A DSP LABORATORY DESIGNED FOR TEACHING FUNDAMENTAL CONCEPTS

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ABSTRACT

The senior level Digital Signal Processing (DSP) course at North Carolina State University is designed to teach basic methods of describing and analyzing digital signals and systems. In order to reinforce this approach, the laboratory is designed to demonstrate DSP concepts with actual signals and systems. The lab requires no programming but gives the student the opportunity to see the application of theory by manipulating and analyzing real signals. The basis for the lab is a dual channel, multiple scope software package that allows the student simultaneous viewing of time domain and frequency domain signals.

1. INTRODUCTION

The senior level DSP course at North Carolina State University is designed to teach basic methods of describing and analyzing digital signals and systems. This course is intended as an elective course for students interested in further work in the areas of communications, signal processing or controls. The emphasis of the course is on understanding the relationship between the mathematics of representation and the actual signals and systems encountered in real-world applications. In order to reinforce this approach, the laboratory is designed to demonstrate DSP concepts with actual signals and systems. The lab requires no programming, but gives the student the opportunity to see the application of theory by manipulating and analyzing real signals.

The DSP Lab is based on an MS-DOS 486 platform that supports a stereo DSP board. The board contains dual channel A/D and D/A converters, an AT&T DSP32C digital signal processing chip and 256K bytes of memory. The students do not access the DSP32C directly during the laboratory, but use its substantial capabilities via the commercial software packages DSPHQ and DSPHOST developed by Bittware Research Systems. The DSPHQ and DSPHOST software is designed to aid in the development of digital signal processing algorithms for the AT&T DSP32 series of chips. The DSPHQ software is particularly suited for many signal analysis tasks. Commands can be executed individually or command files can be written which execute a program of DSPHQ commands or external programs. The most useful tool in the DSPHQ package for this lab is a versatile real-time multiple scope simulator which will be discussed in detail later.

The DSPHOST software allows the user access to the DSP32 chips while programming in the C language. The AT&T C compiler is designed for the hardware, but does not allow high level I/O operations. The DSPHOST precompiler permits the user access to virtually all of the I/O features of C while using the speed and real-time processing of the DSP chip. The DSPHOST software is primarily used by the instructors to develop interactive programs that can be executed by the students during the lab. Some examples will show how these packages are used to demonstrate some basic concepts.

2. MULTIPLE SCOPE SOFTWARE

The DSPHQ software package includes a complex command file which allows the student to simulate dual channel oscilloscopes, spectrum analyzers or both simultaneously. The sampling rate of the scopes is controlled by a crystal on the board. In the NCSU teaching lab, 8 kHz sampling is used in all the systems. However, additional crystals are available with a maximum rate of 50 KHz. The most frequently used scope is the combination oscilloscope - spectrum analyzer shown in Figure 1. This screen allows the student to see the time and frequency domains simultaneously, which is an aid

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to teaching frequency domain concepts.

In addition to the common scopes, the software provides scopes for autocorrelation, cross-correlation and transfer function. Both the autocorrelation and the cross-correlation are used in the laboratory sessions dealing with those subjects. It has proven to be a very effective tool to have the student see the changes in the correlation functions in real-time as he/she varies the input signals.

The software allows the student to freeze the scopes and make interactive measurements from the screen. The displays can be magnified as needed to study the detail of the sampled signals and spectra. This feature is also valuable for emphasizing the discrete and quantized nature of the signals. Signals for the laboratories are produced by signal generators, acoustic microphones and DSPHOST programs.

3. LABORATORY TOPICS

1. **Getting acquainted with DSPHQ:** The goal of this lab session is to introduce the student to the equipment and the DSPHQ software. The students learn to use of the multiple scope software, including triggering and scaling; the use of the microphone and signal generators; and the effect of saturating the A/D convertors.

2. **Demonstration of sampling and quantization:** The goal of this lab session is to familiarize the student with the sampling and quantization operations performed by the DSP processor. The students develop methods for calibrating the A/D range on the scope window and for computing sampling interval and quantization step size of the lab system.

3. **Use of the spectrum analyzer:** The goal of this lab session is to review the frequency domain representation of signals, i.e. the Fourier Series and discrete time Fourier transform. The transforms of some common signals are computed and compared to actual signals obtained from the signal generator (a sinusoid, square wave, and a triangular wave), and the voices of the students. In Figure 1(a), a plot of the vowel "a" is displayed on the Channel 1 oscilloscope (top) and and its Fourier transform is displayed on the Channel 1 spectrum analyzer (bottom). In Figure 1(b), a plot of the time and frequency response of the vowel "o" is displayed.

