The Hermode Tuning system

by Werner Mohrlok

The Hermode Tuning, or “HMT,” is a method of dynamically tuning musical instruments. The algorithms of the program are based on the idea of analysing harmonic structures and retuning the notes in these harmonic structures towards just intonation. However, HMT also keeps the retunings close to equal temperament so that the performance retains compatibility with familiar instruments. Thus HMT is different from other notions of just intonation. It is an elastic system, retuning the frequencies of nearly every new note. But these retuning steps are - by careful design - almost below audibility. The HMT reduces tuning commas to small, nearly inaudible pieces.

HMT was created as a result of my own practice in chamber and orchestral music. I still remember that in chamber music about 30 % of the audition time had to be applied for controlling the tuning in common near to the ideal of just intonation. In orchestras there was less time for such discussions. Nevertheless - as to my experience – many of the instrumentalists in orchestras try to follow the idea of just intonation. An orchestra performing music in equal temperament – if ever possible – would sound weak and rough. Indeed, no orchestra performs a continuous perfect intonation. But everyone who has ears to hear will be aware that the idea of tuning in orchestras is the idea of just intonation.

I created HMT as a tool to help me study instrumental parts at home. In 1980, I dreamed of an electronic organ controlled by a sequencer that could automatically retune my performances into just intonation. A half dozen years later the first electronic musical instruments with sequencer functions cameonto the market, but none were equipped with a program for self-correcting just intonation. Therefore in 1987, I decided to create such a program myself: my goal was a tuning method that could imitate the living intonation of well educated instrumentalists in orchestras and chamber music ensembles. It was helpful that my son Herwig possessed a new computer, an “AMIGA,” and he offered to help with the programming tasks. At first, we followed the idea of positioning the chord's root according to the level of just intonation and adjusting only the other notes. But this simple method has problems, for instance when the harmonies would change from a major chord to its minor or inverse. Such frequency changes are clearly audible!!! I still remember my disappointment. After a sleepless night I decided that a new idea was needed: to adjust the tuning of each chord (or harmonic structure) so that the center was at the same level as the equal tempered original. This was the right solution for the retuning problem, and is the heart of the HMT.

HMT originally is written for electronic musical instruments. It is possible to implement it as an internal program for such instruments. It is even possible to control electronic musical instruments by MIDI with HMT tuning. It is even possible to implement it in sequencers in order to control the plugins. It is possible to control virtual instruments with HMT tuning. Nevertheless it is my dream that one day physical instruments will be controlled by HMT. Maybe we can realise it with pipe organs. We actually discuss this.

The first instrument equipped with HMT has been the “Microwave” synthesiser of Waldorf Instruments. I am no fan of typical synthesiser sounds and for many of such sounds HMT doesn’t bring an audible improvement. But many users have been enthusiastic and they explained me that hard overdriven sounds will be destroyed by equal temperament. With HMT against this major chord would sound like a “hammer”. I believe them. Nevertheless my personal ideal is that HMT should present electronic orchestral sounds more originally and all classic music, even with key instrument simulations, to a better sound.

HMT presents different program variations, so-called “HMT modes”. One of the modes leads to perfect tuned fifths and thirds (as far as possible), one of the modes adds the natural seventh (which ,indeed, cannot be handled without audible tuning breaks), one of the modes controls all fifths and thirds as near as possible to just intonation, but equalises the frequencies to temporary not absolute perfection as soon as retuning conflicts occur. Another HMT mode controls the frequencies of the harmonic structures to different perfection, presenting a kind of “key characteristic” and favouring the chords in the center of the actual key.

“Just intonation” in this context means the following tuning values:

Interval	frequency ratio	Cent distance of interval
pure fifth	2 : 3	702
major third	4 : 5	386

All other tuning values are calculated as derivations of these two intervals.

As already mentioned, one of the modes additionally presents the “natural seventh”.

Interval	frequency ratio	Cent distance of interval
little major seventh	4 : 7	969

This is a very nice frequency ratio for jazz and pop music. Nevertheless it is an unruly interval.

The first patents of HMT have been applied for in 1988.

The functions of HMT.

The default tuning values:

In order to get a tight approach of the new calculated frequencies to the level of equal temperament and in order to keep the frequencies as stable as possible, HMT positions the frequencies of the notes of every analysed chord and interval structure in a way so that the sum of deviation from the line of equal temperament will be near to “0”. The following diagram shows two examples. The numbers mean Cent values in distance from the level of equal temperament.

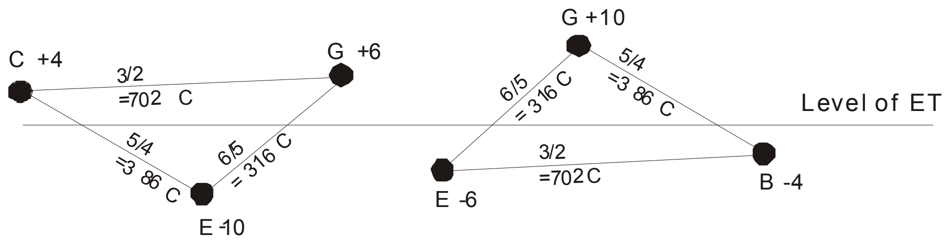


diagram 01

Predefined chord and interval structures.

HMT controls according to analysed interval and chord structures. Therefore the first step was to lay down which interval and chord structures should be tuned to just intonation. There have been the following structures selected:

2 tones: major third
minor third
pure fifth

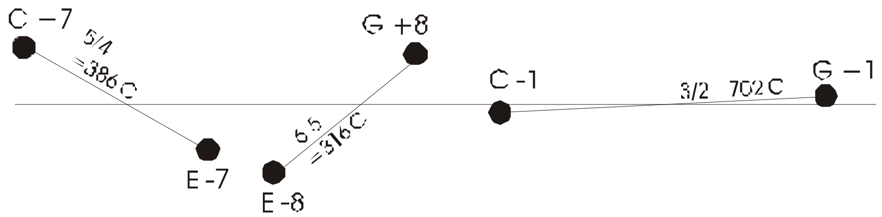


diagram 02

3 tones and more:
The major and minor chords as shown by diagram 01.
All structures which could be understood as a part of a structure shown by the example of diagram 03.

