EE 218 LINEAR SYSTEMS II LABORATORY
Missouri University of Science & Technology

LAB 1: SIGNAL, SPECTRUM AND AUDITORY PERCEPTION

Aim: In this lab you will examine a few simple audio frequency signals using your ear, an oscilloscope, a spectrum analyzer, and a PC. The primary aim of this laboratory experiment is to learn to use your ear, oscilloscope, spectrum analyzer and a PC to analyze and understand different type of simple signals including sinusoids, square wave, and triangle wave and chirp signal.

Required Background:

- Signals: Sinusoid, triangle, square wave, periodic signal, and energy signals.
- Spectrum of signals: Fourier series (FS), Fourier transform (FT), discrete-time Fourier transform (DTFT), discrete Fourier transform (DFT/FFT).
- Thevenin and Norton equivalent circuits. Load and source relationship for maximum power transfer.
- Sampling of signals (i.e. continuous-time to discrete-time signals). Nyquist sampling rate and aliasing.

Introduction: One of the most basic signals in linear system analysis is the sinusoid. You have probably generated this signal previously in labs using signal generators. Like all things in the real-world, signal generators do not produce ideal sine waves. These real-world imperfections can cause serious problems with real-world systems. For example, communication systems use a lot of sine wave generators. A non-ideal sine wave may make it impossible to properly communicate, or may cause one transmitter to interfere with others. A navigation system like the Global Positioning System (GPS) relies on extremely precise clocks and nearly perfect waveform generators. The sine wave generators on-board a set of orbiting satellites must maintain synchronization to within 1 nanosecond or better for the system to work properly. It's a good idea to get in the practice of estimating the accuracy of your measurements and the accuracy of the equipment you are using. You will also measure the output impedance of the signal source.

The next set of tasks will allow you to estimate your current range of hearing. While your ears can be damaged by accident, disease and age, the most common form of hear loss among college age students is due to intentional abuse (listening to loud noises and music). This lab will give you some idea if you have suffered much damage yet, although you would have to have a high quality audio test performed by a trained specialist to determine the extent of the damage. By the way, most hearing loss of this type is permanent.

The last set of tasks involves measuring the amplitude spectrum using a spectrum analyzer and a PC running Matlab.

Procedure:

1. Select a signal generator in the lab, and set the controls so it produces a sine wave at 1 kHz and amplitude of 1 Volt (peak). Connect the signal generator to an oscilloscope and verify the amplitude and frequency is correct.

2. The last task seemed pretty simple, but how well did you do it? For example, did you just write down a number for your measurements (like 1 kHz), or did you give some measure of the accuracy, or confidence, you have in your measurement? Whenever possible, measurements should have a description of accuracy associated with them. There are at least three ways to measure accuracy:

- Significant Digits. You should have learned about these in High School. Use them whenever possible. Return to problem 1, and determine if your answer (assuming it was 1 kHz) should be written as 1 kHz, 1.0 kHz, 1.00 kHz, etc. Carefully justify your reason for choosing the number of significant digits you use.

- Absolute Precision. What is the smallest frequency increment you can reliably measure in the previous experiment? Can you see an error of 1 mHz, 1 Hz, 10 Hz ? Repeat the first problem, but write down your answer in a form like 1 kHz +/-10 Hz. Again, you must carefully justify your reason for stating the accuracy you selected.

- Relative Precision. What is the ratio of frequency error you can detect? This is like the absolute precision measurement, but now you are going to state the error in a percentage like 1 kHz +/-1%. If you are using highly accurate instruments, you may wish to use the units of ”Parts Per Million” or PPM rather than percent. Once again, carefully justify your answer.

3. What range of frequencies can you generate with the signal source? What range of frequencies can you measure with the oscilloscope? Which, if any, of the three accuracy measurements stays reasonably constant over the range of frequencies the signal source generates?

4. Repeat tasks 2 and 3, but look at the amplitude of the sinusoid rather than the frequency.

5. In a textbook a sine wave is described by three parameters: Amplitude, Frequency and Phase. What is the phase of the sine wave you generated in task 1?

6. Measuring frequency is essentially equivalent to measuring time. Using currently available technology, how accurately can you measure time? We want to make this measurement in Rolla, MO. Give both the general approach, cost and accuracy of a variety of techniques.

7. Repeat the last problem, looking at the problem of making precise voltage measurements.

8. Function generators are not ideal voltage sources. Model the signal source as a Thevinin equivalent circuit. Perform whatever experiments you feel appropriate to measure the Thevinin equivalent impedance. Determine the load impedance that provides maximum power transfer, and find the maximum power the signal generator can supply.

9. Connect the signal to a high quality speaker (such as the large, black, speakers in the lab with the JBL logo on the front). Leave the scope hooked up to the signal generator output also. Did you notice the voltage drop, and drop significantly, when you connected the speaker? Was the voltage drop what you expected? What is the maximum amount of power you can get into this speaker?

