Session 1526

AN INTEGRATED COMMUNICATIONS, DIGITAL SIGNAL PROCESSING (DSP) AND VERY LARGE SCALE INTEGRATION (VLSI) LABORATORY

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Abstract - The hallmark of the Rowan College of Engineering undergraduate program is to provide effective laboratory based instruction that illustrates important scientific concepts. This paper presents the results of an effort by the Department of Electrical and Computer Engineering at Rowan University to configure a novel method of teaching the junior level Communications (COMM), Digital Signal Processing (DSP) and Very Large Scale Integration (VLSI) courses under a common laboratory framework. These three courses are taken concurrently during the spring semester of the junior year. Twelve interdisciplinary experiments that cut across individual course boundaries and that integrate hands-on experience and software simulation are proposed. The first four experiments deal with the very basic concepts. The next four experiments expose the students to multimedia standards approved by industry. The last four experiments deal with various applications that link COMM, DSP and VLSI. Software is integrated with the experiments through MATLAB and SIMULINK, C/C++ and Mentor Graphics.

Introduction

This project is an effort by the Department of Electrical and Computer Engineering at Rowan University to configure a novel method of teaching the junior level Communications (COMM), Digital Signal Processing (DSP) and Very Large Scale Integration (VLSI) courses under a common framework. These three courses are taken concurrently during the spring semester of the junior year. The effort is aimed at establishing a “proof of concept”. The main developed prototype will be a laboratory manual. A long term goal is to use this prototype to develop a laboratory oriented textbook.

There has been a historical division and separation of the fields of Communications, DSP and VLSI in electrical engineering education. This separation has crept up to the very high professional circles in both industry and university. Engineers specialized in one area find it hard to collaborate with their colleagues and separate cliques within the department start to form. This type of segregation is no longer acceptable as we must provide an integrative experience at the undergraduate level.

Rowan University began as a teacher education institution. It then evolved into a comprehensive state college and now into a university. The School of Engineering is a recent expansion for the college; a major gift in 1992 from the Rowan Foundation was the catalyst for adding engineering. Our new engineering programs seek to use innovative methods of teaching and learning to better prepare students for entry into a rapidly changing and highly competitive marketplace. Key program features include: (1) an analytical and hands-on balance created through collaborative laboratory and lecture material; (2) an emphasis on teamwork as the necessary framework for solving complex problems; (3) incorporation of appropriate technologies throughout the curricula; and (4) creation of continuous opportunities for technical communication. To best meet these objectives, our programs include a multidisciplinary *engineering clinic* <u>every</u> semester [1][2][3]. Sharing many features in common with the model for medical training, the clinic provides an atmosphere of faculty mentoring in a hands-on, laboratory setting. In addition to the clinic, specialized courses are taught to deliver a well blended combination of theoretical and practical skills. This project is in accordance with the aims of our new programs and strives to meet the requirements of industry in hiring engineers who can move across rather artificial course boundaries with great ease.

The common educational framework we envision will enable the students to better comprehend the conceptual relationships of COMM, DSP and VLSI. Implementation of our ideas is facilitated by the fact that the three courses are run in the same semester. Each course has three hours of lectures and three hours of laboratory per week. Illustrative laboratory experiences that enforce the conceptual relationships are planned. This philosophy is further motivated by the need to promote the two main learning styles that students have [4]. Most students, instructors and curricula are sequential in that the process functions with partial understanding, there is steady progress, and details are emphasized [4]. Global learners need the big and overall picture for proper comprehension and progress in leaps despite being slow initially [4]. The present implementation of our curriculum caters extremely well to the majority of students that adopt sequential learning. However, stressing the common framework and thereby the big picture that envelopes COMM, DSP and VLSI accomplishes the very important need of addressing the minority of global learners who would otherwise be weeded out and be a serious loss to society [4].

Goals and Objectives

We want to accomplish the following:

1. Expose students to the different aspects and conceptual relationships among COMM, DSP and VLSI. This will be achieved by (1) laboratory experiences that cut across the course boundaries and (2) tuning the lecture material to stress how the fundamentals (including the mathematical framework) envelope the material in each course.
2. Perform hardware based work that will involve test and measurement equipment, specialized boards (like XILINX Field Programmable Gate Arrays (FPGA) and Texas Instruments DSP boards) and VLSI architectures. The VLSI digital circuit designs are done using complementary metal oxide semiconductor (CMOS) technology [5].
3. Integrate software simulation with hands-on laboratory work using MATLAB, its associated SIMULINK package, C++ programming, Hewlett-Packard Benchlink and Mentor Graphics all of which we have at Rowan.
4. Expand student teamwork experience by making group laboratory projects an integral part of the course structure.
5. Continue to improve written and oral communication skills of our students.
6. Develop educational materials that include a laboratory manual, Java applets and CD-ROMs. The materials will have an impact on a wide variety of courses in our curriculum including the multidisciplinary clinic sequence, core courses (other than COMM, DSP and VLSI) and elective courses.