4. **Investigation of the Autocorrelation function:** The goal of this lab session is to investigate the autocorrelation function associated with a signal. The students generate autocorrelations for a sinusoid, square wave, and triangular wave; verify their autocorrelation computations; and demonstrate shift-invariance of the autocorrelation function.

5. **Exploration of autocorrelation and cross-correlation:** The goal of this lab session is to continue the exploration of the autocorrelation and cross-correlation of signals. This lab also investigates some of the problems encountered with the noise commonly present in real-world applications. The students use cross-correlation to identify signals and the determine the position of pulses. Figure 2 shows the cross-correlation of a sinusoidal waveform with a triangular waveform. The upper windows show the input signals in the time domain and the lower window is the cross-correlation of the two input signals.

6. **Demonstration of the DSPHQ board anti-aliasing filter:** The goal of this lab session is to investigate the properties of anti-aliasing filters used in digital sampling and the character of the bandlimited signals that are produced. The students measure the frequency response of the system's anti-aliasing filter; and demonstrate its bandlimiting characteristics. Figure 3 demonstrates the effects of the anti-aliasing filter on a square wave which has been input to the system.

7. **Digital signal generation:** The goal of this lab session is to examine the properties of digital systems and signals. Students generate simple digital signals and examine them to check their properties. They also examine several digital systems using input from the signal generator and microphone. The students listen to the difference in amplitudes to get a feel for the dB scale; compare the digitally generated sinusoids from DSPHOST with those of the signal generator; generate digital impulses; and consider the effect of bandlimiting the impulse. Figure 4 illustrates the impact of bandlimiting an impulse in both the time and frequency domains.

8. **Decimation and interpolation:** The goal of this lab is to demonstrate the spectral effects of decimation and interpolation. The students generate impulse trains with the DSPHOST programs and then use the impulse trains to subsample signals from the signal generator. They then design low pass filters and for use in interpolation of the subsampled signals in real time. Students encounter the effects of aliasing again in this lab.

9. **Characterization of digital systems with known form but unknown parameter values:** The goal of this lab session is to use various properties of the time and frequency domain to characterize unknown systems. Several software systems have been created to which the students can input a known signal and examine the output. The input for the system can be generated either by the microphone or by the signal generators. In this lab, the students are given mathematical forms of the systems which can be described by a few parameters whose values are unknown. Generally, the systems can be characterized as linear or nonlinear, time-variant or time-invariant, stable or unstable and causal or noncausal. To make life a bit easier, students may assume that all the systems encountered in this lab are causal.

   Having built a foundation in DSP concepts, the student now begins to use them to estimate parameters of systems. The systems are programmed in C and run via DSPHOST. Examples include echos, modulation and frequency selective filters.

10. **Characterization of digital systems with unknown parameters:** The goal of this lab session is to use various properties of the time and frequency domain to characterize unknown systems. Two systems have been designated to which the student can input a known signal and examine the output. The students are asked to determine the parameters of interest to characterize unknown software systems run via DSPHOST.

11. **Characterization of analog systems using digital methods:** The goal of this lab session is to again use various properties of the time and frequency domain to characterize unknown systems. The students are asked to characterize an analog "black box" which has only input and output ports. The box may have adjustment such as sliders or dials which vary the output in a parametric manner. The students are asked to develop a mathematical model for the box.

4. SUMMARY

With the support from the National Science Foundation, North Carolina State University has been able to develop a real-time Digital Signal Processing Laboratory for use in its undergraduate curriculum. The laboratory provides the students hands-on experience using a real-time DSP system on a 486-based platform.

