TUNING IS BIG!

THE STUDY OF CONTROLLING INTERFERENCE BEATS WITHIN EQUAL TEMPERAMENT

Exploring Ideas on Adjusting the Equal Temperament Tuning System

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ADVANCES IN DIGITAL TECHNOLOGY EXIST TO CORRECT MANY, IF NOT ALL, OF THE TUNING DEFICIANCIES FOUND WITHIN EQUAL TEMPERAMENT AND THE STUDY AND IMPLEMENTATION OF THIS PROCESS SHOULD BE INITIATED

ABSTRACT

The rationale for this thesis on exploring ideas on adjusted tuning is three fold:

1. To bring awareness to and remind musicians, music lovers, and the tuning industry of the shortcomings of equal temperament (ET) and to inspire development of ways to improve upon the prevailing system in a way that embodies the true aesthetics of harmony and nature.
2. To foster a desire to develop a system that is capable of analyzing music, making pitch adjustments in *real time* to produce improved tuning. These adjustments would be similar to what fine musicians do on a regular basis, when not tied to the confines of fixed pitched instruments (keyboards). This approach, most probably, would make acoustic pianos and organs "period" instruments.
3. To encourage a means to standardize this improved tuning system and show how the fixed pitched instruments can be come flexible.

I. For the love of beauty, things must be improved!

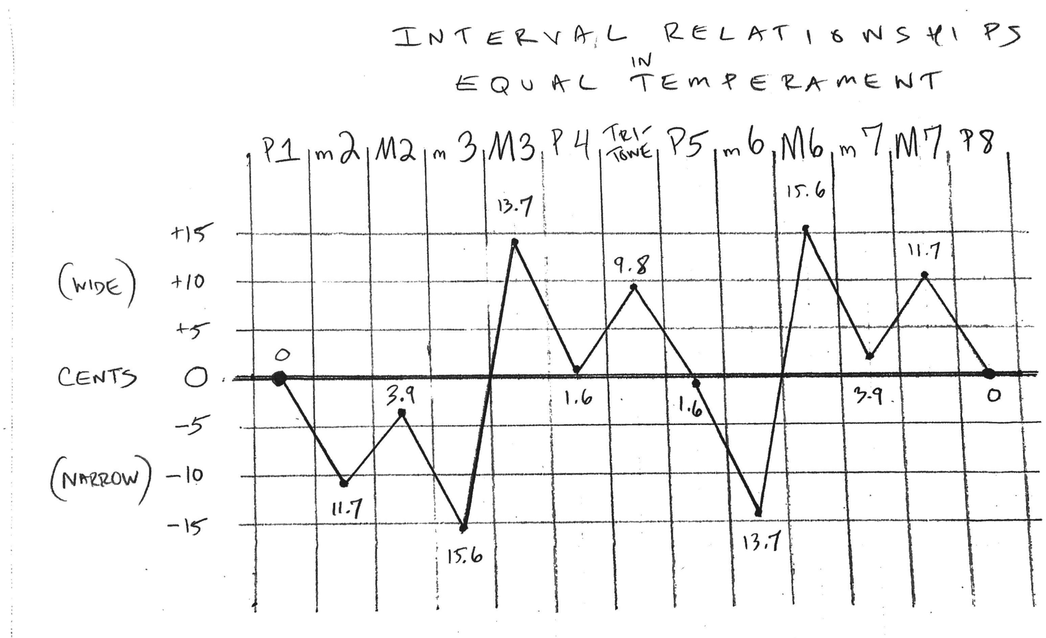
In tune tones create harmonious and pleasing sounds. The sound waves are "in sync", or in phase, and aligned when tones are in tune, or "pure".

Out of tune tones create unpleasant interference beats. Interference beats are the sounds generated by two out of tune frequencies that compete with each other, causing chaos. In equal temperament (ET) tuning, there are zero interference beats in only the unisons and octaves. ET divides the octave into 12 equally spaced frequencies. This does not mean, however, that the many different intervals (thirds, fourths, fifths, etc.) are equally in or out of tune. It is interesting to note that interference beats in intervals in extreme ranges, low or high, are not as recognizable, e.g., on the high end, because the interference beats are so fast and so many per second, and on the low end, so slow and so few.

