INTRODUCTION TO SOUND

The objectives of this experiment are:

- To study some basic features of simple and complex sounds and to investigate the relationships among the frequencies of notes on the chromatic scale.
- To learn how to use Mouse Keyboard and FFTSCOPE software programs.

APPARATUS: Computer, microphone, and speakers.

INTRODUCTION

In this experiment you will learn how to use the computer to produce, collect and analyze sound wave data. We will use one program (Mouse Keyboard) to produce sounds from the speakers attached to the computer and then we will use another program (FFTSCOPE) to analyze the sounds being picked up by the microphone. A microphone is a transducer; that is, it converts energy from one form to another. In this case the energy of the sound wave is converted into electrical energy, i.e. a voltage, by the microphone. (Note that a speaker works in the opposite sense: converting electrical energy into sound.) The voltage from the microphone, in turn, is sampled by FFTSCOPE, which can display the data as a graph in different ways.

An oscilloscope is a very useful device in physics that allows one to see how an input voltage varies with time. In today's lab you will use a computer program that does this. The same program can also be used to analyze the time variation of voltage, by doing what's called a Fast Fourier Transform (FFT) on the input signal. Later in the course we will study Fourier Transforms, but for now all you need to know is that an FFT tells you the amount of power in the input sound wave as a function of frequency. If you have a pure sine wave input to the FFT it will produce a spike in the FFT plot – this is telling you that all of the power in the input signal occurs as one single frequency. The FFT is extremely useful for analyzing sounds.

There are many possible musical scales. Different scales and tunings are sometimes called "temperaments". Modern Western music typically employs a system called "equal temperament" which is based on a 12-note *chromatic* scale. There is also the *diatonic* scale (seven primary notes) with which even non-musicians are familiar as "do-re-me-fa-so-la-ti-do." This scale can be played with the white keys on a piano keyboard, starting with *C*. As you go through a diatonic scale it is eight steps from *do* back to *do* again. For this reason, this range of notes is called an *octave*. The black keys on the piano form yet another scale called *pentatonic*. Together the *diatonic* and *pentatonic* scales make up the *chromatic* scale.

Musical scales are tied closely to mathematics. You will use a computer-interfaced microphone to record the waveform of the sound that is produced and use an FFT to determine the fundamental frequency of the sound. Your challenge is to measure the frequencies of all the notes of a chromatic scale and then to determine the mathematical patterns which exist between them.

PROCEDURE AND TECHNIQUES

Be sure there are not two FFTSCOPE windows open at the same time – bad things can happen to data.

1. Plug the microphone into the lower Labtec speaker input, if it isn't already plugged in.

2. Turn speakers on. Open the Lab Softwares folder on Desktop. Open FFTSCOPE and

Mouse Keyboard (MK). MK should be set to program 80, Chords = None, Pitch and Modulation wheels = 0. MK has a volume control; the speaker volume control will affect both the FFT Function generator and the MK amplitudes together. Point and click a MK key; use left Ctrl to lock tone. Click again to unlock. If it does not lock, run program up, then reset to 80. If there is no Mouse Keyboard sound, check that "MIDI Out" is not set to None. Mouse Keyboard is pictured below, with C4 locked.

EXPERIMENTS

(1) Pure tone: Produce middle C (C4, frequency approximately 261.63 Hz.) with MK. This is the key with the faint green dot. It is incorrectly identified as C3 by the MK software for some reason. Lock the note. Hold the microphone close to the speaker. Set FFTSCOPE in Oscilloscope mode (FFT/OSC button toggles between FFT and OSC modes) and select 0.1 or 0.2 seconds for Time (this sets the sampling rate – larger values mean longer integration times and higher frequency resolution in FFT mode). Be sure Silent is selected under Function Generator. When you press GO/STOP a plot of voltage vs. time should appear. This is the same information provided by an actual oscilloscope. Increase speaker volume to get as clean a sin curve as possible, but avoid clipping (flat-topped sines). Acquire data for a number of samples. Expand the horizontal scale of the graph appropriately using the mouse (click and drag). To reset the scale to default, choose "Reset x and autorange y" under the "View" pull-down menu. Find the time difference for a number of cycles (10 or so), calculate the period T and then the frequency f.

Switch FFTSCOPE to FFT mode by pressing the FFT/OSC button. Select the "View" pull-down menu and choose "Toggle FFT Averaging on/off" (or just press the green button with the red arrow pointing downward). Signal/noise improves as the square root of observation time: the random noise involves some cancellation so it accumulates only as the square root. Stop data acquisition before, or soon after, signal stops since the noise will not stop when signal does, and the signal/noise advantage of averaging can be diluted. The point here is that the peaks in the FFT mode spectrum will become cleaner (i.e. less noisy) if you allow this averaging to occur. You just want to see the spikes in the spectrum more distinctly. Expand the horizontal scale and read the frequency corresponding to the peak power of the note. To improve accuracy, try increasing the sampling rate (i.e., set Time to a value between 1 and 10 s).

Record your data in the table in the Lab Report Form. The entry labeled "% Difference" is defined as **(experimental value – theoretical value) / theoretical value × 100**
The "Estimated Uncertainty on Freq. from FFT" is asking for you to comment on how far off your frequency measurement with FFTSCOPE might be on the basis of the smallest unit of frequency in Hz that the software allows you to measure. As you move the cursor along the screen you can see the value of frequency at the bottom of the window change. If, for instance, the smallest change in frequency you could detect was 1 Hz then a measurement of 550 Hz would be 550 give or take 0.5 Hz (because we know it is between 549.5 and 550.5 Hz). Of course 1 Hz is the wrong answer, so you must decide for yourself what the tolerance of the software is.

