Echo and Reverberation

EE 224: Signals and Systems I

1 Overview

This experiment focuses on the Digital Signal Processing (DSP) application area. Echo and Reverberation are two of the simplest applications of DSP. This laboratory shows how models of Echo and Reverberation can be designed using MATLAB and Simulink.

MATLAB can be augmented by the Simulink package. "Simulink®is an environment for multidomain simulation and Model-Based Design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing."

What this means is that Simulink can be used to quickly put together prototypes and models of systems using a graphical user interface. Systems can be built by connecting together different blocks. These blocks can be selected from pre-defined "block sets" for a particular application (e.g. communications, image processing), or can be defined by the user. User defined blocks can be created by specifying the mathematical operations that are carried out on the block inputs.

2 Learning Objectives

By the end of this lab, students will be able to:

1. Explain the differences between echo and reverberation
2. Describe a system that will produce echo/reverberation
3. Use MATLAB Simulink to simulate a system
4. Modify an existing Simulink model

3 Pre-Lab Reading

3.1 Simulink Background

To get a head start with Simulink, you should watch the Getting Started with Simulink tutorial: `https://www.mathworks.com/support/learn-with-matlab-tutorials.html`. You are also strongly advised to read through the Create a Simple Model documentation at the Mathworks site.

3.2 Introduction to Echo and Reverberation

Reverberation and echo both occur because the listener hears two or more versions of the same sound, where each version arrives at a slightly different time instant.

3.2.1 Echo

Echo is audible because the speed of sound is relatively slow, about 400 meters per second. If we consider only one echo path (as shown in Figure 1), then an echo can be simulated using the following equation:

$$y[n] = x[n] + Gx[n-k] \tag{1}$$

where $G < 1$, due to losses in the echo path.

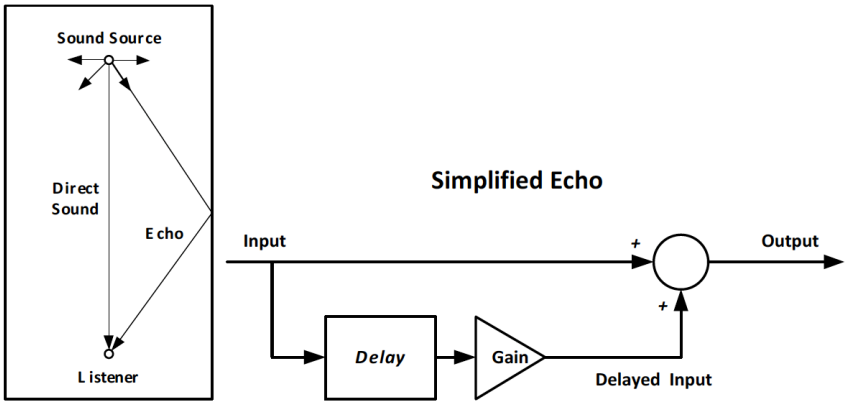

Figure 1: Example of an echo

A real room will have multiple echo paths, as illustrated in Figure 2. The key point to note is that the echo is derived solely from the input. This type of system is known as a Finite Impulse Response (FIR) system.

3.2.2 Reverberation

Reverberation (or reverb) is very similar to echo, but rather than creating a few distinct copies of the original sound, reverberation creates many copies of the sound that are typ-

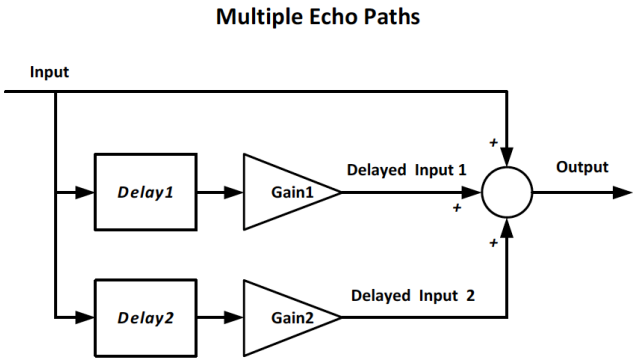

Figure 2: Basic block diagram representing multiple echo paths.

ically closer together in time. One way reverb is created is through feedback as shown in Figure 3.

