SCI220 – Foundations of Musical Acoustics
Cogswell Polytechnical College
Fall 2008

Week 1 – Class Notes

Harmonic Motion: Simple and composite (FMA)

Chapter 3: Simple Relations of Sound and Motions

3.1 Mechanical Motion of Sound Source and Eardrum

As seen previously an object struck and set in motion will vibrate. Remember that a *vibration* is a rapid back-and-forth movement of an object.

The vibrations produced by an impulse can be transferred from one object to another that is not in direct contact with it. In a similar manner, our eardrums move when an impulsive sound reaches them.

3.4 Oscilloscope Display of a Particular Clang

We can make the following observations from examining an impulsive sound generated from a skillet clang:

a) A disturbance of impulse character generates an irregular back-and-forth motion (as shown by the signal captured by a microphone and thus our eardrums).

b) In this particular case, the complex motion lasts 250ms. The motion is originally violent and has a rapid decay pattern. The decay occurs in such a way that the motion falls by equal fractions in equal intervals of time.

c) The behavior of the vibrational mode involves reversals that take place every 1000-2000 per second.

d) The finest details in the motion take place in such a way as to imply alterations in the motion that take place at a rate in the range of 3000-5000 per second.

Chapter 4: Characteristic Frequencies and the Decay of Composite Sounds

4.2 Repetitive Properties of an Impulsive Motion

An impulsive sound is repetitive in its own right. For example, the repetitive motion created by the rocking of the water surface in a filled glass that has been bumped. The surface tilts back and forth in a smoothly oscillating motion that dies away in the course of time. The repetition rate of this motion is constant.

We can say that the repetitive nature of an impulse sound is thus its vibration.

4.4 Experimental Search for Vibrations Having Several Repetition Rates

If a tuning fork is struck somewhere in between the base and the middle of the fork we can hear a single sound of well-defined pitch (say A440). Now, if we strike the fork near the tip of a tine we hear two distinct pitches. One is our original sound, A440, while the second is heard at a higher pitch.

When the forks signal in the first case is analyzed, we can observe that the first pitch has a smooth, sinuous line, with an exact and well-defined repetition rate. We observe a *sinusoid.* The analysis of the second case shows a different pattern. We can observe a repetitive motion at 440 times per second. However, we can also notice a wavy pattern to it that matches a repetition rate of 2660/second that corresponds to the higher pitch heard. It can be concluded that the microphone is responding to disturbances produced by two different repetition rates.

4.5 Patterns Made by Adding Two Different Repeating Motions

Graphically, we can add the graph of one disturbance to the graph of another in order to show the composite motion taking place simultaneously. In the tuning fork case two sinusoids with a repetition rate of 440/sec and 3000/sec are added to produce the complex waveform.

4.7 The Characteristic Oscillation of a Struck Object

The sounds produced by either striking or plucking an object can be analyzed to show that the signal is composed by a collection of sinusoidal oscillations. Each object has its own characteristic collection of these oscillations, each with its own frequency. Regardless of the source all patterns will have the exact shape when looked upon at the waveform level. In addition, these oscillations will decay in a similar manner.

The decay pattern we are referring is said to have a *having time* since the amplitude of a signal decreases by half at equal amounts of time. For example, if the magnitude of an oscillation is reduced by half after 1/10 seconds; we will find that this new magnitude will be reduced again by half after another 1/10 seconds. The amplitude is reduced in similar fashion until it completely, or almost, reaches zero.

We observe the following amplitude curve in time intervals of 1/10 seconds:
1, ½ , ¼, 1/8,…, $1/n^2$.

4.8 The Formal Description of a Decaying Sound

Damped sinusoidal oscillation: oscillation of sinusoid nature that dies away (decays) eventually. We can specify this motion by its, 1) frequency of oscillation, 2) initial amplitude, and 3) halving time ($T_{1/2}$).

Source of Sound (MA)

Classifying Sound Sources

Transient sounds: sounds that are temporary and quickly die away. They occur when sources are set in vibration at one moment but left alone thereafter.

Steady sounds: sounds that continue at the same level as long as we choose to sustain them.

Percussion Instruments (Idiophones)

Sound is produced by striking a hard object against another, bars or membranes. While they are in contact at the point of impact, each object is exerting a strong force upon the other and causing some distortion, such as a dent. If the object is highly elastic, the dent is only temporal and the distorted part will return to its original form once the force is removed. Simultaneously, in order to relieve some stress, part of the deformation has been transmitted to the adjoining material in the same way as sound waves pass through air. The deformation spread farther and farther away from the point of impact.

We can describe the following properties of the air vibration near the struck object:

1) The dynamic of the sound depends on the amplitude of the vibrations of the solid object and the surface area that is vibrating.

2) The sound is transient in nature. Vibrational energy is converted into heat by the flexing of the object, by the transmission of energy into the surrounding air, and by the transmission of energy through sound.

3) In many cases, the sound does not produce a clear sensation of pitch. That is it is classified as a indefinite pitch.

4) Regardless of the pitch sensation, there is a perception of pitch height. The frequency is determined by the size of the object and by the speed at which vibrations travel through it. The speed of travel is determined by the stiffness of the material and by its mass or inertia.

String Instruments (Chordophones)

Sound is produced by exciting a string by either striking, plucking or bowing them. The length of the string determines the pitch perceived because of the time required by a transverse wave to go from one end to the other and back.

