

Using Computers, Simulators and Sound To Give Hands-On Experience

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Abstract

This paper describes hands-on, computer assisted classroom activities and projects which have been fully integrated into an introductory signals and systems course. They combine a system simulator with audio input and output to produce an effective and interesting educational experience. Audio input and output is very useful in making a result relevant to a generation of students who were raised on rock music. The block diagram oriented simulator allows students to work quickly and independently. This reduces the need for faculty and TA support so that activities can be done in the usual class periods or as projects assigned as part of homework. For this reason the approach described in this paper could be used in other classes without significantly affecting the present syllabus. In addition, many of the described activities and projects could be easily extended to courses in communication, control, digital signal processing and speech processing.

Introduction

At least one signals and systems course is required for electrical and computer engineering majors in nearly all programs. It usually introduces students to important continuous and discrete time system concepts and develops and applies Laplace, Fourier and z-transforms. These courses usually do not have laboratories or hands-on activity associated with them. However, these courses are very important because they provide the foundation for important areas of electrical engineering including circuits, systems, communications, control and signal processing.

Unfortunately, many students do not recognize the relevance of the material at this point in their careers and have difficulty because it appears to be "only math and theory." The resulting low motivation often results in insufficient effort on course assignments. Students today face an incredible range of activities and entertainment options competing for their time. It should be no surprise that this generation of students cannot be counted on to take full advantage of the educational opportunities presented to them in a traditional engineering course.

Many authors have published papers arguing that today's students are much more strongly motivated and successful with problems that allow them to actually "do" things (See for example, [1-10]). In addition, students are motivated best by problems they readily appreciate as relevant and some authors have reported excellent success using audio signals to increase student interest and performance in laboratories [4, 8].



Putting Hands-on Experience in a Signals and Systems Course

Unfortunately, it would be very painful to add even a one-credit laboratory to a signals and systems course in a tightly structured curriculum. Instead, significant hands-on experience was integrated directly into the course with projects and interactive classroom activities. Students now work on high performance computers using SIMULINK, which is a graphical, block diagram oriented simulator that runs as an extension of MATLAB. The computers are also equipped with a high accuracy signal conversion card for input and output. Students work easily in the simulator on block diagram models of physical systems and then apply them to real, physical signals such as the student's voice from a microphone. The outputs can be played through a speaker as well as plotted and analyzed with the computer.

The simulator is very easy to use and allows students to implement a system quickly as a graphical interconnection of blocks which can be customized or chosen from an extensive library. The block diagram orientation is excellent for a course like signals and systems because it forces the student to solve real system problems by building models using mathematical descriptions and block diagrams. It also allows students to work quickly and with considerable independence. This reduces the need for faculty and TA support and allows several activities to be comfortably done in a usual class period or as projects assigned as homework.

Using student selected audio input and output with the simulator is very useful in making results relevant to a generation of students who were raised on rock music. They can see the waveforms and hear them. In addition, audio is especially useful in a signals and systems course because it helps connect the frequency domain to reality by associating the natural spectrum analyzer of the ear with plots of waveforms and spectra on the computer.

In order to make use of the simulators for interactive activities during class, the classroom was equipped with 16 personal computers so that 32 students could work in teams of two. The layout of the room was modeled after what has been done at Rensselaer Polytechnic Institute for introductory physics classes with integrated classroom and laboratory activity [9]. In addition, active group learning methods were adopted using techniques similar to those published by Karl Smith [10]. The use of active, group learning methods were an important contributor to successful student activities in this course.

Projects and Interactive Class Activities

Interactive activities on the simulator enhanced group learning and about one in five classroom problems used the computers. Most textbook examples or homework problems can be turned quickly into effective interactive activities since the MATLAB and SIMULINK environments make development simple. For example, Figure 1 shows the block diagram for a Fourier series activity that also shows the Gibbs phenomena. Students click on the button valves in turn and the fundamental and harmonics of a square wave are summed to produce a successively better approximation. Students can easily select their own combinations to explore the impact of each frequency. They can also quickly change the amplitude or phase of any term to see the disastrous effects.

In addition to classroom activities, a total of five continuous time projects using the simulator were assigned as homework in the one semester signals and systems course. Projects were assigned at one and a half to three week intervals starting after the fourth week of introductory material. Each project is designed to take each student in a team about three hours, including writing the report. The projects cause students to actually apply important concepts such as impulse response, convolution, filtering, Fourier spectra, modulation and



demodulation, frequency and time division multiplexing and sampling. In addition, MATLAB problems from the textbook were used for discrete time assignments [11].

All of the projects involve speech signals. By sampling at 48 kHz, which is over ten times the voice bandwidth, waveforms look and behave like continuous time problems even though they are actually discrete time in the computer. Since sampling effects are not covered in most texts until the end of a treatment on modulation, it is useful to keep students away from these issues in early projects. Continuous time sampling effects and discrete time issues come together in Project 5. Some of the sampling and discrete time issues in the early projects are usefully explored with students after this project.