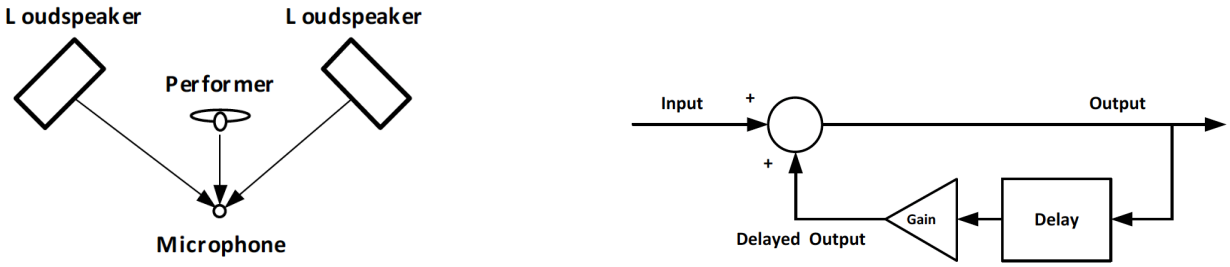

Figure 3: Illustration of reverberation.

In reverberation, the output is derived from both the input and the previous output:

$$y[n] = x[n] + Gy[n-k] \tag{2}$$

This system feeds the input back.

A real room will have several echo paths. When sound is reflected off a surface there will be "colouration." Certain frequencies will be absorbed and there will be phase changes. Therefore, a commercial echo/reverberation unit will contain many different delay paths.

3.2.3 Pre-lab Questions

Your preparation should enable you to answer the following questions:

1. What is the main difference between echo and reverberation?
2. Why does the slow speed of sound mean that echo can be heard? What would happen if the speed of sound was much faster?

Answer these questions in Canvas before your lab begins.

4 Lab Exercises

We shall start by running the Echo and Reverberation Simulink models. These use .wav files as the inputs.

4.1 Echo using Wave File

4.1.1 Opening the Echo Simulink Model

From MATLAB, open *EchoWav_simulink.slx*. First open Simulink by typing `simulink` at the command line. Make sure that the directory containing your sound file and the Simulink model are on your MATLAB path.

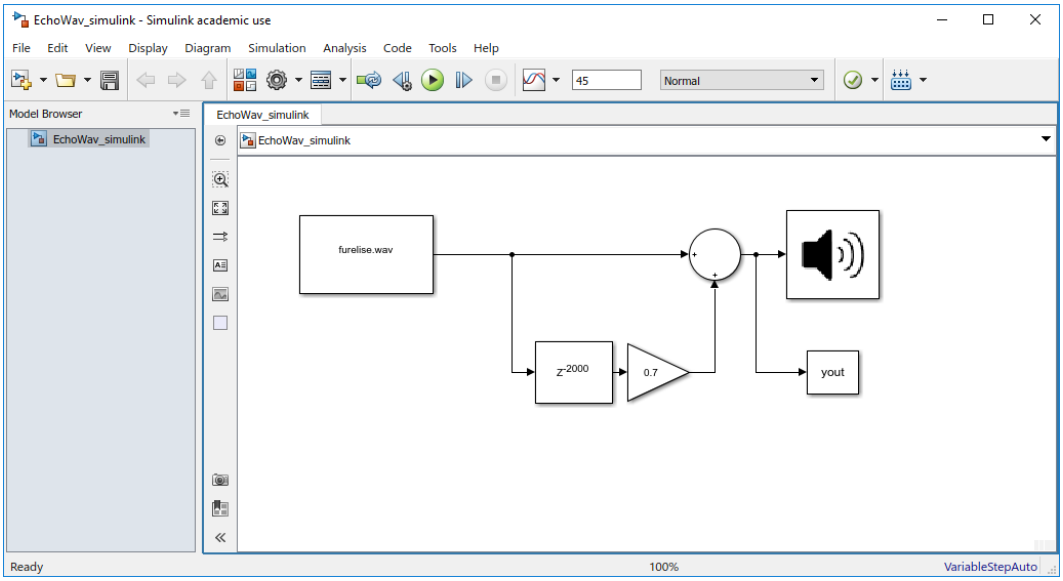

Figure 4: Echo using a .wav file

Run the model by clicking on the green arrow at the top of the window and listen to the effect of the delay. Verify that you can hear the echo. This model has one input, a sound file, and two outputs, an audio port and a variable called `yout` in the workspace. In Simulink, you can click on any block to see and set its parameters. (You may need to set the source to the correct file.) If you wish, you can change the input sound source to something more pleasing to you. Please avoid explicit and/or offensive versions of songs. Also, please use headphones! Be sure to note the sampling rate of your input.

