ROSE-HULMAN INSTITUTE OF TECHNOLOGY
Department of Electrical and Computer Engineering

ECE 300 Signals and Systems Winter 2006-2007

Audio Signals and Spectra

Lab 08
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Objectives

- To become familiar with the concept of an aperiodic signal spectrum
- To investigate typical temporal and spectral features of audio signals
- Use MATLAB to investigate audio signal processing

Equipment

Laptop Computer with MATLAB	Function Generator
Agilent E4402B Spectrum Analyzer	Oscilloscope

Background

We are learning that a signal can be represented either in the time domain or in the frequency domain. Learning some basic realities of this dual representation will be an important goal of this course. One of the cardinal rules is that events that happen quickly in time contain higher frequency content than events which occur more slowly. Sounds converted to and from electrical audio signals provide an excellent way to investigate these relationships.

The human ear can hear sounds of frequencies in the range 20 Hz to 20 kHz. However, most sounds we work with only contain frequency content in the range of about 100 Hz to 8 kHz. Lower frequency sounds, such as a tug boat whistle, have more frequency content in the low part of the audio range. Higher frequency sounds, such as bird song or dog whistles, have more content in the upper part of the range.

Plotting the signal waveform versus time is familiar from our classwork. When we plot an audio signal versus time, we become aware of events happening on different time scales. For example, we might see the amplitude of the signal go up or down on the scale of tenths of a second. This time scale determines mostly amplitude effects. The signal also oscillates on the scale of tenths of a millisecond. This time scale determines the frequency or pitch of the sounds.

We can also think of the signal as being composed of a number of sinusoids, each having a distinct frequency, amplitude, and phase (similar to a Fourier Series). The tug boat whistle can be thought of as containing sinusoids at lower frequencies, while the bird song contains sinusoids with higher frequencies. (Be sure you can differentiate between amplitude and frequency in terms of sounds.) The frequencies present and their relative amplitude and phase comprise the spectral content of the signal. The signal spectrum is simply a plot of this spectral content vs frequency, or how signal energy is distributed in frequency, just as the waveform plot displays how signal energy is distributed in time. However, this display is averaged over a period of tens or hundreds of milliseconds, thus losing information on the scale of seconds.

There are a number of tools available for examining the spectral content of the signal. The spectrum analyzer is able to display the spectral content of the signal in pseudo-real time, in the same manner as an oscilloscope (the refresh rate determines how close to real-time the display is). We can also investigate the spectral content of the signal by examining its digitized content with a digital signal processing (DSP) application called the Fast Fourier Transform, or FFT. This creates a view of the spectral content of the signal based on the entire signal sample. In this way, the FFT cannot display the spectral content in real time, but rather displays only the spectral content averaged over the entire duration of the signal sample.

Yet another DSP application is available which displays how the frequency content of the signal varies with time (sorta). This is called a spectrogram, or time-frequency plot. This combines the time and frequency dependent behavior of the signal by calculating a “Short-Time Fourier Transform” over a small time window of the signal. The center of the window (in time) is then shifted forward in time, and a new STFT is calculated. These STFTs are displayed as a function of window center time, resulting in a display of how signal spectrum evolves with time. This tool allows the evolution of the spectral content over longer time scales to be examined.

Pre-Lab

Investigate audio signal processing with MATLAB:

1. Create a directory on your laptop called “Matlab sounds”. Copy all of the files from the ece 300 audio lab directory into this directory. Store all of your MATLAB programs and data files in this directory.
2. Create a MATLAB program (not a function) which will allow you to display the time waveform of an audio signal as a plot. The sound waveform samples are stored in “.mat” files, which are MATLAB format data files. In each file is stored an array “y” of signal samples and a sampling rate “Fs” (case is important). (The sample rate is equal to the reciprocal of the time between samples Ts. From the sampling rate, you will need to construct a time vector.) You can see what variables are present in a .mat file by typing “`open filename.mat`” at the MATLAB command prompt. To actually load the data into the MATLAB workspace, type “`load filename.mat`”. Test your program on the sample audio files. Plot and compare the time waveforms of the train whistle file to that of the chirp, noting on the plot both short- and long-term structure in the waveform versus time and important timescales. Your figures should look like those in Figure 1.
3. Add a line to your MATLAB main program which will play the sounds using the “`soundsc`” command. (Type “`help soundsc`” at the MATLAB prompt for details.)