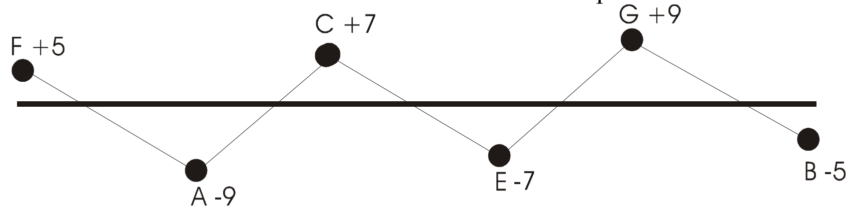


diagram 03

“A part” of this structure means at least 3 tones of it, likewise:

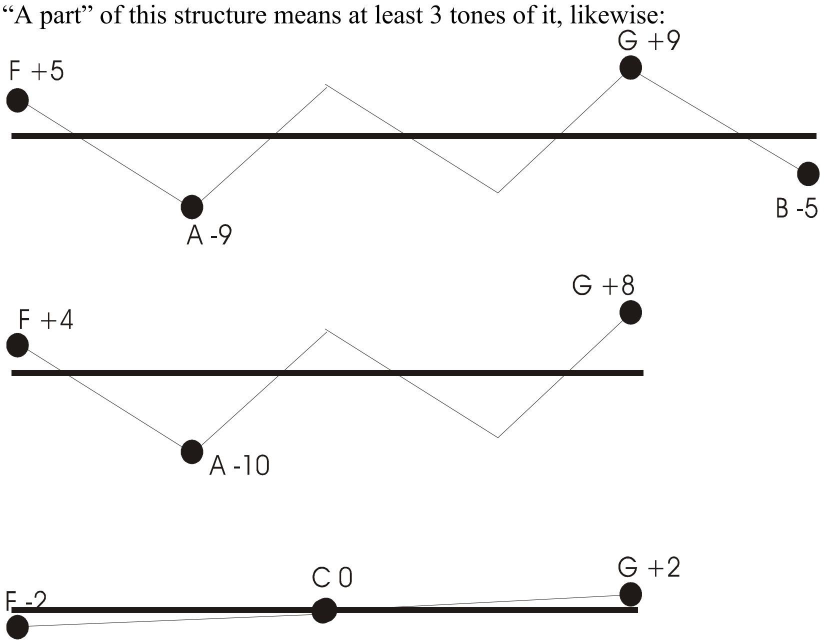


diagram 04

A structure of more than 6 tones cannot become predefined as at least the seventh tone would show an ambiguous character. In the example shown with diagram 03 the seventh tone would be a D. This D could be understood as a sub-fifth to the A or as an upper fifth to the G. If this tone really would appear as the7th note, it would be tuned to a compromise position, near to equal temperament.

On the other hand it may be asked whether it is necessary to bring such extended structures to just intonation, as a correction to the ratios of just intonation for such complex structures doesn’t bring an acoustic improvement. (Indeed, it sounds different to equal temperament, but not “better”). But it is advantageous to do so, as even when two chords, everyone with only three specific notes will follow each other legato, there could during a short moment all 6 tones (or 4 or 5 of them) be “on”.

This is a musical example:

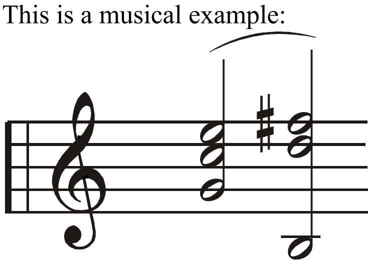


diagram 05

And this could be the effective “note on” situation during a short moment:

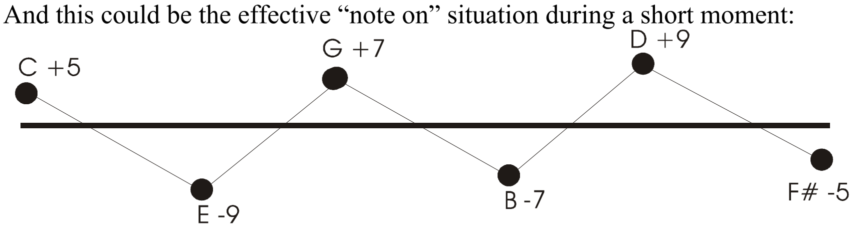


diagram 06

For a high stability of the system the frequencies of the second chord should be tuned to just intonation as soon as they appear. Unfortunately, this will not always be possible.

A special question in a system of fifths and thirds in just intonation is how to tune the "little major seventh chord". This chord is of irregular structure, but a constituent part of music. How should the seventh of such chords be tuned by a system of pure thirds and fifths?
A 5 : 6 ratio of the fifth to the minor seventh seems to be obvious, but the large distance of some frequencies to the default line of equal temperament will cause compatibility problems:

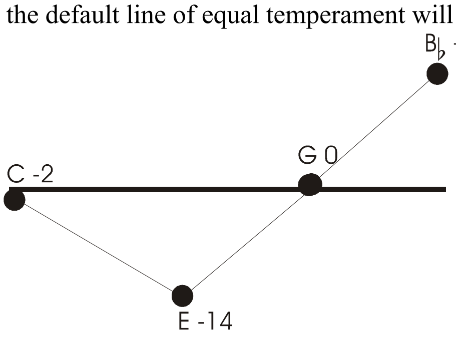


diagram 07

A second idea: The seventh tuned as a double-sub-fifth to the chords root shows less position problems but more retuning problems:

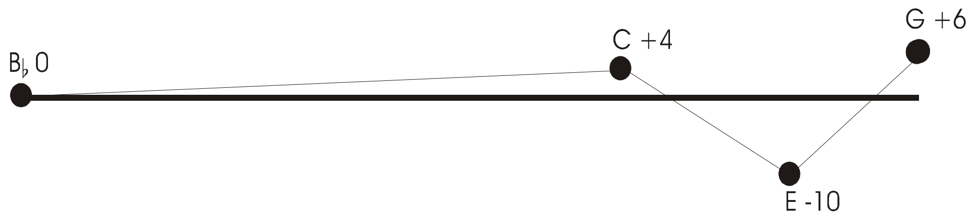


diagram 08

Actually HMT tunes this seventh almost to a tempered position. This seems to be the best compromise:

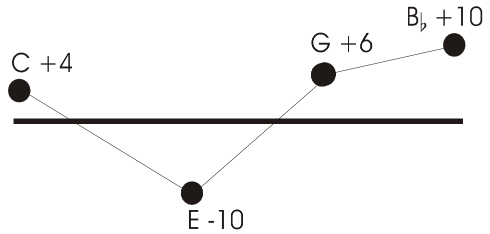


diagram 09

What happens when other, not predefined structures will be analysed? The notes of such structures will not be tuned to predefined tuning values. But this doesn't mean that such structures always will be tuned to the frequencies of equal temperament. For instance, when there will be played an augmented triad C-E-G# and the first two incoming note on messages will be C-E, than these two notes are tuned to just intonation and the last one, the G#, will be tuned to the equal temperament level:

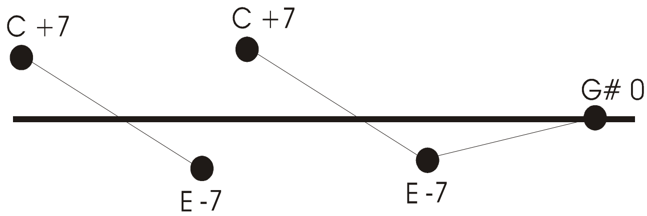


diagram 10

But what happens, when this chord will be repeated and the first two notes then will be E-G#? Changing the temperament would be problematic as it will cause a distinct change of sound. Therefore HMT says: The frequency values of such chords will be hold as long as (only) the specific notes of this chord will be repeated.
As a result of this the interval E-G# in this example will not be tuned to just intonation, as long as only these two tones will be repeated.
The same compromises have to be done with diminished triads (C-Eb-Gb) and diminished seventh chords (C-Eb-Gb-A).

In all other structures that are not predefined, the temperament will change according the effective sequence of note-on messages. This means: It can happen that complex chords or harmonic structures may sound different at repetitions. But at such complex structures the change of temperament is less audible.

