A Guided Tour Through The Harmonic Series and an Introduction to Overtone Chant and Musical Temperaments

I. The Monochord

A. A monochord consists of a single string stretched over a sound box, with the strings held taut by pegs or weights on either end.

B. It was used earlier by others, but most of our current knowledge of the instrument is of its use by Pythagoras as early around the 6th century BC for scientific research on the nature of sound.

C. The instrument is most important in Western music for its scientific research, rather then its musical qualities.

D. Other cultures, however, such as in many parts of Africa, Brazil, and Hawaii (just to name a few) have used it as a musical instrument.

E. Jeff Cottrell cites on the importance of the instrument in early cosmology, numerology, and music theory. “Pythagoras' study of ratios on the monochord led philosophers to believe that these ratios also governed the movement of planets and other cosmic matters (Ptolemy). This provided the bridge between the world of physical experience and numerical relationships, giving birth to mathematical physics. In addition, this elevated music to one of the highest intellectual pursuits. Furthermore, since the "perfection of sounds" could now be revealed by numbers, all simple numeric ratios could be visualized as sounds. Kepler's "harmony of the spheres" is based on this, as well as harmonically resounding architecture. If the visible proportions of a building can be expressed in numeric ratios, then their relationships can be "heard" as chords. Like the "golden section" of architecture, musical harmony "imposes order in the hearts and minds of men by virtue of their simple, natural relationships" (Harnoncourt). This also helped support the baroque

idea that music was a reflection of the divine order (unless you were a minstrel, perhaps)."

II. The Harmonic Series

A. The harmonic series is a series of "harmonics" or "overtones" which sound together at the same time to create the note that is sounding.

B. We will look at the first sixteen harmonics from the harmonic series and examine how these intervals.

C. The Monochord used for demonstration has two bridges 100cm apart, below is a chart with note of harmonic, ratio of the harmonic, where the nodal point is, and what interval the harmonic sounds in relation to the fundamental, which is in the case of my instrument a D

Harmonic	Ratio	Node Point	Interval
1	Fundamental	Open	
2	½	50	Octave
3	1/3	33.33	5th
4	¼	25	octave
5	1/5	20	M3
6	1/6	16.66	5^{th}(2)
7	1/7	14.28	m7th
8	1/8	12.5	Octave

9	1/9	11.11	M2nd
10	1/10	10	M3
11	1/11	9.09	Raised 4th
12	1/12	8.33	5th
13	1/13	7.69	Flat 6th
14	1/14	7.14	m7th
15	1/15	6.66	M7
16	1/16	6.25	Octave

D. The above chart shows the intervals in relation to the fundamental or first harmonic, next we will look at how music scales are derived from the series.

III. Temperament and Tuning

A. Above we looked at the Harmonic Series and the harmonics that it consists of. Below we will be looking at how music temperament and scales relate to this system

B. Music temperament is "the tuning of an instrument, that is determining the exact pitches to be sounded. Since pitch also depends on frequency, differences in tuning are created by differences in frequency."

1. Frequency being a physical quantity equal to the number of events in a given time. In music, this means the rate at which an instrument vibrates, measured in cycles per second or Hz.

2. Pitch is dependant on its frequency, that is the number of vibrations per second of a musical sound.

C. The most prevalent temperaments in Western Music have been the Pythagorean System, Just Intonation, the Mean Tone System, and, since 1880, Equal Temperament.

D. Understanding temperament systems is a very complex undertaking but below we will look at the basics of the different systems and briefly discuss the advantages and disadvantages of the different systems.

E. There are quite a number of ways of looking at how intervals are generated from the harmonic series, which is how just intonation, and to a lesser degree the Pythagorean systems work.

1. Graham Breed explains intervals in terms of "adding intervals", "*Adding intervals means multiplying frequency ratios. So, adding a major and minor third gives 6/5*5/4=3/2, a fifth. A fourth is the difference between a fifth and an octave, so 2/(3/2)=4/3. A tone is the difference between a fourth and fifth. (3/2)/(4/3)=9/8. But, a major third is two tones. 9/8*9/8 is not 5/4. So, there are two different tones in just intonation. 9/8 is a major tone, and a minor tone is 10/9. That comes from (5/4)/(9/8)=(10/9).*" This is for just intonation.

