SCI220 – Foundations of Musical Acoustics
Cogswell Polytechnical College
Fall 2008

Week 3 – Class Notes

Pitch (FMA)

Chapter 5: Pitch – The Simplest Musical Implication of Characteristic Oscillations

The relative initial amplitudes of the various sinusoids making up a complex oscillatory motion are not characteristics of the object. These amplitudes depend on the nature of the striking object and the striking location, as well as the relative position of a microphone to the object. See tuning fork example.

5.1 Perceived Pitch of a Composite Sound I

The pitch name of the struck rectangular bar agrees with the frequency of the lowest characteristic sinusoidal vibration. The shape and the material of the bar do not determine its tone. However, many of the ratios of the characteristic frequencies of one bar are somewhat similar to those of any other bars of different materials.

The lowest characteristic frequency for the bar determines the playing pitch (most excited frequency), while the weaker and higher frequency components only add pungency and brightness to the sound.

The most noticeable difference between two bars of different materials is the halving time of the damped oscillations of each bar. Wooden bars have a shorter halving time than metal bars.

5.2 Perceived Pitch of a Composite Sound II

Measured amplitude relations show that listeners assign pitch in agreement with the lowest frequency audible component in the sound despite the fact that higher frequency components may be perceived as stronger. Pitch assignments are not affected by changing the halving time of a vibrating object. However, a pitch assignment is made in part with the information concerning the relationships between the frequency components and not simply on the basis of the frequencies themselves.

5.3 Perceived Pitch of a Composite Sound III

Accurate tuning of a pitch, for example in bells, does not require exactitude in the adjustment of each of the various characteristic frequencies. The amplitudes of the various components in the sound may vary drastically with only small alterations in the perceived pitch. Pitch assignments made by our ears are quite insensitive to the relative amplitudes of the various components.

5.4 Frequency Components of the Sounds from a Plucked or Struck String

The characteristic frequencies of the string of a guitar are found to be very nearly whole-number multiples of the lowest frequencies that is characteristic of the string. Commonly, there are very small departures from the integer ratio.

The frequency ratios measured from the strings of a piano show that they are extremely close to being integers through the middle part of the keyboard. The discrepancies observed found in the extreme registers of the piano are found to be large.

5.5 Sounds Having Whole-Number Frequency Ratios

This relationship can be expressed in the following manner:

$$f_n = nf_1$$

where n is a positive integer and f_1 is the fundamental frequency.

The repetition rate for any idealize string's sinusoidal oscillations is a whole number times the repetition rate associated with its lowest frequency of oscillation. It must be noted that the repetition rate of a composite curve is exactly the same as its fundamental frequency component. Phase shifting in one of the higher frequencies may change the overall shape of the waveform, however the repetition rate is still that of the lowest frequency of oscillations

We can make the following assertions:

1) The repetition rate of the whole signal is exactly the same as that of the lowest sinusoidal frequency regardless of the strength of excitation of the various oscillations.
2) The net repetition rate of vibration is independent of where a string is struck. The perceived pitch is always the same, meaning the perception of pitch is unambiguous.

How can sounds with whole-number frequency ratios be produced?

1) For strings, a truly uniform and tightly stretched material will produce a sound of such characteristics. In reality, a string does not possess such qualities. However, the perception of both sounds will not be that different from one another as long as the frequency relationships are nearly integer ratios.
2) There is a large number of familiar sound sources that produce sounds of such characteristics. For example, the human voice, woodwinds, brasswinds, and strings instruments.

Most of our listening experience have sounds with these qualities or very close to them. We also can notice that the subtleties in music com from the inharmonicities present in the sounds of some instruments.

5.6 The Pitch of Chimes and Bells: Hints of Pattern Recognition

Our ears assign pitch on the basis of any whole-number sequences they can find. In order to perceive a well-defined pitch, say from a bell, our ears do not demand any particular set of component frequencies from it. Approximately harmonic partials serve as pointers as long as there are sufficient number of sonic clues.

5.7 Another Pitch Assignment Phenomenon: Suppression of Upper or Lower Partials

Lopping off the higher frequency components of a sound do not alter the perceived pitch. Altering this same components, by EQ, do not affect the perception of pitch as well, but only the quality of the sound. If we proceed even further with the removal of frequency components and remove all but the highest two in our chosen series will still leave us with a sound that is easily identifiable as our original pitch assignment.

Pitch assignment is based on a few harmonically related partials from an instrument. It can also be stated that pitch assignment of a fundamental frequency is based on the implied whole-number relationships between frequencies of the sound components supplied.

5.8 Pitch Assignments and Frequency Patterns

The nervous system processes incoming complex sounds by seeking out whatever subsets of quasi harmonically related components it can find. Each of these subsets have a “best fitting” collection of true harmonics selected for it in the processor, and pitch is assigned on the base of repetition rate of these fitted components.