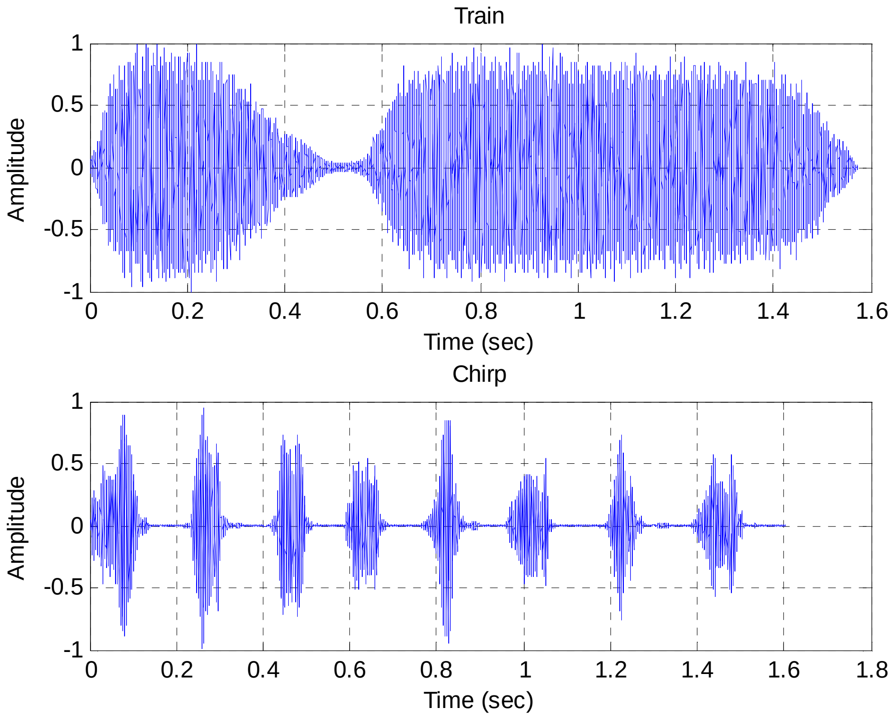

Figure 1: Train and chirp signals.

Procedure

Examining Sinusoidal Signals

1. Use the MATLAB program you created in the prelab to create and display the time waveform $x(t) = 0.1\cos(2\pi 3000t) + 0.1\cos(2\pi 7000t)$ over a duration corresponding to a few periods of the lower frequency waveform. The *sample rate* F_s, which is 1/(time increment), should be 20*8192 Hz. *Print out the plot.*

2. Next, use the provided MATLAB function *baf_fft.m* to view the spectrum of the signal. For this to work properly, you will need to use more periods of the waveform, say at least 64 periods. This FFT function will display the spectral components of the waveform. *Print out the plot.* How many spectral components are there?

Examine the Audio Signal Waveforms

3. Connect the headphone output from your laptop to the input of the oscilloscope using the provided adaptor. Play the chirp and train audio samples using your Matlab script and the `sound` or `soundsc` command, and view the waveforms on the oscilloscope. Displaying the waveform correctly requires you to think about the time scales of the events in the time signal (*autoscale* will not give the results you expect!).

4. Capture the time waveform for the train whistle and chirp samples on the scope over appropriate time intervals (think about this). It will be easiest to do this by loading the sample into the workspace and typing “`sound(y,Fs)`” at the command prompt without hitting return. When you are ready to capture the sample, press return in the Matlab

command window while simultaneously pressing the "Single" button on the scope. (This will take some practice!) *Print out the time waveforms and attach them to the worksheet at the end of this lab*.

Examine the Audio Signal Spectrum

5. Using the function baf_fft.m, plot the fft (time-averaged) spectrum of the audio signal samples (chirp and train whistle). Relate important features in the spectrum to the time waveforms and sound of the signals.
6. Now obtain a spectrum plot from the spectrum analyzer. You will need to think a bit about how to do this. Note that the spectrum analyzer uses a much shorter time average in its display, and thus shows a more real-time version of the signal spectrum.