The most noticeable out of tune interval in ET is the major third. In fact, it produces more interference beats (being 13.7 cents wide) than can even be counted easily by the human ear. For instance, the major third interval from A440 down to F creates 26 interference beats per second. If it were in tune, it would have zero interference beats per second and would be considered pure.

The chart below demonstrates how ET varies from pure tuning in terms of cents. There are 100 cents between each semitone (half step) in ET, however, the intonation of each interval vary greatly. Equal does not necessarily mean in tune. The unison, octave, perfect fourth, and perfect fifth are most in tune, and the thirds and the sixes are most out of tune.

Note: The minor third is 15.6 cents (narrow) out of tune, but is not as much of a concern, for other reasons, possibly because of the natural dissonance of smaller intervals. It is yet to be explored.



It is most interesting that the "perfect" intervals (P1, P4, P5, P8) need most to be in tune for our ears to accept. It would be most noticeable if these intervals were not in tune or nearly so. P1 and P8 must be in tune. P4 and P5 must be very close.

<u>In Tune Pitch Priorities (Pecking Order)</u>

1. Unisons and octaves – most important and can not be sacrificed
2. Perfect 4ths and 5ths – a very close second
3. 2nds and 7ths
4. 3rds and 6ths

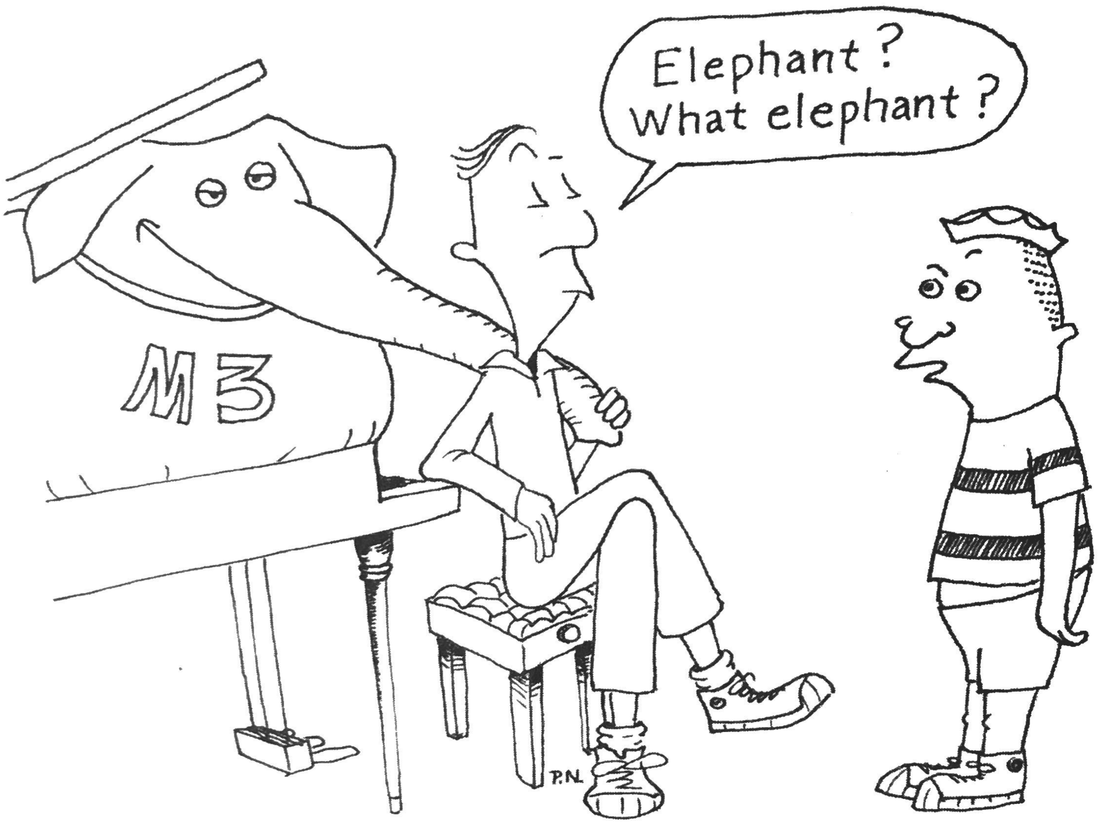
If correcting a third destroys a fifth's intonation, the third must be sacrificed, and so on.