Description of Experiments

The proposed educational material development aims to cut across traditional course boundaries and embodies cross-platform, interdisciplinary knowledge necessary for today′s students. The main focus is to first write a laboratory manual which describes the interdisciplinary laboratory experiences and includes the relevant theory and conceptual relationships linking COMM, DSP and VLSI. A long term goal is to use the laboratory manual to write a laboratory oriented textbook. Examples of laboratory based textbooks in the DSP area include those involving experiments with hardware boards [6][7]. However, the theoretical background is rather brief in stressing the conceptual issues that tie DSP with COMM and VLSI. There is one textbook that shows concepts linking DSP and COMM [8]. It is a traditional book describing the fundamentals, mathematical background and applications but which has no laboratory component.

We now proceed to describe the laboratory experiments/projects that will comprise our laboratory manual. The first four experiments deal with the very basic concepts.

<u>Experiment 1, Exploring the Continuous and Discrete Fourier Transforms:</u> The differences between the Continuous Fourier Transform (CFT) [9] and the Discrete Fourier Transform (DFT) [9] are studied in relation to the sampling theorem [10]. The CFT of a signal pulse is analytically obtained and based on observations of the frequency components of the signal, the maximum sampling period/minimum sampling frequency that will allow reconstruction of the continuous-time signal is obtained. The signal is sampled and a plot of the DFT magnitude spectrum using MATLAB is generated. An attempt is made to reconstruct the original continuous-time signal from its samples. Students are asked to comment on the results given that the original signal pulse has a lowpass characteristic but is not strictly bandlimited.

<u>Experiment 2, Spectral analysis of communication signals:</u> Use MATLAB to generate a white Gaussian noise signal and observe the magnitude spectrum. Synthesize a bandpass amplitude modulation (AM) signal, a bandpass frequency modulation (FM) signal and a NTSC composite video signal (using a VCR). For each signal, view the waveforms on an oscilloscope and view and explain the magnitude spectrum using a spectrum analyzer. The NTSC video signal has a subcarrier signal that contains the chrominance or color infomation. Identify the subcarrier frequency component and its dB level below the fundamental. Digitally acquire the AM, FM and NTSC signals using the HP Benchlink software. Add white Gauassian noise at different signal to noise ratios (SNR) and obtain the magnitude spectrum of the noisy signals using MATLAB.

<u>Experiment 3, Mentor Graphics Design Laboratory:</u> The students begin by learning the basics of schematic layout and simulation with Mentor Graphics tools. Since our focus is

primarily on digital circuit design using CMOS technology, we begin with simple digital circuits composed of a few circuit components (including diodes and transistors). The circuit schematics are built in Design Architect and simulated with QuickSimII (both are Mentor Graphics tools). The progression of tutorial based laboratory assignments is as follows: (1) CMOS inverter and transmission gate; (2) NAND and NOR gates; (3) functional cells (flip-flops). A more involved assignment is to design an Arithmetic Logic Unit that can add 8 bit numbers.

Experiment 4, Convolution: Implement convolution using the direct approach, the overlap-add approach and using a circular buffer [11]. Use C/C++ and then download the code onto a DSP hardware board. Compare the three approaches in terms of execution time as a function of signal lengths. The circular buffer method is especially important since it is often used in floating point DSP chips [6].

The next four experiments deal with multimedia standards. Teaching COMM, DSP and VLSI from the point of view of multimedia forms an excellent vehicle to bring the three courses together. There have been great advances in a number of information technologies like (1) compression of speech, audio, image and video for efficient storage and transmission, (2) high speed data communication based on packet switching and (3) implementation of algorithms of great complexity on high speed, low area and low power VLSI architectures. The concept of multimedia processing seeks to integrate these technologies into networked information systems to achieve synergistic benefits to the human user [12][13]. The importance of learning multimedia through the eyes of COMM, DSP and VLSI can only be repetitively emphasized. The annual revenue in the United States from only some interactive multimedia opportunities exceeds 120 billion dollars [14] and can only grow with time. An emerging example of how COMM, DSP and VLSI go hand in hand is in High Definition Television in which there are existing standards known as MPEG-2 [15] and MPEG-4 [16]. We will definitely prepare our students for this new market by formulating experiments that emphasize comprehension of multimedia standards approved by industry.