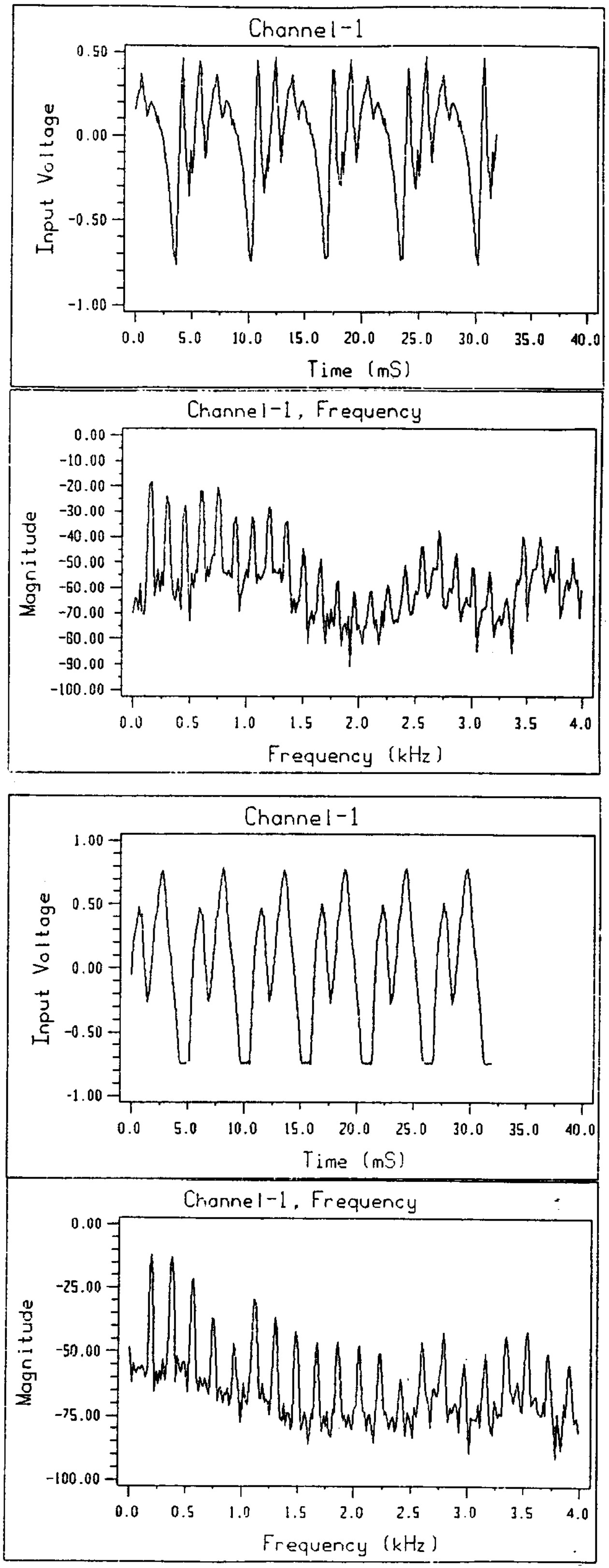

Figure 1 (a) Vowel "a", (b) Vowel "b"