Humans are capable of adjusting thirds of ET, but the decisions become more complex when that adjustment is detrimental to perfect fourths and fifths, as explained above. A computer should be capable of the same, immediately identifying the pecking order.

Another parameter must be that the root of the chord is most important and should, by and large, remain equally tempered, regardless of its placement. Unmentioned problems of passing tones, fast passages, and complex atonal music etc., are not necessarily complete in this study. There will be times when ET must remain unchanged.

One must, however, always recognize that interference beats hurt. They cause chaos with the eardrum, as well as with the natural properties of the overtone series. These imperfect distributions of hertz, hurt!

ET fights harmony, the harmony of nature. We have developed a tolerance to the egregious major third and we have learned to tolerate that elephant in the room. Why?



Ignoring the mammoth Major 3rd of ET

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My basic premise is to devise a computer software system that will adjust pitch relationships in *real time* to remove the interference beats of any two (or more) musical sounds, while still maintaining the integrity of our 12 tone ET system. (If computers can drive automobiles through the judgment of the relationship of physical objects using cameras, satellites, etc., certainly, it must be possible to do the same with sound frequencies in conjunction with the tuning of fixed pitch musical instruments.)

The successes of earlier tuning systems made playing in certain keys sound better, but it was not possible to venture beyond those keys. If you did, your ears would be in peril.

Equal temperament took care of that need to avoid certain other keys, but to do so, it made certain intervals <u>more</u> out of tune. That's the problem!

Fine vocal, woodwind, string, and brass groups can and do achieve this tuning goal through constant focus on listening, decision making, and adjustment. Most important is who must and/or must not 'give' for success.

The a cappella classical vocal group, Ghostlight Chorus, for example, achieves this high standard of intonation. (www.ghostlightchorus.com) The director, Dr. Evelyn Troester DeGraf, is acutely aware of the need for adjustment and constant analysis of chord progressions and intervallic relationships. Being a member of this group has been instrumental in my awareness of refined intonation. Our singing would be changed greatly if we were accompanied by a piano. In this a cappella setting, we are free to minutely adjust pitches to create beautiful sounds.

When I sing as a soloist, accompanying myself on the piano, often I will omit the third of the chord in my playing, so I can sing the third where it is better in tune. As an oboist, I'm constantly aware of adjusting pitch when playing in orchestras or chamber ensembles depending on my role in the chord. Sensitive and aware musicians are always doing this and have since the beginning of time.

Our standard of fixed pitched instruments encourage out of tuneness for the multitudes. If we could change the sounds that are produced by these instruments as a standard, it could refine how all performers perceive their role.

The inflexibility of fixed pitched instruments, like the piano, organ, keyboard, and fretted string instruments, are most problematic. The answer may be in their electronic counterparts.

II. Computer pitch altering systems already exist!

Let's step back to better understand how we came to equal temperament, ET, in the first place. We did not begin with its out of tuneness.

Tuning systems of the distant past (Pythagorean, Meantone, Well Temperament, etc.) each had strengths, but were limited. Certain keys, chords, and progressions in these systems were very well in tune, but others were not tolerable to the ear.

Prevailing Well Tempered tuning systems such as Werckmeister III, Rameau, Kirnberger II and Thomas Young, were used from the 17th to 20th centuries. Bach composed in the Well Tempered system, as noted in his Well Tempered Clavichord pieces, which demonstrated songs in all twelve keys. Still, there were tuning issues.

Although this concept dates back to the Chinese five thousand years ago, equal temperament, became codified in the West in the 20th century. This system eliminated the *key problem* by dividing the octave into 12 equally spaced tones, but produced (except unisons & octaves) varied out of tune relationships. The minor third is 15.6 cents narrow, the major third is 13.7 cents wide, the perfect fourth is 1.6 cents wide and the perfect fifth is 1.6 cents narrow, all in relation to pure intonation. In addition, ET competes with the natural tendencies of the Harmonic (Overtone) Series. In the Harmonic Series, the fifth partial (a major third to the fourth partial) is intrinsically low (making the interval narrow, even lower than pure intonation). The major third in ET is very high (making the interval wide) thus exasperating the problem and going against nature's natural sympathetic vibrations. ET is a compromised system beyond what it needs to be, considering today's advances in digital technology.