Experiment 5, Pulse code modulation: Write C/C++ code to implement the G.711 multimedia standard 64 kilobits/second Pulse Code Modulation (PCM) system [17]. Implement the PCM system by downloading the code onto the Texas Instruments DSP hardware boards.

Process twenty different sentences and conduct a Mean Opinion Score (MOS) test that assesses the perceptual quality of the PCM decoded speech.

The MOS test is a formal listening test of decoded speech where the perceptual quality of each sentence is rated as 5- Excellent, 4 – Very Good, 3- Good, 2-Fair and 1-Poor. The benchmark for comparison is the original speech signal. The people rating the decoded speech comprise a sample of typical consumers that are not necessarily electrical engineers. Starting from a set of scores that each laboratory group assembles, we get an ensemble of scores from which a mean, standard deviation and confidence interval can be calculated. The MOS test is used in industry to rate speech coders [17]. From this exercise, students learn how to perform an MOS test as is done in industry. The main objective in speech coding is to develop low complexity coders that operate at low transmission rates and simultaneously yield decoded speech of high perceptual quality. The PCM coder is extremely simple to implement, gives rise to an MOS score of about 4.0 but operates at a very high transmission rate. The next experiment deals with a Code Excited Linear Prediction (CELP) coders [17][18] that lower the transmission rate at the expense of some increase in complexity and some decrease in MOS score.

<u>Experiment 6, Code Excited Linear Prediction (CELP):</u> Write C/C++ code to implement the G.729 multimedia standard 8 kilobits/second CELP system [17][18]. Implement the system on DSP hardware boards. Examine a VLSI and parallel architecture based application specific integrated circuit (ASIC) design and implementation of the CELP system using CMOS technology. Concentrate on achieving a high speed, low area and low power design [19]. Use Mentor Graphics as a schematic driven layout tool. Fabricate your design using the MOSIS Educational Program (an NSF funded program that provides free fabrication of integrated circuits designed by students). Compare and contrast the VLSI design with the standard DSP processor architecture of Texas Instruments. Do a formal mean opinion score (MOS) test of the CELP system and compare with the results obtained for PCM.

<u>Experiment 7, Error Correcting Codes:</u> This experiment is devoted to implementing parity check and convolutional codes [20] using a Field Programmable Gate Array (FPGA) architecture on a XILINX board [21]. Students are then asked to develop a VLSI architecture for this purpose and compare it to the FPGA architecture. Integrate the design with the CELP coder, simulate bit errors and compare the output speech quality with and without error correction.

Experiment 8, MPEG-4: Students are asked to implement the video coding part of the MPEG-4 [16] multimedia standard in C/C++ and as a VLSI architecture (similar to the experiment on CELP but for a different multimedia standard). Process twenty images and do a Mean Opinion Score test based on subjective visual quality. Fabricate the VLSI design by submitting to MOSIS.

The next four experiments deal with various applications that link COMM, DSP and VLSI.

Experiment 9, Comb Filter for Noise Suppression: Students are asked to implement both finite impulse response [22] and infinite impulse response adaptive comb filters [11] to suppress the noise component in signals corrupted by noise. Experiment with different signal to noise ratios, different types of signals (simple sinusoids to more complicated ones like speech and audio) and different types of noise (white, colored, uniform and impulse). Does one type of filter perform better than another? Implement the filters using an FPGA architecture.

Experiment 10, Channel Equalization: Consider a baseband model of a digital communication system consisting of a communication channel and an adaptive equalizer. Implement the least-mean squares and recursive least-squares algorithms to run the equalizer and hence, compensate for the channel distortion [23]. Special attention should be given to nonminimum phase channels (examples include a telephone channel and a fading radio channel [23]) for which the equalizer may be unstable [24]. In such a case, consider the technique of truncating the impulse response to achieve on-line restoration of the input data. Implement the algorithms using a VLSI architecture and fabricate the design.

Experiment 11, Digital Phase Locked Loops: The Digital Phase Locked Loop (DPLL) performs the function of generating a clock signal which is locked or in synchronization with an incoming signal [25]. The component blocks of a DPLL are discussed and design options are investigated. The students will examine the loop components: phase detector, loop filter, voltage controlled oscillator, and divide-by-N counter. They will be required to investigate alternative designs for each of the components before choosing a particular implementation. Each of the components will be simulated before the full implementation is simulated. Once the students have a working design for their circuit, they will accomplish the integrated circuit layout. This final product will then be submitted to MOSIS for fabrication.