The brain operates upon its sensory data in a manner closely analogous to the procedures followed by statisticians when they make estimations according to "the method of maximum likelihood". The better heard components agree among themselves regarding the degree of harmonicity in their relationships, the better and more certain we are in our pitch estimation.

Chapter 14: The Acoustic Phenomena Governing the Musical Relationships of Pitch

14.1 Heterodyne Components

These are harmonically related components created from by sounding together two sinusoidal frequencies. While these are not detected by wave analyzers, they can be found either by using surgical techniques in which the middle and inner ear are probed. In these areas of the ear, evidence of these extra vibration components will be shown. The second way of finding these components is by means of electric probes that will detect impulses sent to the brain by the auditory nerves, proving that the hearing mechanism is creating new components. We can say that both mechanical and neurological processes in our hearing response create these component.

For example, lets say that two sinusoids, P and Q, of determined frequency are played together. Their heterodyne components will be the following:

Original components	Simple Heterodyne components	Next Heterodyne components
P	(2P)	(3P)
	(P + Q), (P – Q)	(2P + Q), (2P – Q)
		(2Q + P), (2Q – P)
Q	(2Q)	(3Q)

The first column presents the original components in the original sound. The second column has the expected double frequency heterodyne components in addition to the components having equal sum and difference. The third column has the triple frequency components as well as the four heterodyne signals that result from a diverse interbreeding of P and Q.

It is possible to continue with these numerical combinations indefinitely, however for musical purposes involving our ears, the second column provides the most common manifestations of the phenomenon, The third column occurs rarely and beyond this column there are negligible auditory effects.

The heterodyne phenomenon has to do with the generation of new partials. Heterodyne frequencies are sometimes referred to as combination tones, summation or difference tones, subjective tones, intermodulation components, and occasionally beat tones. The term tone has been avoided here to name these components due to the fact that tone deals with sounds made up of exactly harmonic partials.

In summary,

1) The ear shares with various other systems the ability to generate within itself new heterodyne components in response to externally supplied signals.
2) Out of the very large class of possible heterodyne frequencies within the ear, those of most musical importance are confined to those of equal sums and differences, as well as doublings of the applied signal frequencies.
3) The amplitudes of the heterodyne components depend on the amplitudes of the original input signals.
4) Heterodyne components with frequencies below 20Hz are inaudible.
5) If two heterodyne components happen to be close together in frequency, they themselves can beat. It is possible for them to beat with a nearby ordinary component that is supplied from outside the ear.

14.3 The Musical Tone: Special Properties of Sounds Having Harmonic Components

The auditory system tends to process tones constructed of harmonic partials as a whole unit. The notes of a musical instrument may have a distinct "color", but the partials of each note do not stand out as individuals. Sources with widely spaced inharmonic frequencies are recognized as two distinct sounds.

14.4 Pitch Matching: The Unison and Other Special Intervals

There is no guarantee that a sequence of mathematically determined reference frequencies would necessarily give our ears a uniformly spaced set of pitch impressions, since equal changes in frequency (physical quantity) do not give equal changes in pitch (perceived attribute).

We can state the following,

1) Pitch matches between alternatively presented sounds do not always agree with matches made when the sounds are presented together.
2) Pitch equality of two sounds heard simultaneously is attained at the same time that their repetition rates are equalized. The zero-beat condition matches the equal-pitch condition, provided we deal with musical tones (sounds with

harmonic partials).

3) If a pair of tones in which only their first few partials have appreciable strength is used, the two methods of pitch matching (alternation, superimposition) give an almost identical results, without much regard for the details of vibration recipes or the sound pressure level. This is particularly true for sounds heard in a room.
4) Most musical tones behavior is described by the previous statements.
5) The presence of heterodyne components for tones having only two or three strong partials apiece intensifies and make more audible the beats produced by a slight departure from equal frequencies.
6) A pair of tones with slightly different fundamental frequencies, each having a large number of strong harmonics, may not be heard as giving very clear beats. The resulting large collections of heterodyne components grouped near each harmonic can become confusing to the ear.
7) Because of the dependence of many heterodyne effects on the amplitudes of the originating components, a given pair of tones may behave either as described in statement 5 or as in statement 6, depending on the loudness with which they are heard.
8) Musical note names and the words describing pitch relationships may have different meanings in different contexts.
9) The performing of musician uses the written notes to get himself close to the required pitches. He then listens and exerts whatever skill he has to set them accurately in their own context.
10) Acoustical cues similar to those which single out the special relationships normally provide the basis for the correction process mentioned in the previous statement.
11) Pitch relationships are the guideposts of music since their exact or approximate presence is generally perceived with extreme speed. They are physical and neurological in nature, and not culturally determined.
12) The previous statement should not be interpreted to mean that a composer or player is wrong if he knowingly chooses to avoid specially related sounds. Such avoidance in itself may gain auditory impact because it contrasts with the various special, neurophysics-based relationships between tones that are exploited in music.