Logic seems to dictate that the basic structure of equal temperament must remain, in that the equal spacing of twelve tones within the octave is paramount. Otherwise, tonal centers would wander aimlessly as the modulation of chord progressions varied.

The computer must be programmed to make decisions based on where the music is "coming from" or "going to" where the same "adjusted" tone in the "coming from" category, might not lead well into the same "newly adjusted" tone for the "going to" category around the basic confines of equal temperament. Presently, the talented and well-trained human mind can make these fine decisions.

Through developing pitch-altering software, possibly building upon principles akin to Auto-Tune or Melodyne, I feel tuning can be improved and thus our aural experiences heightened. Tuning one note at a time is easy enough, but how do we approach several notes at a time, harmony, and how do we approach harmonic progressions? Tuning, or altering the frequency to lock in with ET is standard and fixed. But, what if we want it to truly be in tune, for it to have pure intonation?

We need to prioritize which notes take precedence in the tuning pecking order, in terms of their intervals, their function, and in relation to where they are going. The major third is the most egregious offender. How does the software adjust when the note that was previously a major third, now becomes the root, or the fifth, and so on. Again, there needs to be a hierarchy established. See "Pitch Priorities" on page two.

Here are ways to adjust intonation using these principles. In this chorale passage by J.S. Bach, BWV 262, the major third on beat 1, (the F# in the tenor line) needs to be lowered.

If we lower the pitch by 13.7 cents (which is how far this Equal Tempered note is out of tune), it becomes in tune. I did some experiments on this using a keyboard and calibrated tuner. I also experimented altering the pitch by less than 13.7 cents to hear the difference. It sounds much better when lowered 13.7 cents from ET. Then I played it into a DAW software program, Logic Pro and adjusted the tunings there. Below is the best sounding approach, (less interference beats). Logic Pro doesn't adjust to tenths of a cent, so I adjusted to -14 cents.

The first set of regions contain the adjusted major thirds, the second set is in ET. I listened back and forth several times to hear the difference. There is an ease and comfort to the adjusted phrase, and an unwelcomed edge to the ET phrase, when compared.

On beat 2 of measure 1, the same F# in the tenor needs to come back up to ET in order to make a nice fifth with the B in the bass. The B in the soprano line on beat 4, should come down 13.7 cent, as it is the major third of G. The passing tone, F#, on the "and" of 4 in the tenor goes back to ET. The C# in the alto on beat 2 of the second measure, the A major triad, should have the major third lowered by 13.7. Finally, the two F#'s on beat 3 and 4 should be lowered. If they are lowered by 13.7 cents, it will be in tune.

These simple adjustments can make a great difference. They can make harmonies richer and more resonant. This is where the software comes in.