2. Pitch can also be looked at in a mathematical way (which I'm not versed in this method well enough to explain) by which "*Scientists have devised a standard unit for measuring the size of perceived intervals resulting from two frequencies vibrating at a given ratio. This unit is called a* ***cent*** *because it equals 1/100th of a half step. A half step is the smallest interval between two notes on the piano. There are 12 half steps in an octave, and so one octave = 1200 cents. By definition.*

This means that all of our normal intervals on the modern piano are divisible by 100 cents. For example, what musicians call a

half-step (C up to Db) = 100 cents
whole step (C to D) = 200 cents
minor third (C to Eb) = 300 cents
major third (C to E) = 400 cents
perfect fourth (C to F) = 500 cents
augmented fourth (diminished fifth, C to F#) = 600 cents
perfect fifth (C to G) = 700 cents
minor sixth (C to Ab) = 800 cents *etc.*

There is a rather complicated formula for figuring out how many cents large an interval is:

Divide 1200 by the logarithm of 2.
If you use base 10 logarithms (any base is permitted), 1200/log 2 = 3986.3137...
For any ratio n/p,
the number of cents in the interval is

log (n/p) x 1200/log 2

If you're using log 10, then
cents = log (n/p) x 3986.3137...” Kyle Gann

F. The unit of measurement of cents as a means for looking at frequency will come into play later when we compare musical temperaments.

G. One last thing to point out is that, all these ratios can be much easier heard from different sized musical strings, chimes, metal rods, midi synthesizers, etc, but I’m giving you a pretty thorough introduction to this very complicated subject.

IV. The Pythagorean System

A. Pythagoras devised a system of tuning based upon the interval of a fifth, the most consonant interval after unison and the octave.

B. It's generally believed that by constructing a series of both descending and ascending fifths from the same starting point he came across a basic diatonic scale.

C. Basically, Pythagoras took the series of fifths from a starting point 1 / 1, and produced them by successively multiplying by 3 / 2 to give 3 / 2, 9 / 4, 27/ 16.

D. The descending fifths were produced by successive multiplication by 2 / 3 to give 2 / 3, 4 / 9, 16 / 27.

E. The next step was transposing the intervals and subsequent frequencies the range in the range of one octave. The chart below from midicode.com shows the original scale and the transposed scale.

Original fifth	Pitch	Transposed fifth
27 / 8	B	27 / 32
9 / 4	E	9 / 16
3 / 2	A	3 / 4
1 / 1	D	1 / 1
2 / 3	G	2 / 3
4 / 9	C	8 / 9
8 / 27	F	16 / 27

F. The next step is then to arrange these in order by pitch sequence. Peter A. Frazer shows us this chart from his website.

Sorted fifth	Note name
1 / 1	D

8 / 9	C
27 / 32	B
3 / 4	A
2 / 3	G
16 / 27	F
9 / 16	E
1 / 2	D

G. As will be noted later this system was far from perfect. Up until equal temperament western music was more interested with melody and these intervals were fine for that. Harmony wasn't emphasized and this tuning system worked well for the music of the time.

V. Just Intonation

A. Just Intonation is a system of tuning with distances of pitches that are based on the harmonic series.

B. A pretty simple explanation that is quite difficult to completely understand.

C. David B. Doty, in his introduction to the Just Intonation Primer, says, "*Technically, Just Intonation is any system of tuning in which all of the intervals can be represented by whole-number frequency ratios, with a strongly implied preference for the simplest ratios compatible with a given musical purpose*".