As a result of the fundamental position idea of HMT, shown with diagram 01, a change from a major chord to its minor parallel chord and inverse causes only little retuning steps. This makes the system very stable. But not stable enough. Avoiding audible retuning steps requires additional equalising means.

<u>Shifting the line of equal temperament.</u>

With the default positions described above there is a first approach of the frequencies of identical notes in different harmonic functions. Nevertheless - and as the human ear is a very sensitive tool - HMT approaches the frequencies of such notes “as tight as necessary”, especially when they change their function “legato”.
But what is the limit of audibility for retuning steps? The audibility of retuning steps is very different. Sounds with chorus as well as flabby and beating sounds are less sensitive than clear sounds. With frequencies between about 500 and 4.000 Hz retuning steps are more audible than with lower or higher frequencies. Frequencies in this context means not only the frequency of the partial tone 1 of a musical tone, but even of its partial tones 2, 3, and more, if they will sound distinctly. The limit of audibility for such tones and in situations when the new frequency will be masked by a new sounding tone is by about 3 or 4 cents. In order to avoid audible retuning steps, HMT equalises by shifting the reference line of equal temperament. See the following examples:

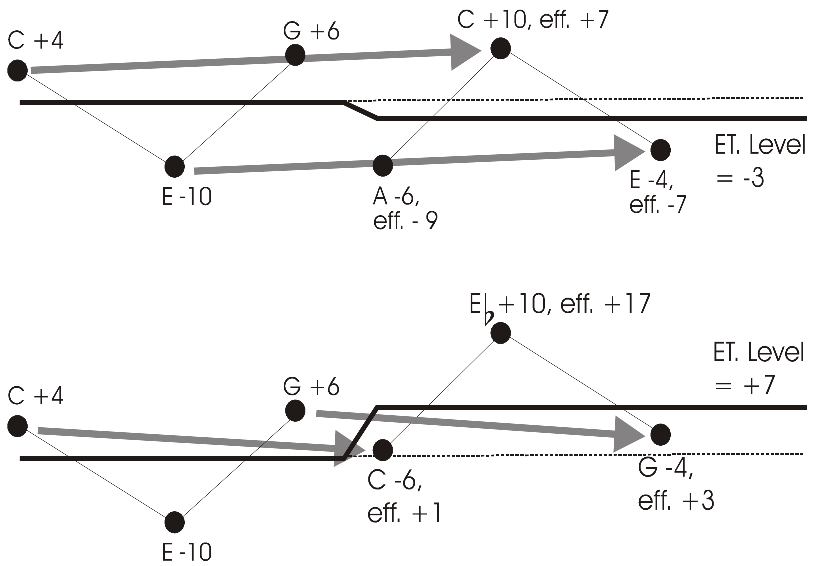


diagram 11

The system remembers this shifting and returns back to the default line of equal temperament step by step if ever possible:

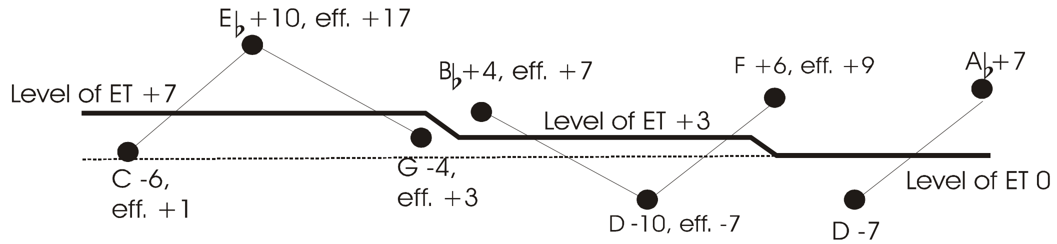


diagram 12

In principle it is possible that this line of equal temperament might be shifted up or down forever.

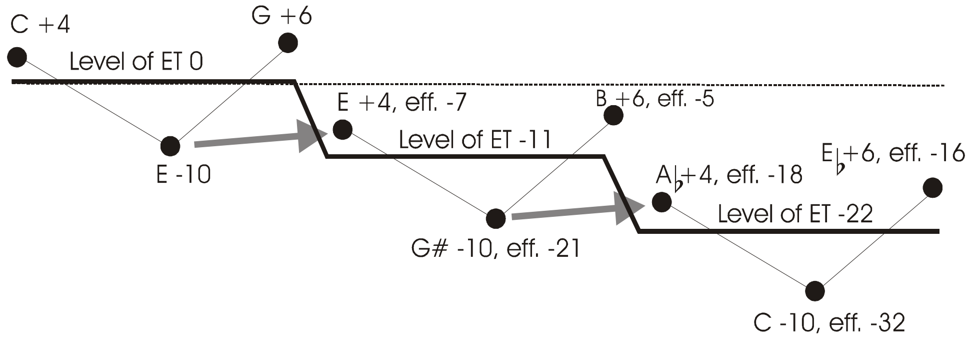


diagram 13

Therefore HMT limits this drift. It doesn't allow to shift the line of equal temperament to more than 20 cents distance to the default level. This means: The more greater the distance of the actual line of equal temperament from the default level, the higher the allowed retuning steps will be. In this way the line of equal temperament isn't allowed to drift more than 20 cents away from its default level.:

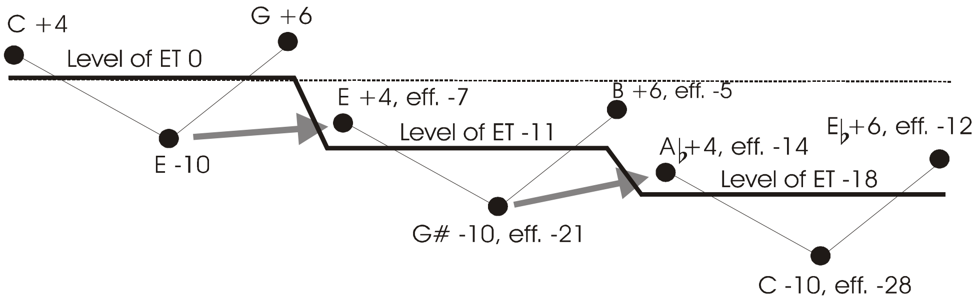


diagram 14

The drawing above shows the "HMT reference" mode. This is a mode with pure thirds and fifths, "holding the default tuning values in every case".

The following drawings shows"HMT classic" mode for the same situation.

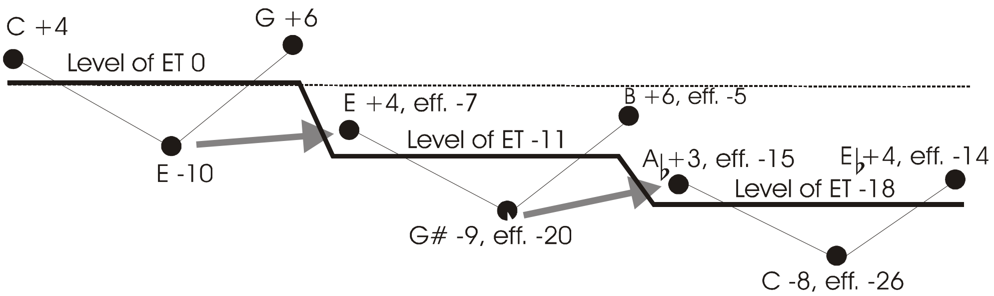


diagram 15

This mode flattens the tuning values. In diagram 15 the C major chord shows a perfect just intonation. Against this, the A flat major chord shows a tempered third C-Ab of 389 cents and a tempered fifth Ab-Eb of 701 cents. As a result of this flattening the retuning step from the G# to the Ab is less than with the "HMT classic" mode.