4.1.2 Changing the Delay Time

Double-click on the "Delay" block and change the "Delay length" to a different value (see Figure 5). Run the model and hear how the effect has changed. Try a few different settings between 100 and 20000 "Delay (samples)."

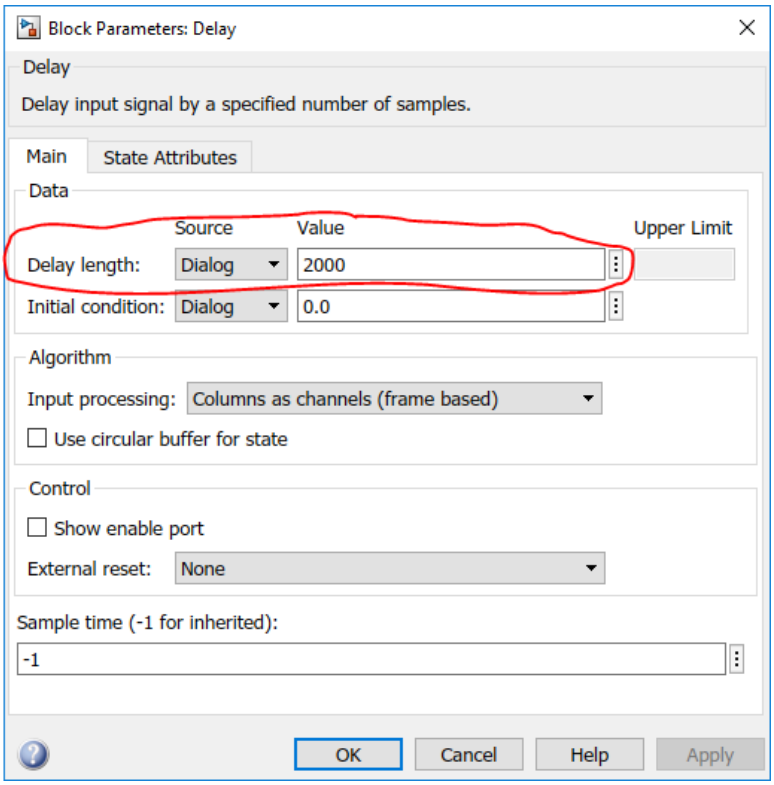

Figure 5: Changing the delay time

4.1.3 Changing the Gain

Double-click on the "Gain" block and change the "Gain" setting to a different value. Run the model and hear how the effect has changed. Try a few different settings between 0 and 2. Note how the output changes.

Demonstrate to a TA that you can change the gain. Your TA will then sign your verification sheet.

4.1.4 Echo Questions

1. How do you calculate the delay length in terms of time? What is the smallest delay (in ms) that allows you to hear an echo? For an input with a sampling rate of 8000 Hz, what is time duration of a 1500 sample delay?

2. Describe the sounds that you hear with a delay of 0.25 s and a gain of 0.5, 1, and 2. Discuss why you hear different outputs.

4.2 Reverberation using Wave File

4.2.1 Opening the Reverberation Simulink Model

From Simulink, open *Reverb_Simulink.slx* and click play to listen to the reverb effect.