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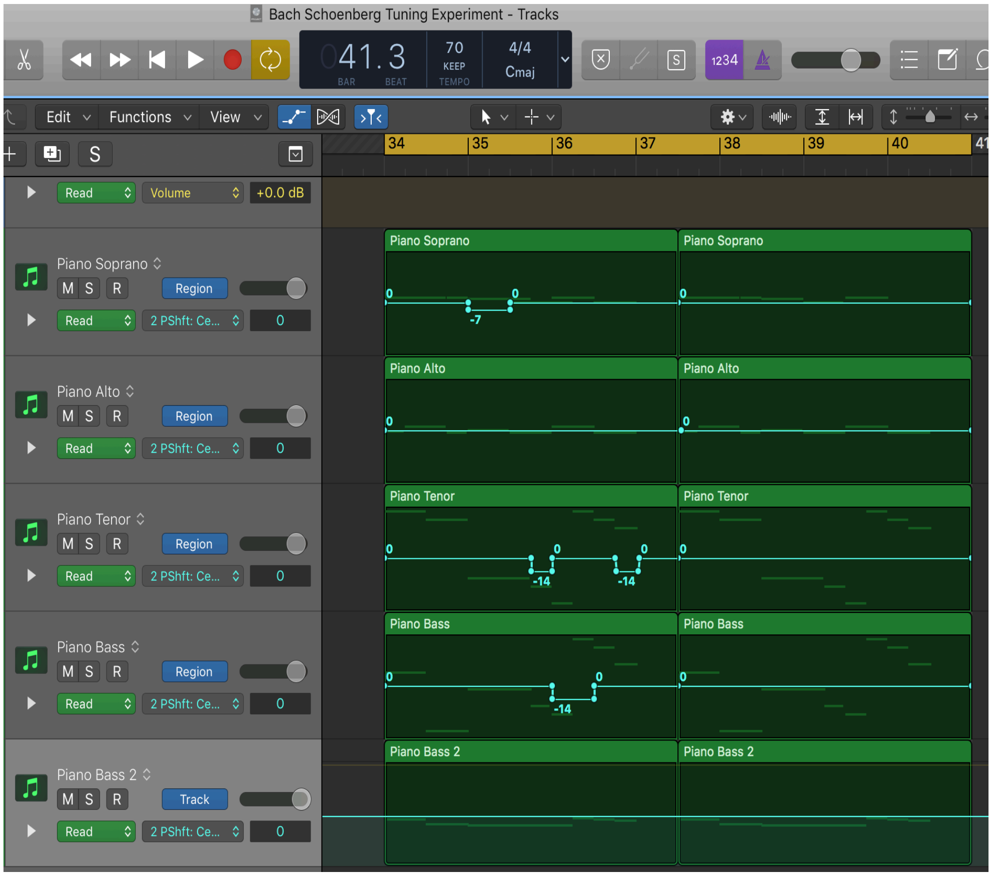
Here is an excerpt from Schoenberg's *Friede auf Erden* piece for a cappella choir.

At rehearsal marking 2, the chord on beat one and two could be analyzed as an Asus7 (13). There is a major third in this between the top two notes in the alto and soprano, D and F#, respectively. If you lower the F# 13.7 cents to make the major third in tune, it creates interference beats with the rest of the chord, so I experimented lower it different amounts. I found lowering it 7 cents created the least interference beats and the most overall harmonious sound. When we go to beat 3, we have a major third, G and B, between the tenor and alto. Ideally, the B should be lowered in this case, but it can't be because the perfect fifth between the E in the bass and B in the alto, is more predominant and would be narrowed to the point of it being intolerable. The order of the fifth, in terms of importance, is above the third. Beat four has a major third from the bass one to the tenor part, D to F#. This sounds better being lowered 13.7 cents.

In beat one of the last measure the C# in bass one needs to come down 13.7 cents, as does the B on beat two. They are both major thirds. Finally, beat four of the tenor, C# in this last measure needs to come down 13.7 cents. The ear still perceives A as the root, so this major third needs to adjust.



Listening and comparing vocal performances of two excellent vocal groups singing/navigating this dissonant piece has been eye (ear) opening. Intonation is clearly the separation between the two. One stayed within the confines of ET and the other adjusted. The beauty of the adjusted choir prevailed!

Listening for interference beats is the most organic and natural way to truly hear and feel what sounds best. For those who hear interference beats readily, it's obvious when it should be adjusted and when it shouldn't. The computer should be able to do the same by listening for the interference beats and adjusting in *real time*.

We must believe that much of the amazing capabilities of the human mind can, and should be expected of a computer.

III. Let's create a new standard in adjusted tuning!

There's good reason why ET has not been changed in Western music and must remain as a prominent template. It has allowed us to use all 12 notes in conjunction with each other ranging from the most elementary melodic mind to the complexities of Arnold Schoenberg.

But why not continue to improve? We've had many developments over time. Bach's Well Tempered Clavichord predates ET. The keyboard has become so dominant that it has been the determining factor for all other musicians to conform to. But, vibrations are vibrations. Out of tune is out of tune. It's time for a better system.

Although vocal and non-fixed pitched instrumental groups have vastly improved performances within the confines of ET tuning, it is a very individualized process and certainly not one that could be applied easily to the fixed pitched instrument. Therein lies the problem. Obviously, the smaller the group, the easier it is to improve the problems of ET. So the question is, how can this be applied in a more standardized systematic process to allow for everyone to benefit. It's one thing for all of us to accept ET and play out of tune with all its fancies, but implementing a new and better system will be a great challenge that we should all engage ourselves in. (This is not to say that ET needs to be replaced. It must, in fact, remain the guiding force.)