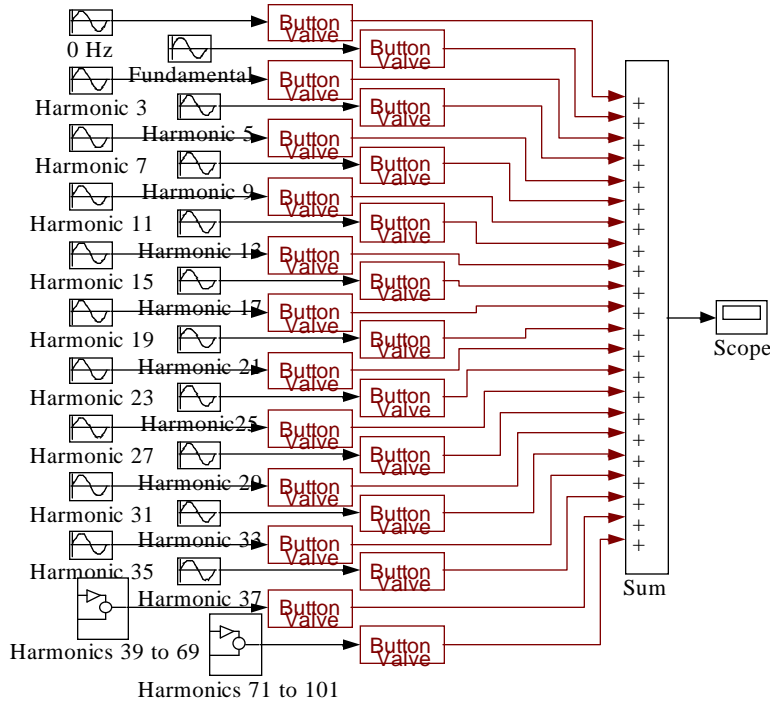


Figure 1. SIMULINK Display for an Interactive Activity on Fourier Series

In order to simplify the learning process, custom SIMULINK blocks are provided to students in the form of a SIMULINK file. This saves considerable time. It also allows the instructor to confine students to the particular issues desired in each activity. In addition, processing can be outrageously slow if care is not used in setting up the simulator blocks. In order to optimize processing speed for most of the projects, the most processing efficient, discrete time blocks were used inside each custom block. The example shown in Figure 2 has many custom blocks as well as a collection of acceptable SIMULINK blocks. Students simply drag and drop blocks onto a work area and interconnect them.

Project 1.) Impulse Response. This introductory project familiarizes students with the simulator while they learn about impulse response representations of systems. Students are asked to go into two classrooms, one of which is a lecture hall with a severe echo problem, and record the approximate impulse response of the rooms with a portable digital audio tape recorder and microphone (They might slap a pair of rulers for example). They also capture someone speaking with approximately the same geometry of source and recorder. The students then build a simple convolution system which models the room with the approximate impulse response. They

process their voices with the simulator and compare the result with their tape recordings. They also experiment with various impulse responses that they create.

Project 2.) Filtering and Spectra. This problem helps students appreciate the concept of signal bandwidth and the impact of systems that selectively pass signals on the basis of frequency. Students are given a custom simulator filter that has a stopband which is 10% above the passband edge which they specify. The passband has 1 dB ripple and minimum stopband attenuation of 40 dB. Students are asked to experimentally determine the minimum upper and maximum lower frequencies of a bandpass filter so that a male and female voice at the filter output will not be significantly changed between input and output. Common communication system band limits offer an interesting comparison at the end of this project.

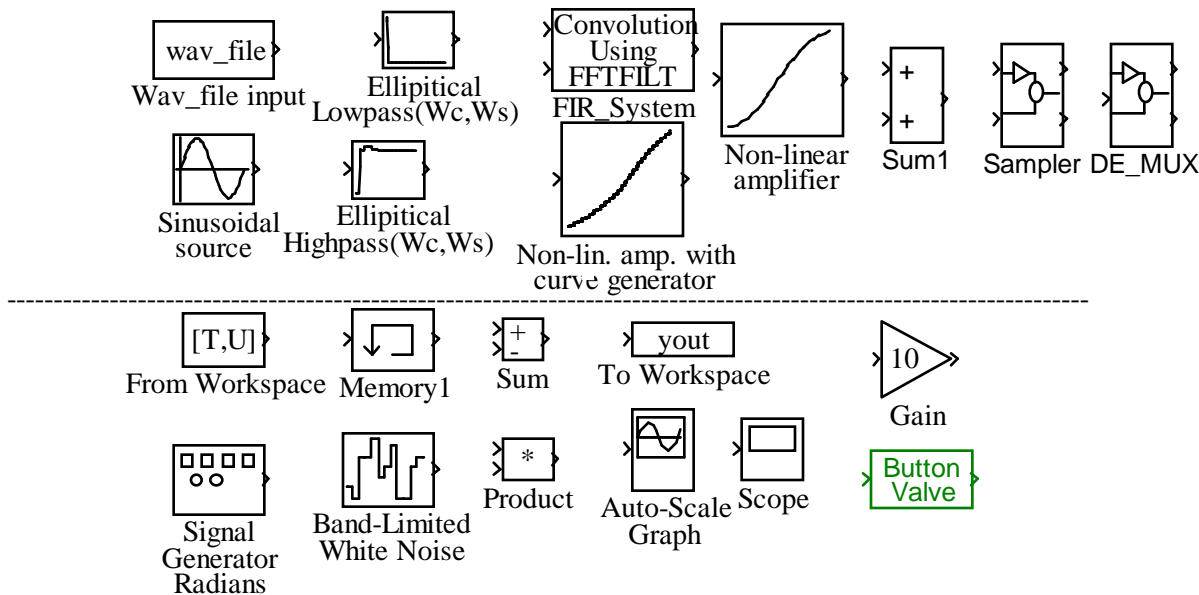


Figure 2. An Example of a Custom SIMULINK File Provided to Students.

Project 3.) Modulation and Demodulation. This project is based on problem 7.14b in the popular text Signals and Systems by Oppenheim, Wilsky and Young [12]. It is a great problem but, when given as ordinary homework, students somehow do not seem to find it particularly interesting. It asks the students to draw the block diagram of a speech scrambler that uses multipliers and filters to reverse the audio spectrum. In the project, students design and implement a speech scrambler which works on their recorded voice signal which they bandlimit to be between 120 and 3200 Hz. They design the block diagram using multipliers, sine wave generators and some supplied highpass and lowpass filter blocks which have passband and stopband edges that they can select. For convenience, these filter blocks are preset for 1 dB passband ripple and 40 dB minimum stopband attenuation. They implement their designs in the simulator and arrange tests to verify that it worked to scramble and unscramble their own voice and sinusoidal test signals. Most students seem to be astonished when they first listen to their own voice with the spectrum reversed.

Project 4.) Frequency Division Multiplexing. The project requires that students design and implement a system for combining two voice signals together into a single waveform using frequency division multiplexing. They must also design a demultiplexer to pick out either of the two original signals. The signals are to be multiplexed using single sideband suppressed carrier modulation. Students are challenged to accomplish the design with minimum order filters to obtain natural sounding output without noticeable interference or

distortion. Figure 3 is a student's submission of a working block diagram to produce the multiplexed upper sideband signals. None of the filters are higher than eighth order. The multiplexed single sideband signals are virtually unintelligible when played through a speaker.

Project 5.) Sampling and Time Division Multiplexing. In this project students design a time division multiplexing system. They are provided a synchronous sampler block which takes two inputs and samples each on opposite, alternating halves of a square wave at the sampling frequency. They are also given a demultiplexer which produces two sampled outputs, one for each signal from the multiplexed sampled input. Students must design the complete time division multiplexing and demultiplexing system using the appropriate minimum filtering for an 8 kHz sample rate. After their system is running well, they are asked to put a 5.6 kHz lowpass filter in the multiplexed signal path and explain why the output includes considerable crosstalk. A final part of the project is to reduce the sample rate and compare performance through listening and measurements. Aliasing does terrible things to the way the output sounds and that dramatically underscores the need to sample at sufficient speed.