(2) Voice Analysis: Hold the microphone away from the speaker and speak, sing or whistle into it (don't blow at it). Observe the Oscilloscope time patterns and the FFT frequency patterns for vowels and consonants. Can you make nice sine waves (approximately pure tones)? If so, for what types of sounds? Compare the FFT frequency patterns for a spoken vowel and consonant. Which of these sounds has more overtones (i.e., a larger number of peaks in the power spectrum)?

(3) Chromatic Scale: For each of the notes listed in the table on page 7, find and record its frequency from either the Oscilloscope time plot or the FFT frequency plot as done above for the pure tone. Notes 1 – 12 are the notes of one octave. Notes 13, 17, 20, and 25 are in higher octaves. Use the piano keyboard diagram as a reference point to locate the different notes. The musical notes are also listed in the table, with a subscript number indicating what octave they are in, such as C_4 (recall that MK erroneously shifts these octaves down, so that MK reads C3 when it is playing C4, etc).

Note: The same black key note may sometimes be written as a sharp, or as the flat of the next higher white key. The choice depends on the ascending or descending context in the musical composition. This is actually an oversimplification, because a note may be written as a sharp or flat in certain keys irrespective of ascending or descending context. In addition, in certain temperaments (systems of musical tuning), the sharps and flats are actually distinct in pitch. This is the case for instance, in the Pythagorean and Just intonation temperaments (though not in our familiar system of equal temperament).

1. Calculate the difference in frequency between each note (except the first and the last three) to the previous one. Record your result in the column labeled Delta f (Hz) in the data table.
2. Calculate the ratio of each frequency (except the first and the last three) to the previous one. Record your result in the data table.
3. Fill in the unshaded cells of the last column by calculating the ratio of the frequency of the note to the frequency of the C_4 note.
4. Study your data on the white keys (the diatonic scale). These notes are listed in bold in the data table. Try to identify a pattern to these frequencies and ratios. Can the ratios in the last column be converted into ratios of small whole numbers? What would those whole-number ratios be (Example: ratio = 1.33; small whole number ratio = 4:3)? Actually, it is only in the Just intonation temperament that the interval ratios between notes in the diatonic scale are exact ratios of small integers (3:2 is a fifth, 4:3 is a fourth, 5:4 is a major third, 6:5 is a minor third). For the equal tempered intervals of MK, these will be off a bit. In your Lab Report Form you should state what the approximate ratios are, as though you were dealing with a piano tuned to Just intonation rather than equal tempered intervals.
5. Considering all the notes, what patterns exists between successive notes? Explain, citing specific evidence from your lab work. Bear in mind that the octave is broken up into 12 parts in the equal tempered scale. Since each tone is related to each other as a ratio, with the octave being twice the frequency of the tonic, the equality of ratios of adjacent tones in this chromatic scale is the twelfth root of 2. So A5 is twice the frequency of A4 (880:440 = 2), and B-flat must be 440 + twelfth root of 2 Hz, etc.

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LAB REPORT FORM

NAME: ______________________________________ DATE: _____________

PARTNER(S): ____

FREQUENCY AND PERIOD

(1) Pure tone:

Record your values and do not forget the units!

Frequency of middle C (C_4)	
Number of Waves Counted:	
Time Duration for these Waves:	
Period of One Wave:	
Calculated Frequency:	
% Difference:	
Frequency from FFT:	
Estimated Uncertainty on Freq. from FFT:	
% Difference:	

(2) Voice analysis:

Were you able to make an approximately pure sin curve? _______If so, how? _________

____

Describe your spoken vowel and its FFT frequency spectrum: _______________________

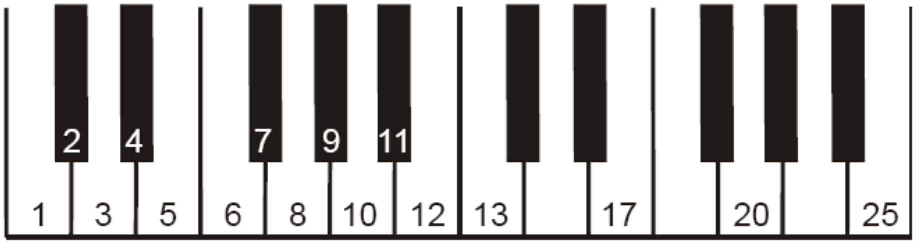
____

Describe consonant: ____

____

Which has more overtones? ____

(3) Chromatic Scale:



The figure above has “25” on B6 rather than C6. It should be on C6, one key to the right.

Key #	*Note*	*Frequency (Hz)*	*Delta f (Hz)*	*Ratio to previous note*	*Ratio to C4*
1	*C4*				*1.0*
2	*C4#*				
3	*D4*				
4	*E4*b				
5	*E4*				
6	*F4*				
7	*F4#*				
8	*G4*				
9	*A4*b				
10	*A4*				
11	*B4*b				
12	*B4*				
13	*C5*				
17	*E5*				
20	*G5*				
25	*C6*				

= sharp b = flat

Describe any patterns: