AUDL 1001: Signals & Systems for Hearing & Speech

Lab week 5: Signals and Systems Workbench

Introduction

Signals and systems theory aims to give a quantitative account of how signals, and systems that modify such signals, can be characterised. We have seen how the use of a spectrum gives a quantitative description of which sinusoidal components are present in a signal. We have also seen how a frequency response gives a quantitative description of how the amplitude of a sinusoidal component of a signal is changed by its passage through a system. Together, spectra and frequency responses provide a powerful means for describing signals (including speech signals) and systems that process and generate signals (including the ear and vocal tract).

In this laboratory session we reinforce the ideas of signals and systems theory by passing a number of different signals through a number of different systems and exploring what happens in both the time domain and the frequency domain.

Method

You will use *Esystem*, a computer program, to generate a range of signals and pass them through a range of systems. The waveforms and the spectra of the input and output signals are displayed, along with the frequency response of the particular system you have specified.
http://www.phon.ucl.ac.uk/resource/sfs/esystem/

If you like, you can select *View →Impulse Response* so this option is ticked, although you probably do not yet know what this is! You then choose an input signal and a frequency response for a system. You will then see the input and output waveforms, and input and output spectra (as well as the system impulse response if you have chosen to). Clicking on the input and output waveforms will allow you to hear them.

Input signals

- sine wave of a frequency you can specify
- an impulse
- a periodic train of impulses, whose fundamental frequency you can specify
- a sawtooth wave, whose fundamental frequency you can specify
- white noise
- a *chirp*, which is a sine wave that sweeps a range of frequencies quickly
- open an arbitrary wav file

Systems

- an amplifier, whose gain you can specify
- a resonator whose frequency and bandwidth you can specify
- a low-pass filter whose cut-off frequency you can specify
- a band-pass filter whose cut-off frequencies you can specify
- a high-pass filter whose cut-off frequency you can specify
- a cascade of three resonances (3 resonators in a row) which mimic the frequency response of the vocal tract. You can specify all three resonant frequencies.

Observations

Use the program to answer the questions below. You can print out any picture, but be sure to enter your name as a title.

Spectra of different waveforms

1. What does the spectrum of the input sine wave at 1 kHz look like?

2. What does the spectrum of a pulse train with a fundamental frequency of 200 Hz look like? How does the input waveform and spectrum change if the repetition frequency is changed to 100 Hz? To 50 Hz? To 25 Hz?

3. What does the spectrum of a single (very narrow) pulse look like? Explain this result using your answers to the previous question.

4. What does the spectrum of white noise look like in the program?

5. Ideally, what should it look like?

6. Why is white noise called “white”?

7. If the amplitude spectrum of white noise and an impulse are the same, what must be different about them?

8. Select the chirp and listen to it. What is its spectrum? What other waves is this similar to?

The simplest system

1. Set the system to be an amplifier of +0dB. What does this system do to signals? For sinusoids, does that depend on the frequency of the sinusoid?

2. Set the system to be an amplifier of +6dB. What does this system do to signals? For sinusoids, does that depend on the frequency of the sinusoid?

Frequency response of a simple resonator

1. Set the system to be a simple resonator with a resonant frequency of 1000 Hz and a bandwidth of 100 Hz. If you didn't set these numbers yourself, how would you determine them from the frequency response?

Effect of a simple resonator on a pulse train

1. Set the system to be a simple resonator at 1000 Hz with a bandwidth of 100 Hz. Set the input signal to be a pulse train with a fundamental frequency of 100 Hz. Explain the shape of the output spectrum. Why are some harmonics amplified more than others?

Effect of a simple resonator on white noise

1. Set the system to be a simple resonator at 2 kHz with a bandwidth of 300 Hz. Set the input signal to be white noise. Explain the shape of the output spectrum.

2. What speech sound has the most similar quality to this?

3. Change the resonant frequency to 4 kHz. What speech sound is most similar now?

A simple low-pass filter

1. Set the system to be a low-pass filter at 1000 Hz. What would this system theoretically do to amplitude components of an input signal above 1000 Hz?

2. Set the input signal to be a sawtooth. Explain the shape of the output spectrum. Is the signal or system responsible for the presence of harmonics? Is the signal or system responsible for the envelope of the output spectrum?

3. Set the input signal to be a chirp, white noise and an impulse in turn. What is the common factor in the output spectra? What practical implications does this have?

Use of a band-pass filter for signal analysis

1. Set the input signal to be a pulse train with a fundamental frequency of 200 Hz. Set the system to be a band-pass filter between 950 Hz and 1050 Hz. What part of the input signal can be seen in the output signal?

2. Change the band-pass filter so that it is between 850 Hz and 950 Hz. Why is there very little energy in the output spectrum?

3. How do 1 and 2 show us how we might use band-pass filters to analyse a sound?

Effect of filtering on a speech signal

4. Set the system to be a low-pass filter at 1000 Hz. Set the input signal to be the contents of the file "six.wav". Listen to the input and output signals. How would you describe the change in timbre, or quality, caused by the filter?

5. Set the system to be a high-pass filter at 1500 Hz. How has this filter affected the timbre of the signal?

6. Set the system to be a band-pass filter between 300 Hz and 3500 Hz. How would you describe the change in timbre now? What does this quality remind you of?

Making a vowel sound

1. Set the input to be a sawtooth waveform at 125Hz. Set the system to have a vowel-like frequency response with F1=500 Hz, F2=1500 Hz, F3=2500 Hz. What vowel does the output sound like?

2. Try to find resonator values that sound more like the 'ee' in 'beet' and the 'o' in 'pot'. Hint: Put F1 low and F2 high for 'ee' (between 300 Hz and 2600 Hz). Put F1 high and F2 low for 'o' (centred around 1000 Hz). Ensure that the frequencies don't overlap, so that F1<F2<F3. You may need to move F3 around as well but its frequency is of less importance.

3. In human speech production of vowels like this, the input can be considered to come from the vibrating vocal folds in the larynx, which give off something like a sawtooth wave. In that case, what is the output signal, and what is the system? What changes in the system to give different vowels?