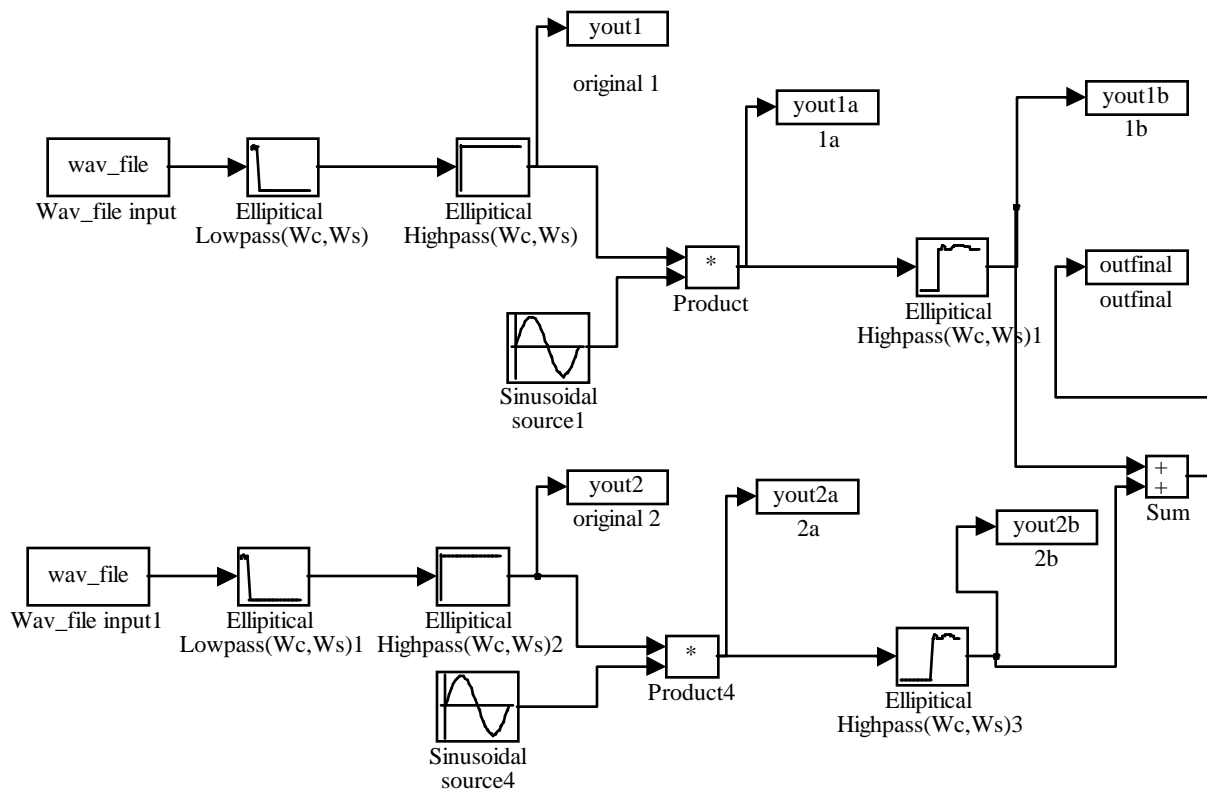


Figure 3. A Student Block Diagram to Generate Two Upper Sideband, Suppressed Carrier Signals in One Output Waveform.

Hardware and Software

The high sample rate needed for the projects puts considerable computation and storage burden on the computer. However, the 120 megahertz Pentium processors with thirty two megabytes of memory rarely took longer than 4 minutes to run even with 10 second records and several sharp filters in the simulation. Processing



speed and memory are important because a nearly 4 megabyte vector is produced in MATLAB from a single ten second record sampled at 48 kHz!

The ADC/DAC card is by Digital Audio Laboratories, Inc. It is a 16 bit, high precision device marketed for professional music recording and for scientific measurements. This board (and its companion waveform editor called "EdDitor Plus") is somewhat unusual because it allows simultaneous ADC input and DAC output so that very high quality stimulus/response measurements are possible. A jumper change also allows measurements to DC. Less expensive 16 bit signal conversion boards, such as Sound Blaster, could probably be used without compromising the projects and activities described in this paper.

Results

Rigorous measurements of educational effectiveness were not included in the course development because the objective was to change the course rapidly to make the hands on experiences and activities work in the context of the signals and systems course. Funding for equipment provided the impetus for changing the course and the effort began just one month before the semester started. Of course it would be very difficult to make firm conclusions about educational effectiveness on the basis of a single section of a one semester course with the large number of variables that are involved. However, there is good evidence that the course succeeded in capturing the attention of students and had the desired educational outcome.

Student motivation with the class material appeared to be very high. Most students put more time into the projects than was required. They often experimented with different filters or used interesting sounds in their simulations. Also students would frequently stay after class and play with a simulation that was used in a class activity. In addition, students (and the instructor) would get involved in the class, lose track of time and over run into the next class period because of questions and discussion. In fact, some care was needed not to fire up the students too far and I had to help some students with their priorities when they began cutting other classes to stay and do things on the computers! In an exit survey, 91% indicated that they spent more time on the signals and systems course than they did on any other course that semester. 73% said that they preferred working on activities in class rather than listening to lectures and 91% of the students indicated that the projects improved their learning.

Exam performance appeared to improve. Care was taken not to diminish the importance of understanding the math and theory required in the course. Many group activities in class did not use the computers at all. The nature and coverage of exams in the course were not changed from previous years and students still made many of the same kind of random mistakes. However, they improved in their ability to make progress on exam problems which were different from the homework. It was clear that the general class understanding of the relationships in the underlying theory was better than it had been for previous classes.

The combination of methods and equipment used in the course worked very well. The course was a great deal of fun to teach and it appeared to have a strong positive impact on the students.

A complete collection of the custom SIMULINK blocks, interactive activities, student handouts and an instructors guide will be available from the author. Electronic dissemination is preferred. The author may be reached at the following email address: npendergrass@umassd.edu.



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