D. Earlier we looked at a quote from Graham Breed in relation to adding intervals together to come up with the frequencies. The scale below is pulled from the relationships of harmonics from the harmonic series. David Cartright puts it this way; *"One way to understand Just Intonation is in terms of the harmonic series; every interval used in Just Intonation can be found somewhere in the harmonic series. By definition, the harmonic series is that sequence of frequencies which is all whole-number multiples of any particular fundamental frequency. Thus, since any just interval is expressible as a frequency ratio of two whole numbers, that interval is also the interval between those same two harmonics. For example, the ratio 7/5 is the interval from the fifth harmonic to the seventh. So by becoming familiar with the harmonic series as a musical scale, one also comes to know all the just intervals included. (To put it in strictly numerical terms, a familiarity with the whole numbers also includes a familiarity with the proportions of whole numbers, i.e., the rational numbers.)"*

E. If we look at the harmonic series and the difference in intervals of the series from the chart earlier, and listen to the intervals from the monochord, we can begin to see the practical basis for this.

E. Below is a chart of the pitches:

Note	**Ratio (or harmonics)**	**Interval (from fundamental)**
C	1/1	Root
C#	16/15	m2
D	9/8	M2
D#	6/5	m3
E	5/4	M3
F	4/3	P4

F#	45/32	+4
G	3/2	P5
Ab	8/5	m6
A	5/3	M6
Bb	9/5	m7
B	15/8	M7
C	2/1	Octave

F. The above chart shows the intervals in relation to the fundamental. By careful examination and by listening to different notes you will see that there are many other possibilities for these same intervals in the harmonic series. For instance the major second purely from the harmonic series is slightly different from the 2^{nd} to the 3^{rd} harmonic then from the 2^{nd} to the 1^{st} harmonic. There are a number of other differences as such.

G. What this then gives the musician or composer is a number of different ways to play similar intervals. This is how the Indian and Middle Eastern systems of music have what is referred to in Western Music Theory as ‘microtones’. These musicians (as well as some Western musicians) will pick the size of the intervals based on the type of ‘scale’ they are playing.

H. Next lets look at ‘equal temperament’, and then a way to compare these three systems and see the advantages of one over the other.

VI. Equal Temperament

A. Equal temperament is the system that has been use for the last two hundred years or so.

B. The two tuning systems above are based on the harmonic series to one degree or another and need to be re-calibrated or re-tuned for each key because the relationships of each note to the other is dependant on the beginning pitch.

C. The above systems are best used for melodic or modal type playing (or harmony by a large group or orchestra), whereas as equal temperament will be shown to reduce these problems (or solve).

D. As mentioned earlier the measurement of intervals generally used is called the cent.

E. In equal temperament all ½steps are equidistant. Look at the chart below.

Pitch	**Measurement in Cents**	**Interval**
C	0	Fundamental
C#	100	m2
D	200	M2
D#	300	m3
E	400	M3
F	500	P4
F#	600	A4
G	700	P5
Ab	800	m6
A	900	M6
Bb	1000	m7
B	1100	M7

C	1200	Octave

F. As you can see above all the minor and major seconds are the same distance away from the previous note.

G. Now we will look at a comparison of the three above systems.

VII. A comparison of the different tunings and temperaments.

A. The Pythagorean and Just Intonation systems are derived from the ratios and or mathematical formulas in relation to a fundamental tone.

B. When the diatonic scales are generated for the above systems the intervals are not uniform throughout. In other words, in the key of c, the major third from C to E is slightly different then the major third from F to A.

C. The above truth makes harmonizing on an instrument such as the piano or guitar very difficult.

D. As mentioned earlier harmonizing would mostly be done by different instrument in ‘concert’ with each other or the music would be more melody based.

E. Let’s look at a chart measured in cents of the differences in interval size for the three systems.

C Scale	Interval	Equal Temperament	Pythagorean	Just Intonation
C	Fundamental	0	0	0
C#	m2	100	114	112
D	M2	200	204	204
D#	m3	300	294	316
E	M3	400	408	386
F	P4	500	498	498
F#	A4	600	612	603
G	P5	700	702	702
G#	m6	800	816	814
A	M6	900	906	884
A#	m7	1000	996	1018
B	M7	1100	1110	1088
C	Octave	1200	1200	1200

F. As you can see there is a great discrepancy in the size of a number of the intervals.

Toning and Overtone Chanting

I. Toning

A. There are a number of methods of toning, from chanting spontaneous sounds to creating precise overtones from the harmonic series in overtone chanting.