Once a string is set into vibration, the energy is passed to the surrounding air. As you might notice, this is a very inefficient process since the effective area of the string is very small and cannot push sufficient air. In order to move more air acoustic string instruments use a mechanical resonator. The motion of the strings is transmitted to a box or soundboard on which they are mounted.

Thus, the small motion of the string is amplified by the resonating body due to its large surface area. In exchange of the greater sound enhancement caused by the sound radiation of the resonator, there is a sound energy loss caused by it.

Wind Instruments (Aerophones)

Instruments in which a constant air stream is the mean of supplying the energy need for a steady vibration. A narrow air stream directed against a sharp-edged rigid obstacle at the right speed and angle will flow smoothly past the edge and will flow rhythmically one way and then another. The disturbance creates a sound wave that propagates outward. The resulting *edgetone* has a definite pitch that corresponds to the frequency of oscillation. If there is an adjacent, nearly enclosed air reservoir of proper size and shape, it may respond to the vibrations at one particular frequency. This resonance modifies and reinforces edgetone vibrations, providing a louder and more identifiable sound.

Fingerholes along the side of the tube allow the player to change the effective length of the tube so that it will resonate at a different frequency and thus play different notes. Manners of wind instrument excitation: edgetone, reed (single and double), lip vibration.

Body shape: cylindrical, conical.

Source Size

If we double the length of a tube, sound waves will take twice as long to go down and back, and whatever regular oscillations occur they will have twice the period as before, or half the frequency. The resulting sound will be heard at the octave below the original pitch.

Sound Propagation

Reflection: the throwing back by a body or surface of light, heat, or sound without absorbing it. If the surface is smooth the reflection will be regular and orderly. A rough surface will cause an irregular or diffuse reflection. A reflected wave will be weaker than the original because part of the sound energy is absorbed at the reflecting surface. The amount absorbed depends on the material. Softer surfaces (for example heavy drapery) will absorb more energy than hard and smooth surfaces (such as marble). Repeated reflections account for the reverberation of an enclosed room.

Refraction: situation in which the speed of sound is changed with position causing the sound energy to follow a curved path. Air temperature and wind can cause sound refraction. If the cold air is close to the ground and warmer air is above (air inversion), the wave front will be slowed down because of the colder air and sound energy is steered toward the ground and it will be possible to hear sound louder than usual. The opposite case in which the air is warmest to the ground and air temperature decreases with height, the sound will travel faster near the ground and the wave crests are distorted upward, thus receiving little sound from nearby sources.

With wind a similar phenomenon occurs. Downwind from the source brings the sound higher up towards the listener more quickly and thus hearing louder sounds from far away. In the upwind case the higher parts of the wave are held back and bent upward casing sound from distant sources to be heard very little.

Diffraction: characteristic behavior of all types of waves, in which they tend to spread outward in all directions after passing through an opening, or to fill in the region behind an obstacle rather than leaving a shadow.

How much a wave is diffracted depends on the relation between the wavelength (λ) and the other distances involved. If λ is about the same size as the width D of an opening, or if its larger, the waves spread with comparable strength in all directions. But if λ is much smaller than D there will be little spreading, and that part of the wave going into the "shadow" region (areas lying outside the opening region) is extremely weak.

Sound wavelengths range from 10m for the lowest audible frequencies to 2cm for the highest. As such, we can observe that bass notes travel around objects more effectively than treble notes.

Here are some interesting effects of sound diffraction:
1) Understanding another person talk when not facing them directly.
2) Use of smaller speakers for treble sounds.
3) Bass notes reach both ears almost simultaneously, while higher notes create a "shadow" region in which one ear perceives the sound weaker than the other.

Outdoor music vs. indoor music: Discuss

The Doppler Effect: an increase (or decrease) in the frequency of sound, light, or other waves as the source and observer move toward (or away from) each other. The effect causes the sudden change in pitch noticeable in a passing siren.

We can describe the phenomenon with the following formula:

$$(f_1 - f_0) / f_0 = V/v$$

Where V is the relative speed of the source and observer, v is the speed of the signal. f_0 is the emitted frequency and f_1 is the frequency received. V is considered positive for approach and negative for separation.

Another formula for this effect is the following,
he apparent frequency of the sound wave reaching the observer is

$$f = f0(v + vo)/v.$$

Here v is the speed of sound and vo is the component of the velocity of the observer towards the source. (vo is negative if the observer moves away from the source.)

For a moving source the perceived pitch of a sound wave also changes if the observer is stationary and the source is moving. Then the apparent frequency of the sound wave reaching the observer is

$$f = f0v/(v - vs).$$

Here vs is the component of the velocity of the source towards the observer. (vs is negative if the source moves away from the observer.)

Interference and Beats

Interference: combination of signals of the same frequency from two or more sources, which may cooperate at some points in space (constructive interference), but cancel at others (destructive interference).

When L_1 and L_2 are the distances from the two sources to the observation point, what matters is how many wavelengths occupy the extra distance. Thus, we have to examine the relationship, $n\lambda = L_1 - L_2$

When ever *n* is any whole number the condition for constructive interference is satisfied. However, when *n* is an integer plus a half, th waves will be out of phase and as a result there will be destructive interference.

Beats: slow rise and fall of perceived loudness when signals with slightly different frequencies are combined. As one wave shifts in phase with the other, there will be constructive interference. As the same wave shifts out of phase, destructive interference will occur. The listener will not hear two different sounds, but one sound whose intensity seems to slowly rise and fall. The beat frequency is given by $f_b = f_1 - f_2$.