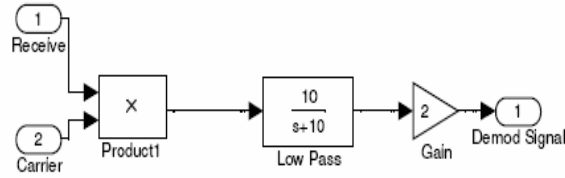


FIGURE 3 DEMODULATOR

The students modified and added to this model in order to further explore the concepts, for example, to expand the model in Figure 1 to demonstrate Quadrature Modulation, shown in Figure 4, and Frequency-Division Multiplexing.

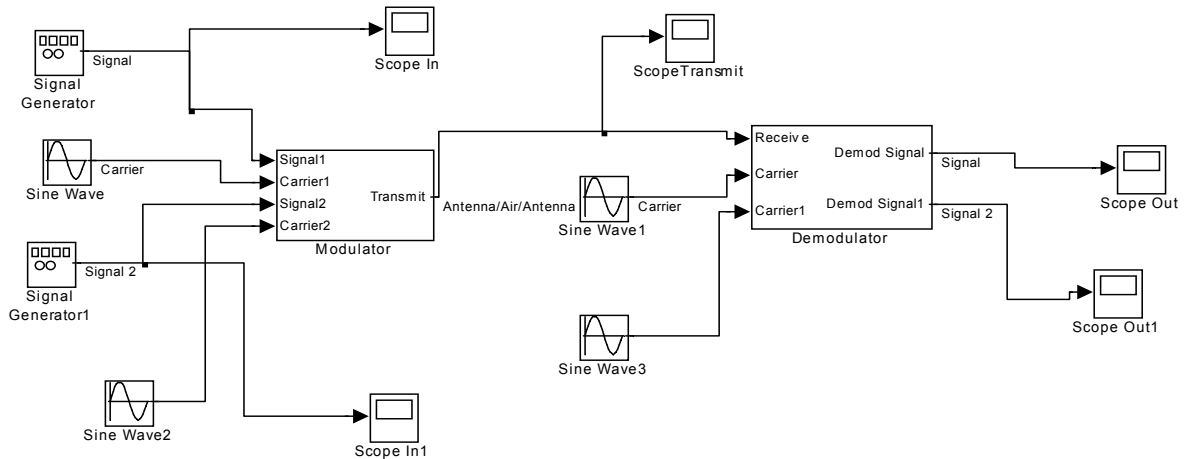


FIGURE 4 QUADRATURE MODULATION

DSP Filtering of Continuous Time Signals

Figure 5 shows the Simulink model developed to demonstrate discrete time filtering of continuous signals. Note that we explicitly used the zero-order hold to show A-D and D-A conversions in order to emphasize the conversions even though Matlab has ‘easier’ ways of simulating this. The students added scopes and similar probes at various points and times in the development to help them see what was happening.

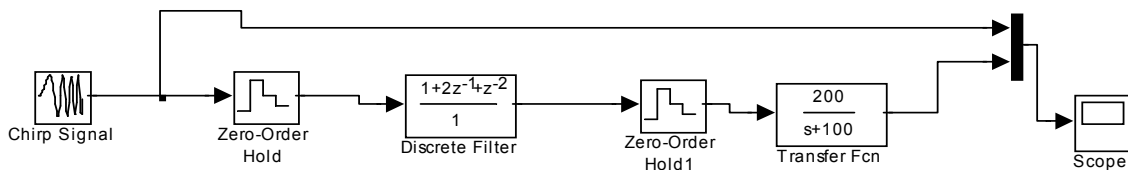


FIGURE 5 DSP FILTERING

Sampling and Aliasing

Sampling and Aliasing is a topic that continues to be a challenge for students. The Simulink model in Figure 6 provides students an opportunity to perform ‘hands on’ virtual experiments to better understand what is happening. Recall that the students are building the model themselves and setting the parameters.