B. Both methods create similar results, slowing down the breathing, bringing a sense of relaxation, and with concerted effort afterwards, bringing an awareness of the "inner sound".

C. The above explanation alludes to a point that is re-iterated in using sound as a healing modality, that is the intent of the "toner" has a lot to do with the outcome. If you are intending the toning to be relaxing it can be relaxing.

II. Basic Toning Exercise

A. This basic toning exercise can be used by itself or as a prelude to the overtone exercises below.

B. Use the five basic vowel sounds, one at a time and tone on each sound for the duration of a breath.

C. Try taking a few deep breaths and, with intent, look within for a sound that wants to come out. This sound can be a long "musical" tone, or something that doesn't sound musical at all.

1. The goal of this exercise is just to trust yourself and the sound that comes out
2. It is important to try to remain in a non-judgmental state
3. Try this exercise when you are under stress and try toning the stress you are feeling.

D. Combine the above exercises any way you feel necessary.

III. Harmonic Chant

A. Harmonic or overtone chant is the use of the voice, breath, tongue, etc to generate overtones through the voice.

B. There are a number of different systems of Overtone Chant. Some systems very ancient and some much younger.

C. In the West we are most familiar with the styles of the Tuvan's and Tibetan's. These systems have a very ancient heritage.

D. Western forms of Harmonic Chant were developed by musicians and Sound Healers such as David Hykes, Jonathan Goldman, and Don Campbell.

IV. Don Campbell

A. A number of years ago I attended a weekend workshop with Don Campbell and was introduced to his method of toning and overtone chanting.

B. Toning uses tones held for long periods of time on the same note.

C. Don Campbell reports of healing a blood clot in his brain through sound in his introduction to "The Mozart Effect", during his workshop he mentioned having being recognized with another tumor (in his chest, I believe), which led to a great deal of frustration and while sitting in his office one day he started to tone, which

he then did for a complete night, and felt much better, and later there was no trace of the tumor

D. "The Roar of Silence" has exercises for toning.

E. The method for creating overtones that Campbell taught in the workshop was the easiest introduction I've come across. It uses the five vowel sounds AEIOU (all long). The exercise is to take a deep breath and starting on the A sound go through the succession of vowels. The trick is to really over-emphasize the shape of the mouth for each of the vowel sounds, and to go from each vowel sound very slowly, changing the shape of the mouth during this slow process. The overtones can best be heard during the periods in between the shape and sound of the distinct vowel sounds.

V. David Hykes

A. I've attended a number of overtone chanting workshops with David Hykes over the last year and exposed to quite a number of concepts that helped expand my awareness of overtone chanting and harmonic awareness.

B. In respect to David wanting to maintain the integrity of his teaching I will only talk about things I've discovered through his system of chant.

C. Through careful concentration to the mouth and tongue placement, relaxation of the throat, and awareness of the harmonic series, a number of the harmonics can be heard and sounded.

D. David can perform and hear very accurately at least the first sixteen harmonic of the series.

E. David's Harmonic Chant has elements of the Tuvan and Tibetan methods with some "normal Western" vocal stylings.

F. A great example of David's style is on the cd "Hearing Solar Winds".

G. One of David's early students was Jonathan Goldman.

VI. Jonathan Goldman

A. Jonathan has taken his harmonic chant experiences and incorporated them into a Sound Healing modality.

B. He calls his system of Sound Healing "Healing Sounds".

C. He describes it as such: *"HEALING SOUNDS focuses on the ability of harmonics to create vibrational changes. These changes may occur in the physical body, or in the mental, emotional and etheric bodies. When these changes occur, they initiate transformation and healing."*

D. Goldman goes on to say *"Harmonics display universal principles and are a constant in the various traditions and societies that use sound for healing and self-transformation. Through experiencing harmonics, we can learn a great deal about ourselves and the worlds around us."*