Examine the Time-Frequency Characteristics of Audio Signals

Create a new MATLAB program (based on your program from above) which will display the time-frequency plot for the various audio samples using the `specgram` command. Note that a slice of the 3D spectrogram plot at a particular time index gives the spectrum at that given time, i.e. a view similar to a spectrum analyzer display at that time. In this way, the evolution of the spectrum in time is displayed in the spectrogram. (Read this paragraph again until you understand it!) For reasonably good spectrogram plots I would use the command (**specgram(y,[],Fs)**), but that's just me.

7. Start with the signal, x(t), from part 1 (covering, say, 1028 periods).Using the **subplot** command, create plots of both the signal versus time and the time-frequency content of the x(t) signal from above. You do not have to print this plot, but do describe what this is showing you on the lab worksheet.
8. Now use the **subplot** command again to plot the signal versus time and the time-frequency content of chirp signal, the train whistle, and any other two sound files. Print out these figures and attach them to the worksheet at the end of this lab. An example of your expected result is shown in Figure 2, which shows the time domain signal and the time-frequency plot for the chirp signal.

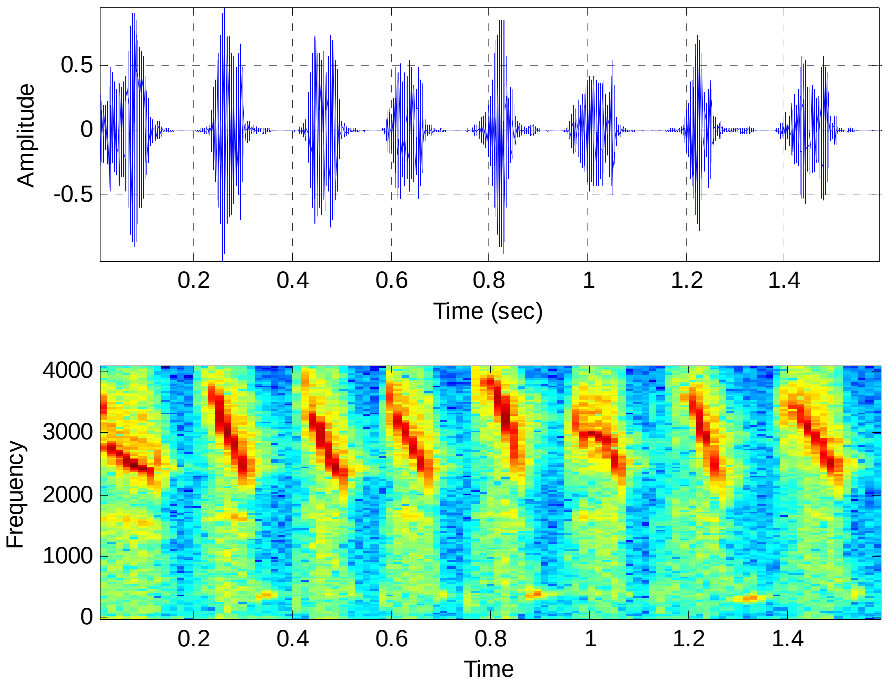

Figure 2: Amplitude as a function of time and time-frequency plots for the chirp signal.

Lab 08
Instructor Verification Sheet

Names____________________________Date:___________

You should have attached to this the following plots/screen captures:

- *The time domain signal and the FFT of the signal x(t) (part 1)*
- *Two spectrum plots using the FFT algorithm (chirp and train whistle)*
- *Two time-domain screen captures from the oscilloscope (chirp and train whistle)*
- *Two spectrum plots from the spectrum analyzer (chirp and train whistle)*
- *Four amplitude as a function of time and time-frequency plots (chirp and train whistle and at least two others)*

1. Describe and explain any significant differences between the spectral plots obtained using the FFT of the whole signal in Matlab (part 5) and the Spectrum Analyzer (part 6)?

2. Describe what the spectrogram is telling you about the signal x(t).

3. Comment on the difference between the short- and long-term time variations in the chirp and train signals, and what those variations correspond to in the signal sounds and time frequency plots.

4. Explain the difference between the information presented in the FFT and the spectrogram plots.

5. Explain the difference between the information presented in the spectrum analyzer and the spectrogram plots.