10. Now it's time to see how much damage you have done to your hearing by listening to loud music. Infants can typically hear sinusoids that range in frequency from 20 Hz to 20 kHz. Things go downhill as you age (trust me). The fine hairs in your ears that sense sound become brittle and break off. Usually the smallest hairs break first, making you lose your ability to hear high frequency sounds. You can speed this process up, significantly, by listening to loud noises like gunfire, jet aircraft, and music. Determine the highest and lowest frequency audio signal you can hear. Sometimes it is hard to tell if you can really hear a signal or are just imagining it. Have someone else turn the signal on/off many times while you are looking away. Have them randomly stop the switching, and see if you can reliably tell if the signal is on or off. Do this for each person in the group.

11. Repeat the experiment above, but using square waves and triangle waves. Compare the sound of sine waves to square waves. Do they sound the same or different? Does your answer depend on the frequency of the signal? Can you hear the same range of frequencies for square and sine waves?

12. The spectrum analyzers you will find in the lab will show you the amplitude spectrum of the signal. Connect a spectrum analyzer in parallel to the oscilloscope and switch the signal generator back to a sine wave. Measure the amplitude and frequency of the sinusoid using the spectrum analyzer. Since spectrum analyzers usually display amplitude in dB, you may have to do a few calculations to relate the display on the spectrum analyzer to the oscilloscope display. It is important that you be able to predict the amplitude shown on the scope from the spectrum analyzer display, and vice-versa. How accurate is the frequency and amplitude measurements on the spectrum analyzer? How does this compare to the oscilloscope measurements?

13. Recall that a periodic signal may have power at the fundamental frequency, and integer multiples of the fundamental frequency (the harmonics). Using the spectrum analyzer, find out if the function generator is producing any power at any of the low order harmonics (2nd through 11th). Ideally there should be no power at these frequencies. If you find power there, specify how much you found by stating how many dB lower the harmonics are than the fundamental. This type of distortion is called harmonic distortion. Notice that the spectrum analyzer can allow you to accurately see and measure this distortion, while the oscilloscope

fundamental. This type of distortion is called harmonic distortion. Notice that the spectrum analyzer can allow you to accurately see and measure this distortion, while the oscilloscope was not much help at all.

14. Next we are going to look at the sinusoids that make up a triangle wave. Find/calculate the amplitude and phases of the first 11 harmonics of a triangle wave. To confirm you have approximately the correct answer, write a Matlab script that will generate 11 sinusoids with the amplitudes and frequencies you found above. Add the entire signal together and see if the result looks approximately like a triangle wave.

15. Generate a triangle wave with the signal generator. Observe this signal on the scope and spectrum analyzer. Use the spectrum analyzer to measure the amplitude of the first 11 harmonics. How closely do they match your calculations from the previous question?

16. You should have noticed that it is impossible to hear a 1 Hz sinusoid, but you can hear a 1 Hz square wave. Can you explain this difference using Fourier Series/Transforms?

17. You can do a lot of signal processing by digitizing a signal and storing it on a PC. Connect the output of the signal generator to the line in port of the PC's sound card. Generate a sine wave and capture a few cycles of it using a utility like sound recorder, and store it in a .wav file. Read the .wav file into Matlab and display the signal on the screen. Can you accurately measure the amplitude and frequency of the signal in this way?

18. Look at the amplitude spectrum of the signal by running an FFT of the signal in Matlab, and displaying the result. The display should be in dB, so it matches the spectrum analyzer display. Can you measure harmonic distortion in Matlab like you did on the spectrum analyzer? If so, do the measurements agree?

19. What is the maximum range of frequencies you digitize using the sound card in the PC? What's the maximum range of amplitudes?

20. Can you find the scaling factor between the input to the PC sound card and your Matlab display -so you can accurately measure the amplitude of the signal using Matlab?

For Your Writeup:

- Make sure you answer every question asked in the lab! There are quite a few questions in this lab so it is easy to miss some. When you answer the question, make sure you include data/calculations to support your answer.

- Part 8: In this part of the lab you determined the Thevenin equivalent resistance of the signal source and found the load that maximized the power delivered to the load. With a 1kHz 1V (peak) sinusoid input, plot the power delivered to the load vs. load resistance to show that maximum power occurs where you said it does. You don't have to measure these values in lab, you can just use basic circuit theory to calculate resistance to show that maximum power occurs where you said it does. You don't have to measure these values in lab, you can just use basic circuit theory to calculate power across the load for each value of load resistance.

- Part 9: Make sure you note the voltage drop when you attach the speaker. This change in voltage will allow you to calculate the speaker resistance which is necessary to calculate the maximum power you can get into the speaker.

- Part 10: Make sure you include the hearing frequency ranges for EACH member of your group.

- Part 11: Make sure you clearly indicate the NEW hearing frequency ranges for each group member.

- Part 12: The equation you find that relates the amplitude in dB on the spectrum analyzer to the oscilloscope display is very important. We will use this equation in almost every lab so don't forget it!

- Part 15: Use a percent difference calculation to compare the theoretical harmonics to the measured harmonics.

- Part 18: Taking the FFT of a signal and looking at its amplitude spectrum is another calculation we'll be performing often in this lab. Make sure you understand how the FFT is working and how to plot the amplitude spectrum vs. frequency correctly.