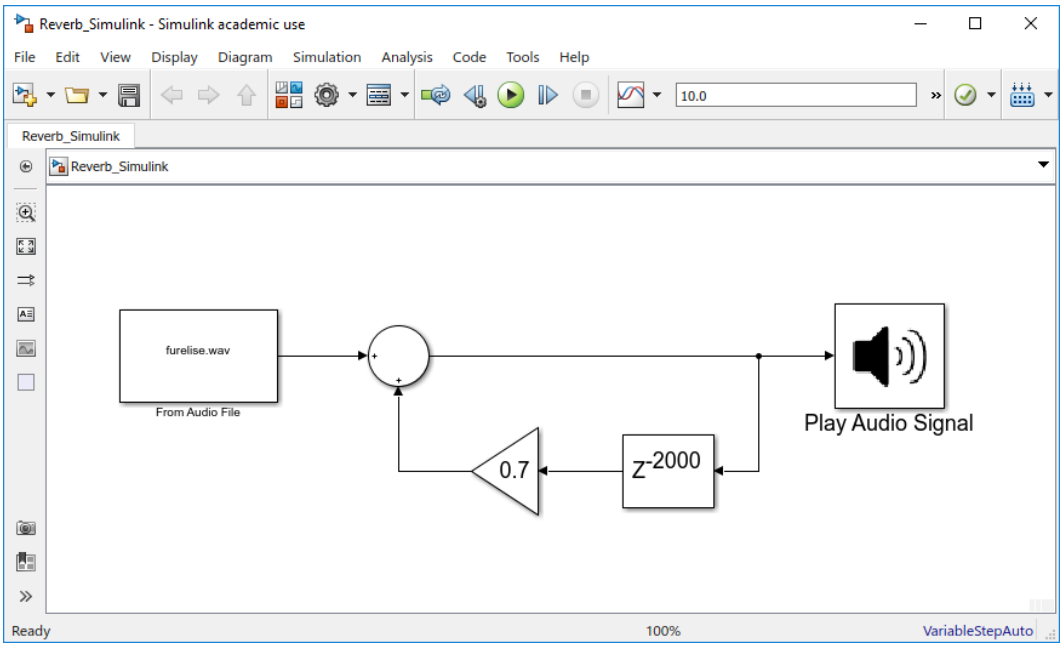

Figure 6: Reverberation using a .wav file

4.2.2 Changing the Delay Time and Gain

Double-click on the "Delay" block. Change the "Delay (samples)" to a different value, then run the model and listen to the effect. Double-click on the "Gain" block. Change the "Gain" parameter to 0.95 then run the model. Listen to the effect.

4.2.3 Reverb Questions

1. Why does Reverberation require a shorter delay time than echo to be noticeable?
2. What effect does the "Gain" block have on the stability of the reverberation system? Give a gain value for the system to be stable and a value for when the system is unstable.

4.3 Working with Simulink Models

4.3.1 Singing Rounds

Set the input of one of the models to the *frere_jacques.mp3* file. This is a simple file of the melody "Frere Jacques." Set the delay so the file plays as a round. You can save your

output file by deleting the `yout` variable and replacing it with the "To Multimedia File" block in the DSP signal processing toolbox under the subdirectory Sinks. Select the menu item *View → Library Browser → DSP System Toolbox → Sinks*.

4.3.2 Modify the Echo Subsystem

In the "Echo Subsystem", add in a second echo path using the Simulink block library in the DSP System Toolbox. Select the menu item *View → Library Browser → Commonly Used Blocks* to find the gain and delay blocks. Try to make the echo as realistic as possible. Be sure to save this system in a new file.

Demonstrate your modified system to a TA. Your TA will then sign your verification sheet.

4.3.3 Extra Credit: Create Your Own Subsystem

Add your own subsystem blocks and add your own signal processing. You might want to design a subsystem with both echo and reverberation. You can get interesting effects by having multiple reverberation paths with delays that are prime numbers. Include both your model and an *output.wav* file in your results.

4.4 Report Checklist

Be sure the following are included in your report.

- Section 4.1.4: Answer the two questions about about echos
- Section 4.2.3: Answer the two questions about about reverb
- Section 4.3.1: Describe the settings used to achieve a round
- Section 4.3.2: Describe your modified echo system
- Section 4.3.3: Describe the sound effect you came up with and include the parameters. Consider including a screenshot.

5 References and Credits

This lab is based on one originally written by Texas Instruments in 2007. The lab was updated by Stewart Worrall, Simon Henley and Philip Jackson (last updated on 4 Feb 2013): `http://personal.ee.surrey.ac.uk/Personal/P.Jackson/ee1.lab/D3_echo/`

"Simulink Documentation." In this guide, The Getting Started and Modeling sections contain useful tutorials that will help you get familiarized with the Simulink interface by building a very basic model.

Original .mp3 file for Frere Jacques are from mfiles.co.uk. Downsampled and made into a mono file by Julie Dickerson.

Verification Sheet

Have a TA sign and date each item once you have successfully demonstrated it. Scan this sheet and include it with your report.

Names: _____

_____

_____

Section: _____

1. Demonstrate that you can run the Echo Simulink model and change the gain value.

   _____ _____

   TA Signature Date

2. Show your updated Echo model that saves the output as .wav file.

   _____ _____

   TA Signature Date