All HMT modes limit the deviation of the effective line of equal temperament to +/-20 cents from the start line. This means: No frequency can deviate more than +/-30 cents from the level of equal temperament. The only one exception is the natural seventh in the HMT mode "Jazz/ Pop". The natural seventh can deviate in abstract to a maximum distance of –47 cents.

Inverse retuning steps requires other equalising means. The mode “HMT reference”performs all predefined structures in their default values, therefore it equalises only by shifting the basic level of equal temperament:

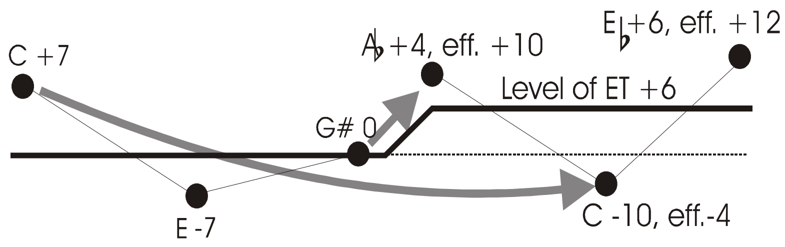


diagram 16

The mode “HMT classic “ controls to more compromise positions, so that the retuning steps will be less. As a result of this the frequency positions will be slightly “tempered”:

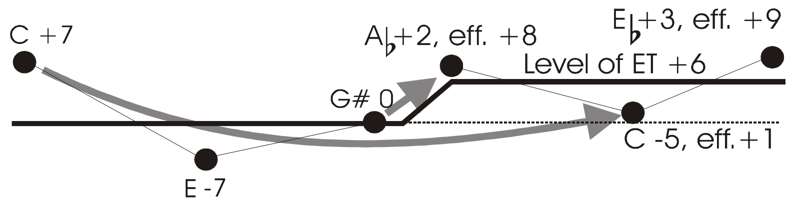


diagram 17

Timing functions

In order to position the frequency of the tones as near as possible to the default line of equal temperament, HMT weights how long a note has already sounded until, caused by a new harmonic situation, this note has to be retuned. In this way fleeting, quick changing situations as they can be caused by irregular touch of keys or by “humanised” note-on/ note-off messages of a sequencer don’t lead to deviations from the default line of equal temperament. The following examples show note-on sequences. The first one with a distance of less than 30 ms between the note-on messages, the second one with a time difference of 30 ms or more:

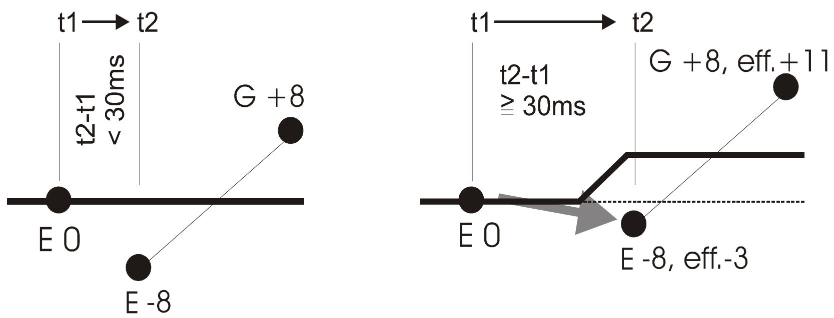


diagram 18

In both cases the frequency position are in just intonation. At the first example, when the notes follow each other quicker than 30 ms , HMT positions both notes as near as possible to the level of equal temperament. The E changes its position by 8 cents, this is inaudible as the human ear will not have realised within less than 30 ms the start frequency.

At the second example, after the time difference of 30 ms the human ear will have realised the start frequency of the E. Therefore HMT now limits the retuning step of the E to a non audible 3 cents.

<u>A special mode: “HMT Jazz/ Pop” with natural seventh.</u>

The seventh of the little major seventh chord is in a system of pure thirds and fifths an outsider. This chord seems to be born with a “natural” frequency ratio of the seventh by singers, wind instrument and string instrument players. And its best sound will be when the seventh is tuned in accordance to the 7. partial tone, so that the frequency ratios of such a chord will be 4 : 5 : 6 : 7. The frequency ratio of the natural seventh to its root corresponds to 969 cents, this causes is big difference to the values of equal temperament:

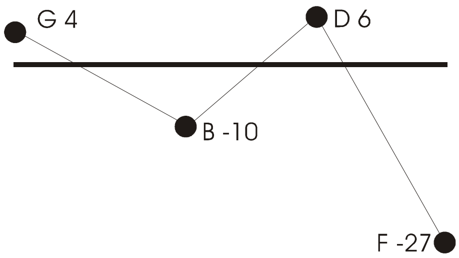


diagram 19

Therefore this seventh cannot be handled with equalising means.

In polyphonic music this seventh will cause sometimes hard retuning steps. Nevertheless in many Jazz or Pop music the major seventh chord or a major seventh ninth chord with natural seventh sounds very impressive.

<u>HMT Depth</u>

HMT in principle is compatible to equal temperament And if one for instance performs music in common with two musical instruments, one of them controlled by HMT and the other by equal temperament, there is somehow the same situation like an orchestra, accompanying a piano at a piano concert. The sound result is better than with an “all equal temperament”.

Nevertheless the best tuning mix in such situations will be when the tuning values of HMT will be reduced to about 60 – 70 % of the maximum pureness. The line of E.T means 0 % of “ HMT Depth”, the full range of HMT messages means 100 % of “HMT Depth”. See the following examples with different HMT Depth:

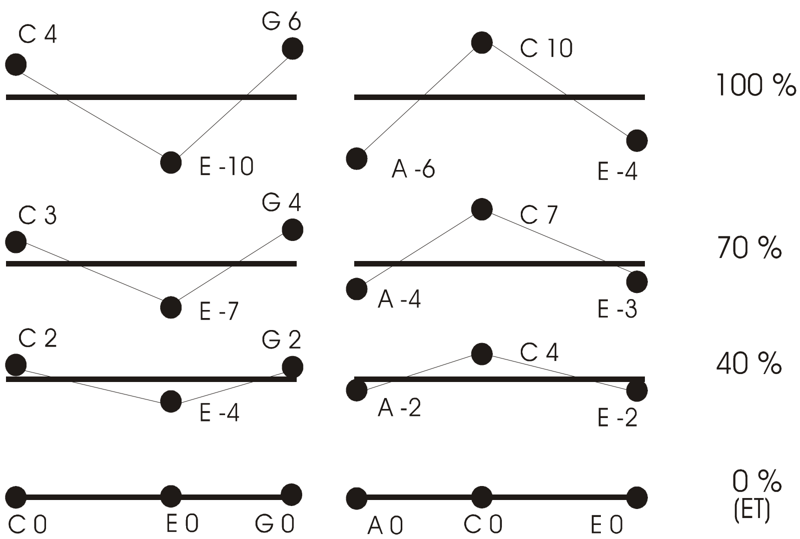


diagram 20

A sophisticated mode: “HMT baroque”.