Experiment 12, Bandpass Digital Communication System: This experiment is an excellent sequel to experiment 5 on PCM. Students are required to design, build and test typical baseband and bandpass digital communication systems. Students will implement a baseband T1 line using a PCM transceiver system. The generated baseband pattern will then be modulated using Quadrature Phase Shift Keying and Quadrature Amplitude Modulation techniques [9]. The entire system will be characterized using input analog voice frequency signals with varying signal-to-noise ratios. System transfer characteristics, eye patterns and in phase/quadrature constellation diagrams will form part of the measurement suite. The eye patterns indicate intersymbol interference [9]. Students are then asked to design digital Nyquist filters [26][27] to eliminate intersymbol interference and then, observe the corresponding eye patterns.

Significant overlap and coordination will be designed into the courses to allow for the interdisciplinary laboratories. For instance, prior to performing experiments 6 and 7 (CELP and MPEG), the COMM course will have covered source coding, the DSP course will have covered digital filtering and the VLSI course will have covered the basics of architectures and integrated circuits. Also, for experiment 11 (DPLL), as the COMM course begins to investigate the functioning of the DPLL in communications circuitry, the VLSI laboratory experience that investigates the design and layout of a DPLL will begin. The DSP course will have covered filter design using analog techniques so that a digital loop filter for the DPLL can be designed. This type of coordination is an example of how we will structure the interdisciplinary laboratories to enhance global understanding of the course material.

Details of Experiment 2

We give a more detailed description of Experiment 2 that deals with spectral analysis of communication signals. This laboratory has 3 parts. In Part 1, the differences between the Continuous Fourier Transform (CFT) and the Discrete Fourier Transform (DFT) are studied. In Part 2, AM and FM bandpass signals are synthesized and their spectra are analyzed. In Part 3, a baseband NTSC composite video signal is captured and its spectrum analyzed.

Part 1 (use MATLAB only)

Consider the time domain signal in Figure 1.

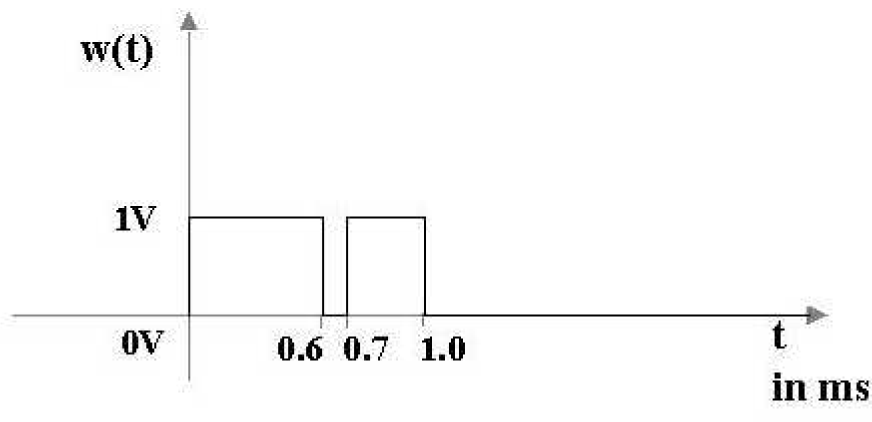

Figure 1 Time domain signal

Perform the following:

- Model the signal as a continuous-time function and plot.
- Obtain, analytically, the CFT of the signal, and plot.
- Based on your observations of the frequency components of the signal, determine the maximum sampling period/minimum sampling frequency that will allow reconstruction of the continuous-time signal.
- Plot the DFT magnitude spectrum using Matlab's *fft* function.
- Attempt to reconstruct the original continuous-time function from its samples, either by: convolving the time domain samples with appropriate Sinc function (difficult), or windowing the Fourier transform and taking the inverse Fourier transform (easier). Comment on your results.
- What is the maximum sampling period/minimum sampling frequency that will allow reconstruction of the discrete-time signal from its DFT, that adequately represents the original continuous-time signal? Show plots of the discrete-time signals, the corresponding DFTs and reconstructions, for sampling intervals at, above and below this maximum allowed sampling period.