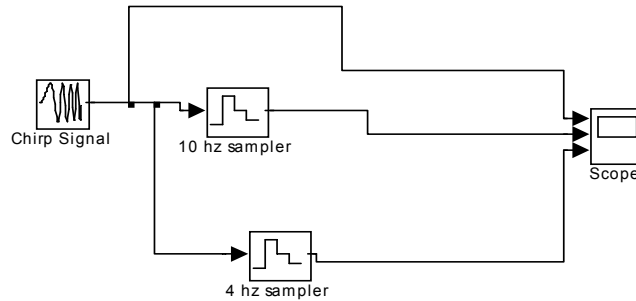


FIGURE 6 SAMPLING AND ALIASING

Filtering of Sounds

One exercise the students particularly enjoyed was when they developed a model for filtering sounds. The model is shown in Figure 7. Again, the students built up the model themselves and could change it. They were particularly encouraged to modify the parameters to see how it affected the results. Note that in this model, in addition to displaying the PSD, the input and output arrays are sent to the Matlab workspace where the students can manipulate them using other tools. For example, the student can program their own DFT subroutine and compare the results.

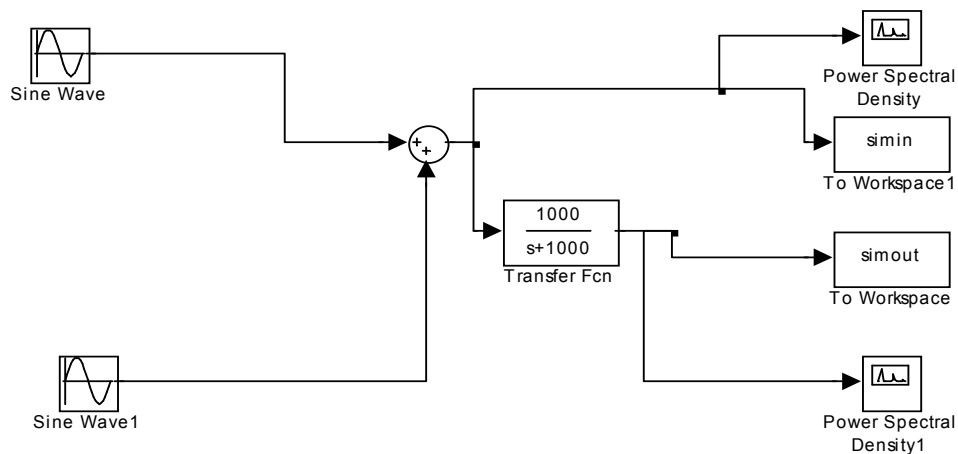


FIGURE 7 FILTERING OF SOUND SIGNALS

One challenge that became evident while using these models was that while these models have meaning to an experienced engineer, this approach did not provide as much motivation of the material for newcomers to the field. This is a refinement needed in future offerings of the class.

Assessment

This class is offered only once a year, in the fall, and has had an average enrollment of about 15-18 students. In the new form of the class, it have been now been offered three times to a total of 49 students. As a result, only limited assessment has been done.

Initial Assessment

We found the Foundation Coalition²'s Signals and Systems Concept Inventory too late in the semester to use it the first year in the pre- post-course format recommended. However, we have used the pre/post format the last two years. Based on feedback each year, we have made other changes to the class each year, adding more hands-on exercises and this year changing textbooks. As a result, there is always uncertainty as the cause-effectiveness of any single change. While this is unfortunate, it would be hard to do controlled experiments with such small programs.

Assessments initially consisted primarily of student comments and other qualitative measures. Overall, post-course student comments were slightly less satisfied with the class than in the previous year but the small sample sizes and the nature of the comments indicate that this may be for unrelated reasons. We found the Foundation Coalition²'s Signals and Systems Concept Inventory too late in the semester to use it the first year in the pre- post-course format recommended. However, many of the questions from that inventory were incorporated into quizzes and exams and the students for the most part did better on those questions than they did on the questions used traditionally in the class. In addition, the written comments at the end of course clearly indicated satisfaction with the studio format of the class.

Current Assessment

The Foundation Coalition's Signals and Systems Concept Inventory (SSCI) "is a 25-question multiple-choice exam designed to measure students' understanding of fundamental concepts taught in standard signals and systems curricula. When administered as a pre- and post course assessment, the SSCI measures the gain in conceptual understanding as a result of instruction."⁸ There are two versions of this test, a continuous time (CT) version and a discrete time (DT) version. Each test is administered in a 60 minute supervised, closed book setting. As such, it requires significant class time to administer and using both in a one-semester class is not feasible. Our class is the only formal opportunity for Electrical engineering students to student all the concepts of Signals and Systems and as such a combination of continuous time and discrete time concepts are taught. So which test should we use?