At very clear sounds, e.g. church organ sounds, the human ear is very sensitive for retuning steps. The limit of audibility is by about 3-4 cents. Therefore with such sounds it is not possible to control the frequencies in every case to optimal just intonation without any audible retuning. If one wants to reduce these audible steps, the HMT modes explained above temporary set the frequencies to tempered positions. But this causes an new problem: changes from “not beating” to “quick beating” situations. With orchestral sounds this is no problem, but at clear sounds this is unpleasant.

An additional aesthetic question for such sounds is, whether the contrast of dissonant and beating note combinations to consonant chords free of beats, in principle should be hard – or whether this contrast should be handled smoother. Many musicians like it smooth, at least with such clear sounds. Reducing the “HMT Depth” to about 70 % could be a solution for this desire. Another and more interesting model for reduced retuning steps is the “HMT baroque” mode. With this tuning model all retuning steps will be less, but the chords near to the actual harmonic center of the performed music will be tuned near to just intonation, others, with a higher distance to the actual harmonic center, will be tuned less perfect. In this way the “HMT baroque” mode is a colourful unequal tuning model with “key character”. It may be compared with historic unequal temperaments. The difference is: A historic unequal temperament forms some chords better than with equal temperament, others worse than with equal temperament and the best tuned chords always are near to C major independend of the actual key. “HMT baroque” against this forms the best tuned chords near to the harmonic center of the actual performed music and controls all chords better than with equal temperament.

Therefore the “baroque” mode analyses whether the actual music shows a “harmonic center”. Additionally it analyses whether this center is a more or less distinct one. If there is a perceptible center, HMT creates a unequal basis temperament. Supposing the harmonic center would be at “C” this basis temperament will show a resemblance to traditional “well tempered” tuning models:

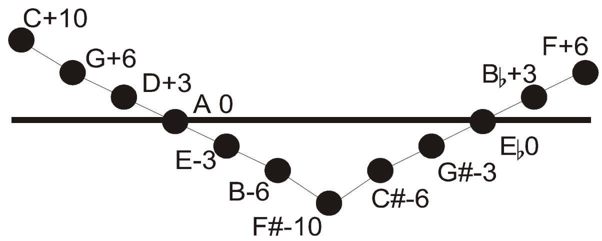


diagram 21

Supposing the harmonic center will be at Ab, the basis temperament against this will be formed as follows:

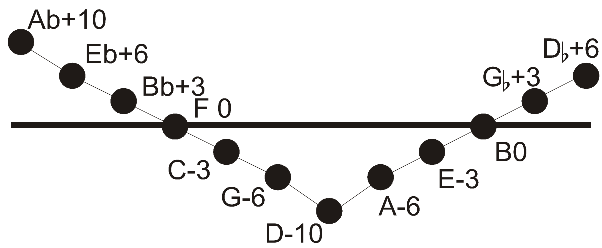


diagram 22

In the “HMT baroque” mode this basis temperament is one of two components. The second component form the variable tuning values depending on the actual existing chord structures as already described at the other HMT modes.

Both components are added. Everyone of the both components is regarded as a “100 % component”. Therefore only a part of both these components will be added to the actual sum of frequency corrections.:
either 0 % of component 1 with 100 % of component 2
– or 10 % of component 1 with 90 % of component 2
– or 20 % of component 1 with 80 % of component 2
– or 30 % of component 1 with 70 % of component 2.

With other words: both components will be weighted to a sum of 100 %.

A first example:

Supposed the harmonic center will be at “C” and the harmonic center will be a distinct one. Than component 1, the unequal basis temperament, will be weighted to a high degree of 30 % and the component 2, the variable chord structure correction will be reduced to 70 %:

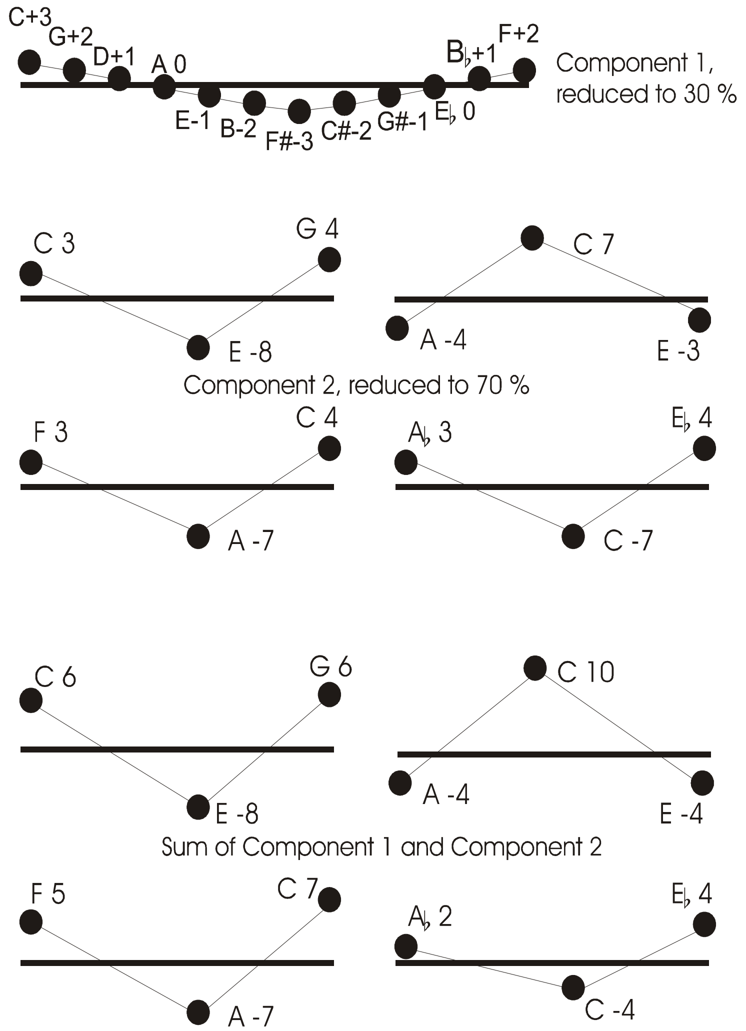


diagram 23

The chords near to the harmonic center of C are very near to just intonation, the tuning of the Ab major chord against this is less perfect.