Part 2 (use MATLAB, HP54645A Oscilloscope, HP33120A Function Generator and HP8591EM EMC Analyzer/ HP Infinium Oscilloscope/ HP 54657A FFT Module)

Perform the following:

- Synthesize a bandpass AM signal, $s(t) = A_c[1 + A_m\cos(2\pi f_m t)]\cos(2\pi f_c t)$ where $f_m = 5$ kHz and $f_c = 25$ kHz.
- Obtain and plot the spectral components of this signal using:
  - Matlab's *fft* function.
  - The spectrum analyzer/ FFT module.
- Add noise to the signal, observe the signal in the time and spectral domains.
- Experiment with various f_ms, f_cs and SNRs.
- Synthesize a bandpass FM signal, $s(t) = A_c\cos[2\pi f_c t + b_f A_m\sin(2\pi f_m t)]$ where b_f = Frequency Modulation Index (choose initially = 10).
- Repeat earlier experiments for the FM signal

Part 3 (use MATLAB, HP54645A Oscilloscope, NTSC baseband composite video source (VCR/Camcorder/RGB to NTSC Encoder/Sony Color Camera), HP8591EM EMC Analyzer/ HP Infinium Oscilloscope/ HP 54657A FFT Module and HP Benchlink Suite or HPVEE)

Consider the composite NTSC baseband video signal in Figure 2.

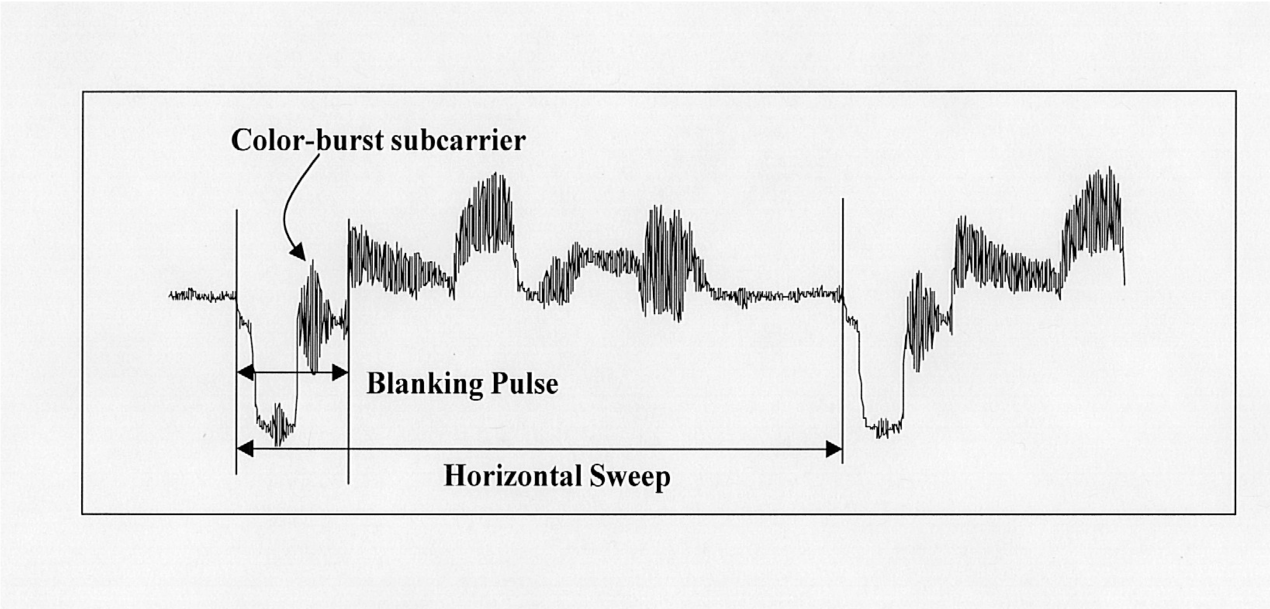

Figure 2 Composite NTSC baseband video signal

Perform the following:

- Observe the NTSC video signal on an Oscilloscope. In particular, measure the horizontal sweep interval time and the frequency and number of the color-burst subcarrier signal located on the "back porch". This subcarrier signal contains the chrominance or (color) infomation.
- Digitally acquire this signal using the HP Benchlink Suite software and obtain its DFT using Matlab. Identify the subcarrier frequency component and its dB level below the fundamental.
- Compare your results with the spectrum analyzer

Summary

This NSF-funded project has just commenced at Rowan. We have described twelve interdisciplinary experiments and given details on an experiment relating to spectral analysis.

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Biography

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John L. Schmalzel has been at Rowan University since 1995, currently serving as Chair of the Electrical and Computer Engineering Department. He has been active in the development of Rowan's new ECE curriculum, with particular interest in the Engineering Clinics, a multidisciplinary, 8-semester sequence. His other interests include instrumentation and laboratory development.

Steven H. Chin is the Associate Dean of Engineering at Rowan University. He has both research, laboratory development and teaching experience in Communications, Information Theory, Digital Signal Processing, Image Processing and Neural Networks. At Rowan, he is the faculty coordinator for ABET accreditation activities. He joined Rowan after spending 8 years at the Catholic University of America.