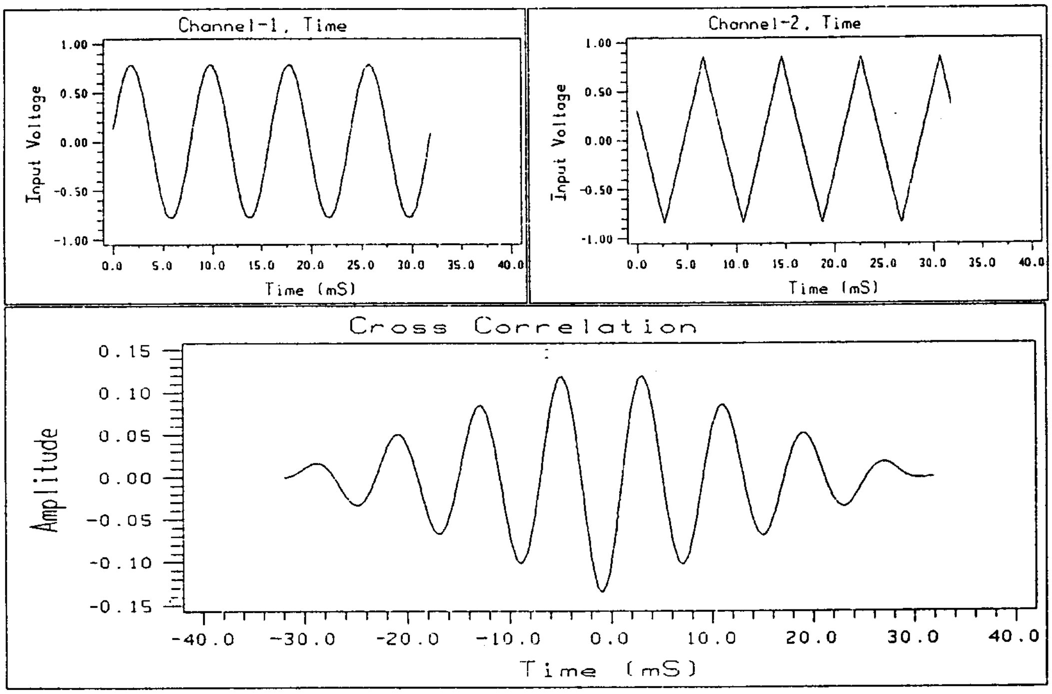

Figure 2 Cross-correlation of sinusoidal and triangular waveforms

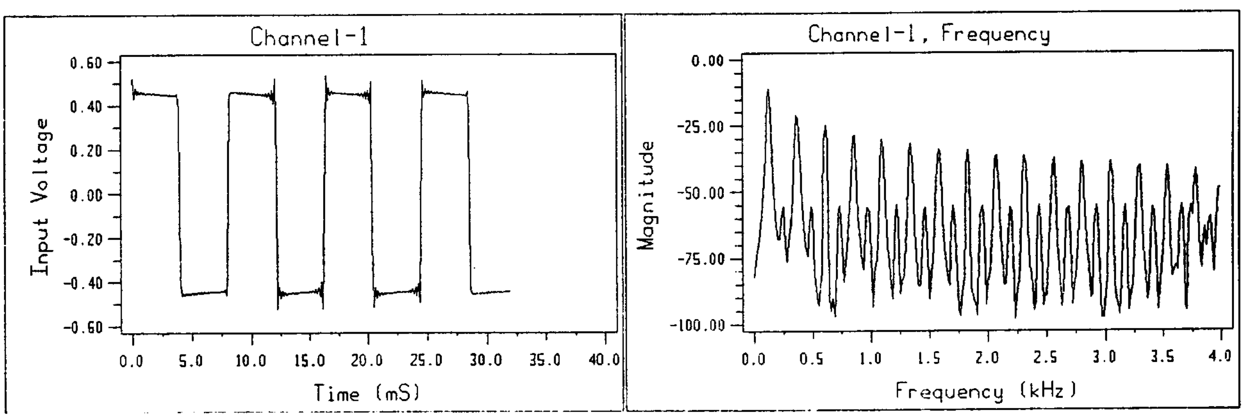

Figure 3 Effect of the anti-aliasing filter on a square wave

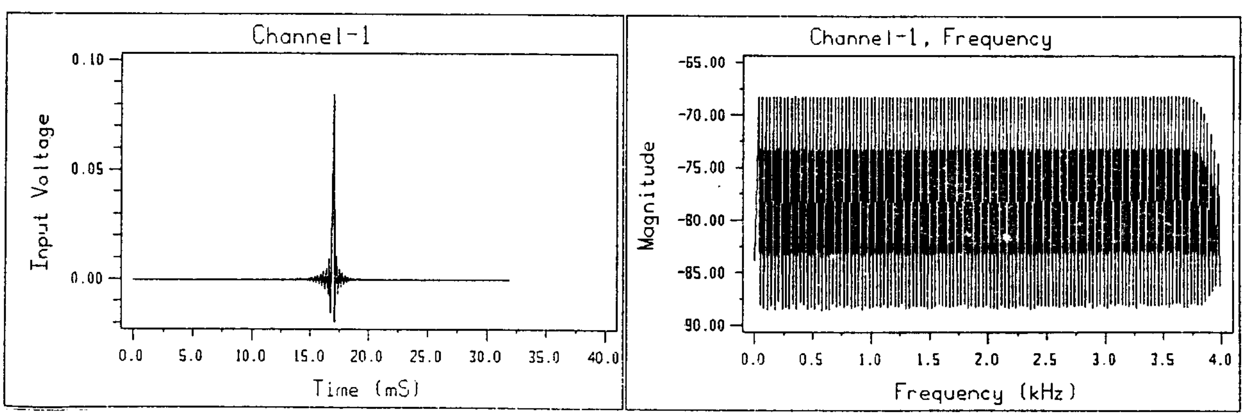

Figure 4 Effect of bandlimiting an impulse