A second example:

Supposed, the center of component 1 is by C, but not very distinct, component 1 will be only weighted by 10 %, therefore component 2 will be weighted with 90 %. Then the tuning results are as follows:

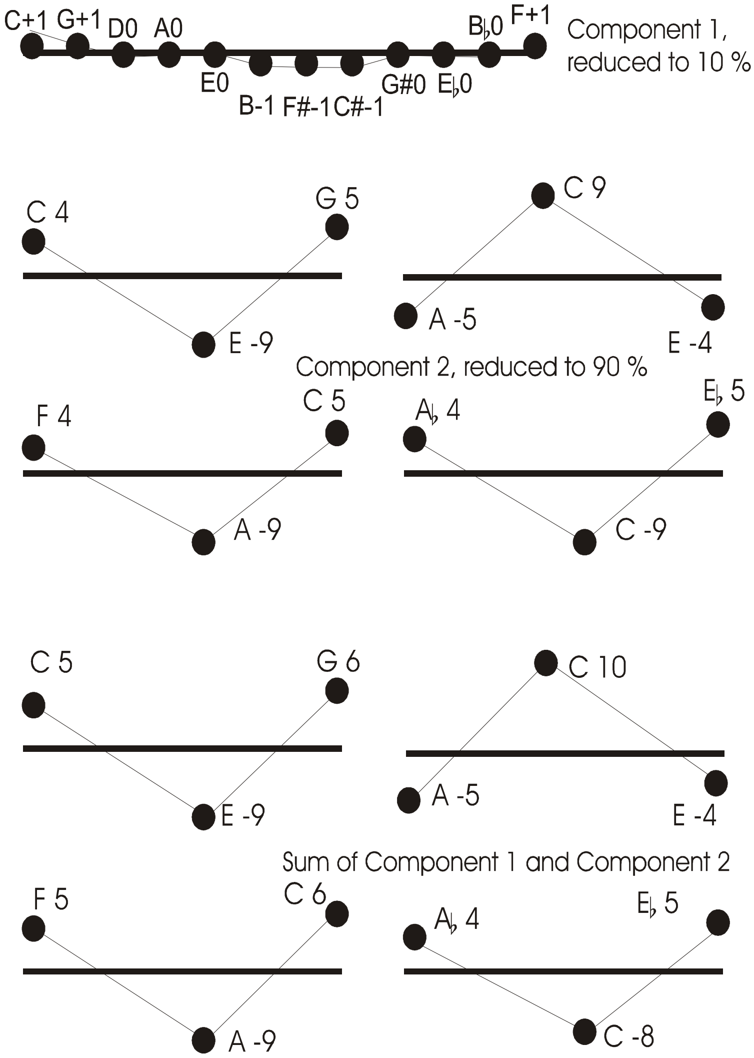


diagram 24

This means, the tuning result is near by the “HMT classic” mode.

How to calculate the “harmonic center”.

This is a simple but effective method:

The frequency values of the last analysed 10 chord structures will be added. (Indeed, one even could add the “last 12” or “last 16” chords, but “last 10” is a very practicable number). The calculated tuning values are stored in a staple memory. The 11th analysed chord structure will delete the values of the 1st, the 12th these of the 2nd and so on, so that only the tuning values of the last 10 chord structures will be stored. The tuning values of the specific notes of these last 10 chord structures will be added.

The following table shows a musical example with the default chord-specific tuning values for its chords, named 1 – 10:

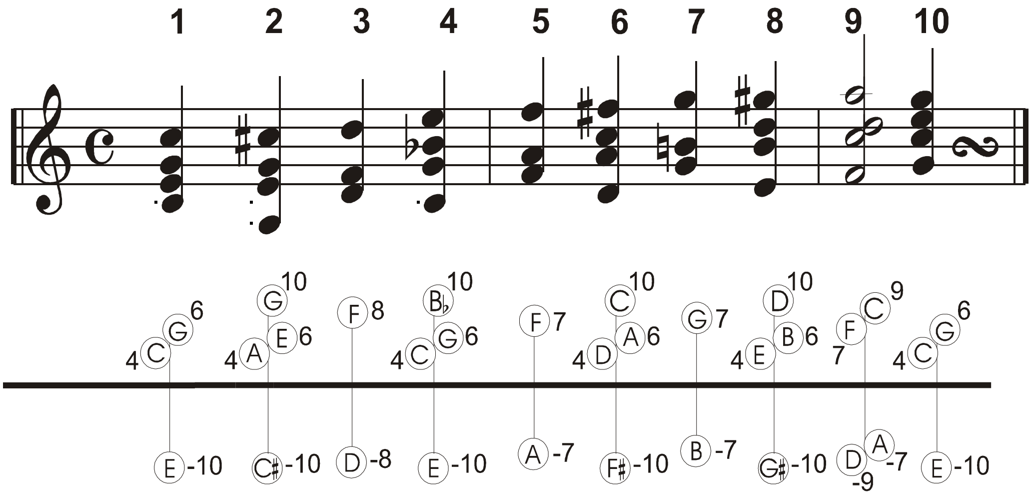


diagram 25

The following table repeats the tuning values, shown above:

Chord Nr.	C	C#	D	D#/Eb	E	F	F#/Gb	G	G#/Ab	A	A#/Bb	B
1	4				-10			6				
2		-10			6			10		4		
3			-8			8						
4	4				-10			6			10	
5						7				-7		
6	10		4				-10			6		
7								7				-7
8			10		4				-10			6
9	9		-9			7				-7		
10	4				-10			6				

Table 1

The following table shows the Cent values added from the first chord to the actual chord:

Chord No.	C	C#	D	D#/Eb	E	F	F#/Gb	G	G#/Ab	A	A#/Bb	B
1	4	0	0	0	-10	0	0	6	0	0	0	0
2	4	-10	0	0	-4	0	0	16	0	4	0	0
3	4	-10	-8	0	-4	8	0	16	0	4	0	0
4	8	-10	-8	0	-14	8	0	22	0	4	10	0
5	8	-10	-8	0	-14	15	0	22	0	-3	10	0
6	18	-10	-4	0	-14	15	-10	22	0	3	10	0
7	18	-10	-4	0	-14	15	-10	29	0	3	10	-7
8	18	-10	6	0	-10	15	-10	29	-10	3	10	-1
9	27	-10	-3	0	-10	22	-10	29	-10	-4	10	-1
10	31	-10	-3	0	-20	22	-10	35	-10	-4	10	-1

Table 1

As already mentioned the next chord No. 11 will delete the Cent values of chord No. 1, No. 12 will delete No. 2 and so on, so that only the tuning values of the last 10 chords will be added.
Table 2 shows the following result for the note with the highest sum of tuning values:

situation after chord No.	1	2	3	4	5	6	7	8	9	10
note with the highest sum	G	G	G	G	G	G	G	G	G	G
sum	6	16	16	22	22	22	29	29	31	35
weights component 1 to %	10	20	20	20	20	20	20	20	30	30
weights component 2 to %	90	80	80	80	80	80	80	80	70	70

The musical example of diagram 25 is analysed to have its harmonic center permanent at the note G. After the 2nd chord the component 2 will be formed with 20 % and with the center G as follows:

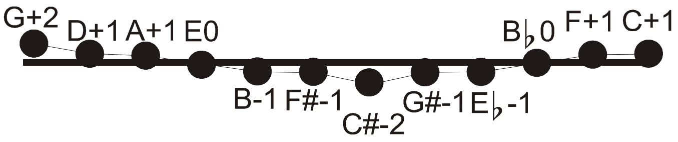


diagram 26

and after the 9th chord with 30 % and the center G as follows:

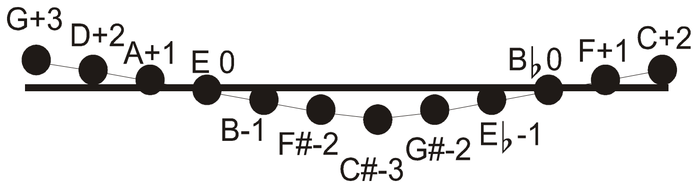


diagram 27

A repetition of the musical example, shown above, will create the following tuning model as an addition of component 1 with 30 % and component 2 with 70:

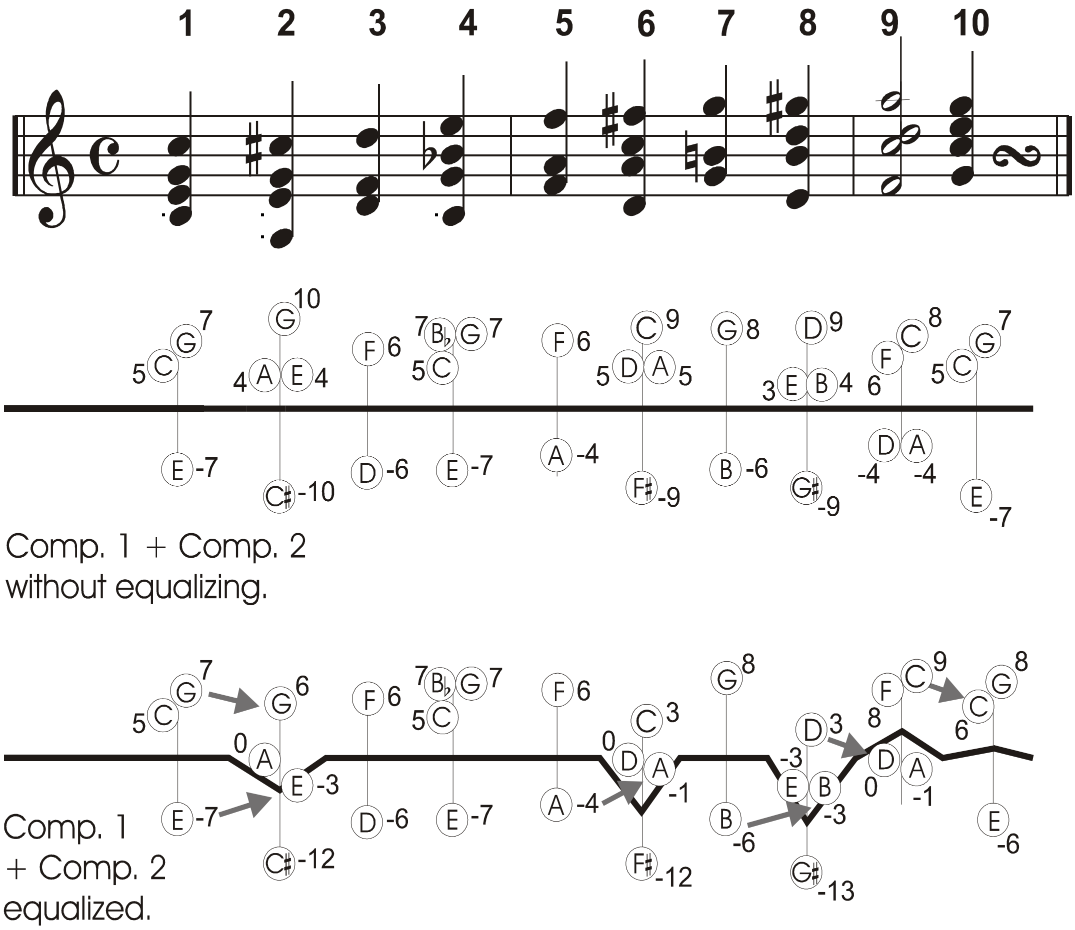


diagram 28

The result is an unequal colourful temperament, on the one hand near to just intonation, on the other hand with very little distance to equal temperament. Many of the melodic (!) steps with fifth and fourth intervals, e.g. E-A from chord 4 to 5, A-E from chord 9 to 10, show tuning values near to equal temperament.

Some annotations for the science of music:

1. The traditional idea of tuning a diatonic scale, e.g. C major to just intonation is a model of fixed tuning values, shown by the following examples for the 7 notes of this key:

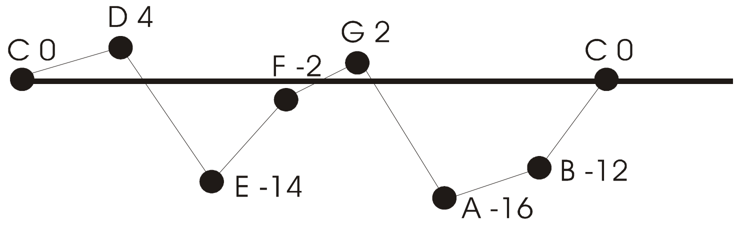


diagram 29

But, in order to be correct, a major key requires two alternate tuning values for its second note. In C major this is the note D and the two alternate positions are a first and higher position for the dominant chord G-B-D and a second and deeper one for the subdominant-parallel chord D-F-A. The distance of both positions is 22 cents, this is the so-called syntonic comma. See the following diagram :

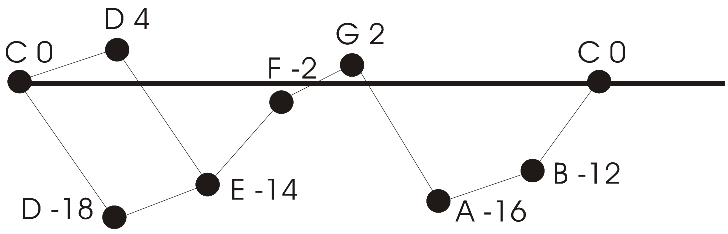


diagram 30

HMT against this shows variable frequency positions for each note. Nevertheless the tuning values for the typical chords of C major only move in a small range. The largest distance between its different predefined frequency positions shows the note "D". With HMT its "syntonic comma" is reduced to 12 cents.

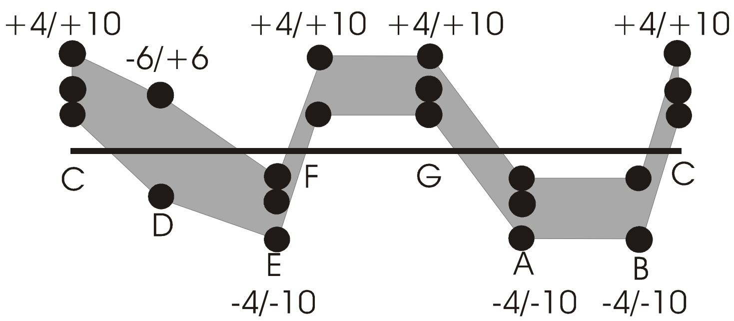


diagram 31

This means: HMT shows a new relation between tuning model and tonality. The resemblance between diagram 31 and diagram 30 is evident.

2. HMT shows by its default position of frequencies a new idea of relationship between different chord structures.

The following diagram shows the frequency positions of a C major chord, tuned by HMT, shown with fat lines. Additionally it shows all other major and minor chords contenting at least one of the notes of the C major chord: The C and/or the E and/ or the G.
All these chords are arranged according their HMT default frequency positions. The distance in frequency values shows: A little distance of the frequency position of identic notes means a high degree of relationship, a large distance between them shows a low degree of relationship.