We have selected the continuous time version for our assessment. We considered developing our own hybrid exam combining questions from both the CT and DT version but felt that the national norming outweighed the advantages of tailoring. Thus, the CT version was

administered both at the start of the semester and again at the end. As suggested by the developers of the SSCI, the students were told that the test would not affect their grades in the class as long as they took it. All students in the class took both exams except if they dropped out of the course.

Scores on the pre- and post- tests for each student were obtained and a normalized gain computed for each student by the equation

$$gain = \frac{post - pre}{25 - pre}$$

This gain, when multiplied by 100, can be thought of as the percentage of questions that the student missed the first time that they got right in the posttest and thus a measure of the effectiveness of the class.

Table 1 provides the average scores (out of 25) for both the pre and post tests as well as the gain.

Class	N	Average Pretest Score	Average Posttest Score	Average Gain
2005	16	9.7	15.38	.35
2006	19	9.15	13.21	.25

Table 1 Assessment Scores

The individual scores are shown in Figure 8 below. Wage reports that in tradition style courses they have studied average gains of .20 have been observed and that when “interactive engagement” techniques are used gains of .37 are achieved. On this measure, our results in 2005 are very encouraging while the results in 2006 are not as good.

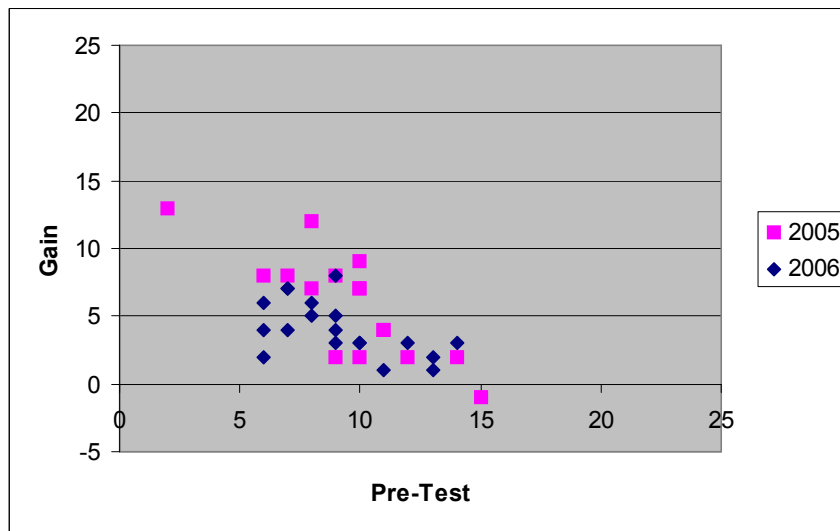


FIGURE 8 DISTRIBUTION OF PRE- AND POSTTEST SCORES

The 2005 results are particularly interesting when the qualitative feedback from the professor teaching the follow-on embedded systems course. His comments all semester have indicated that

the students who took the class in 2005 have remembered significantly more of the material than previous classes. The class from 2006 will not take that follow-on until the fall 2007.

The drop in gain in 2006 is somewhat troubling and needs further review. One change in the class was the use of a very different text book. Previously, traditional Signals and Systems textbooks such as Kamen and Heck⁴ had been used. One desirable feature of the selected texts was a balanced treatment of both continuous time and discrete time. In an attempt to further augment the interactive learning approach being used in the course, we changed texts to McClellan⁹. As discussed above, this is not totally consistent with using the CT version of the test and more emphasis was undoubtedly put on discrete time concepts than had been done in previous years.

Clearly, more assessment (as well as more development) is required before this approach can be fully evaluated. In particular, we intend to make full use of the Foundation Coalition's Signals and Systems Concept Inventory in both its pre- and post-course format for subsequent year's courses. This will provide clear measures of the gain from the course. We intend to work with the Foundation Coalition to obtain data useful for a meaningful control.

Acknowledgment

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