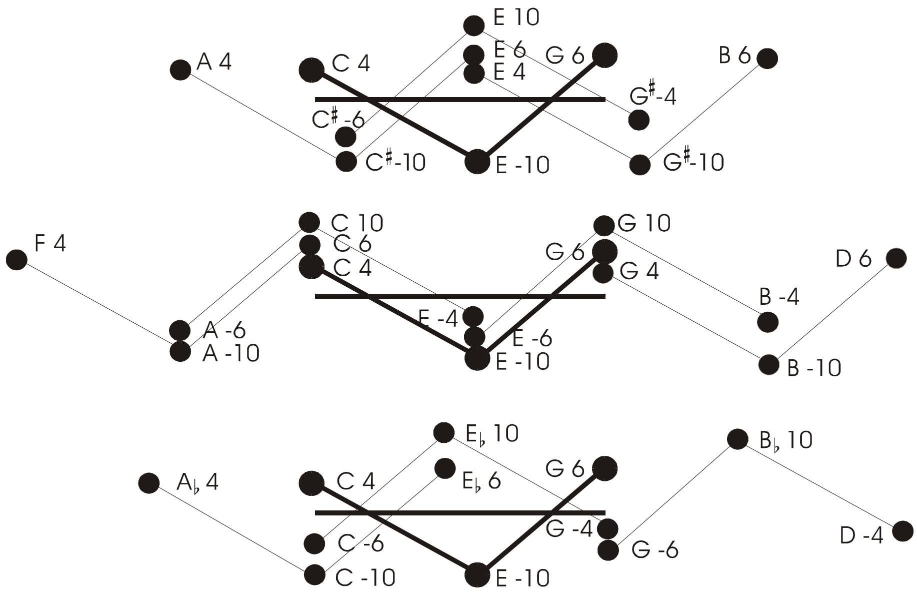


diagram 32

Examples:

- The “C” in C-E-G as basis is tuned to +4 cents.
- The “C” in F-A-C” is tuned to +6 cents. The difference of 2 cents shows a high degree of relationship to the C major chord.
- The “C” in A-C-E is tuned to + 10 cents. The difference of 6 cents shows a medium degree of relationship to the C major chord.
- The “C” in C-Eb-G is tuned to –6 cents. The difference of 10 cents shows a low degree of relationship to the C major chord.

Conclusion:

HMT is a tuning system with algorithms, controlling the temperament of the performed music as near as possible to the frequency ratios of just intonation. HMT controls by analysing chord and interval structures, combining two parameters: The virtual line of equal temperament with the virtual center of the actual chord structure.

The HMT idea shows a new relationship between a model of just intonation and the idea of tonality. Additionally it presents new ideas in the relationship of chords.

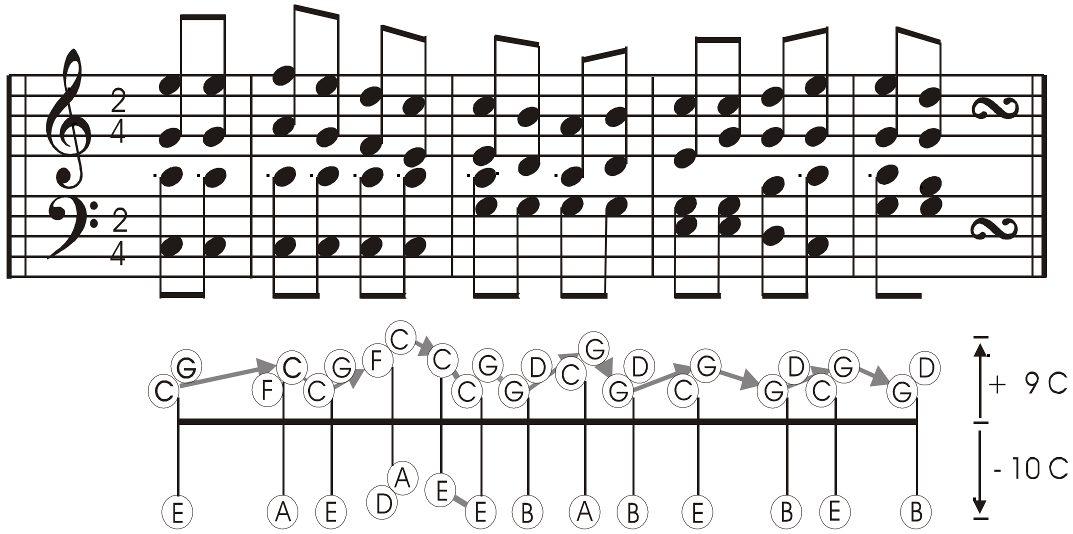
Besides, the HMT tuning models can be regarded as reference temperaments for choirs, orchestras and all other ensembles with wind or string instruments.

Appendix

Two musical examples shown with HMT tuning models

1. An example with conventional chord sequences

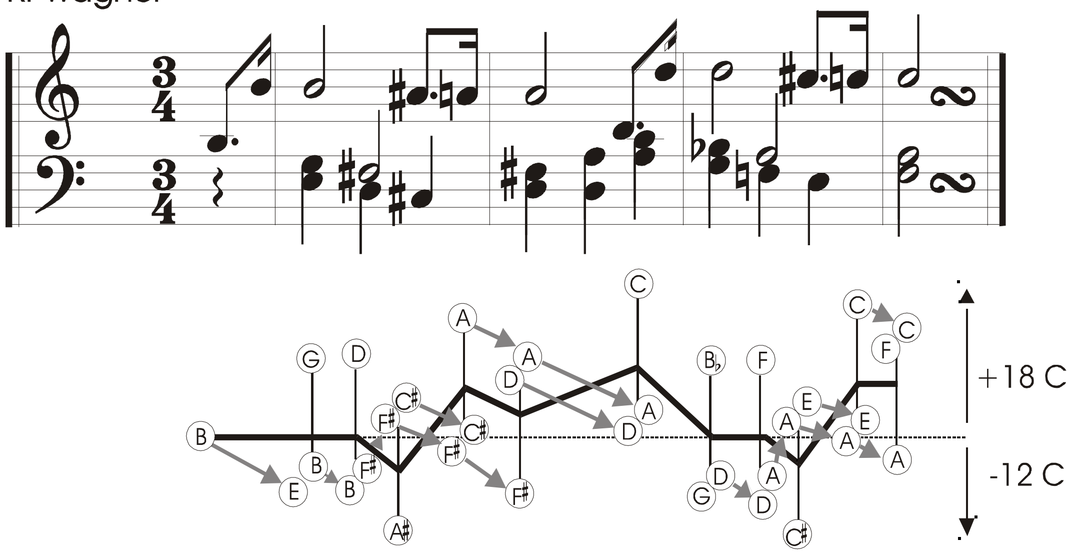
L. van Beethoven



The tuning model is: “HMT classic”

2. An example with more dashing modulations:

R. Wagner



The tuning model is “HMT classic”

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For more informations in the HMT system see:
www.hermode.com