We have to bring those positive and great happenings back into focus. For the sake of harmony and beauty, we should not give up on producing pure intervals. Just because it is difficult to achieve shouldn't make us stop trying. It's for aesthetics, plain and simple.

I've been talking with my musician friends about these ideas. I keep coming up against resistance. A common response is, "Why, Mary?" Why would you want to do something like this?

Dr. Evelyn Troester DeGraf, director of Ghostlight Chorus said, "Yes, the computer should be able to do that, that's true. The question is, if we want the computer to learn that… I think that there is another layer to tuning which is the social aspect. We blend and tune with each other when we like each other and are willing to say "yes" – deep listening and compromising are necessary. We must hold on to the human quality. The vulnerability and attuning to each other is key to the magic."

I say, "Why not? Why shouldn't we strive for something better?"

My father, J. Bruce Gatchell, is a conductor, trombonist and piano tuner. Born into a family full of musicians, he was always interested in sound. Why else would he remember at a young age the overtone sounds of second gear in a 1948 International school bus as producing a minor sixth interval?

He went on to study music in college. There were pianos in the lounges of all the dormitories, and they were all out of tune. Not being able to stand the situation and knowing his mother had saved his father's tuning kit, with just two tuning forks, a few tools, and a good ear, he began tuning these pianos. That's when he discovered that there was a problem in tuning. Pure tuning was far from perfect!

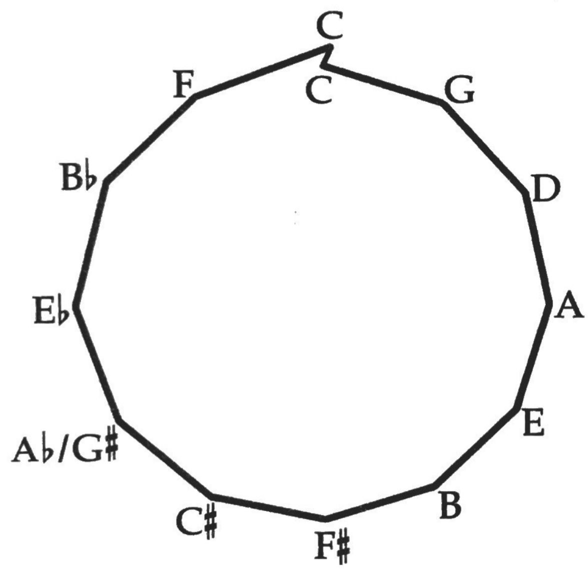
Being a trombone student, my dad had always learned to tune things with a slide, or to sing in-tune. And when he tried to apply that to the piano, when he tried to tune the circle of fifths starting on C, everything sounded so good, that is, until he got back to C. It didn't add up! Being a do it yourselfer, basic trial and error person, it took time for my dad to accept that a bunch of perfectly in tune intervals ended up sounding "wrong".

Pythagorean Circle of Pure Fifths:

$$\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2}\times\frac{3}{2} = 129.746$$

$$\frac{2}{1}\times\frac{2}{1}\times\frac{2}{1}\times\frac{2}{1}\times\frac{2}{1}\times\frac{2}{1}\times\frac{2}{1} = 128.0$$

Figure 3. "Circle" of Pure Fifths.



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When the professional piano tuner came in to tune the department Steinway, my dad went to ask him questions. The technician said he could observe if he didn't talk and didn't make any noise. Questions would be entertained at the end.

My dad's first question was "Why are you tuning the fourths and fifths out of tune? And how can you accept a major third that is so obviously out of tune?" He smiled and said, "You know nothing about equal temperament, do you?" After recommending a book on ET for him to read he said, "You have something to learn about compromising."

CONCLUSION

My goal is to replace the flawed aspects of equal temperament with better solutions. This concept of achieving better intonation should be a tuning beacon for musicians around the world!

"No matter how masterful they are as musicians, many performers today don't hear how bad the ET major third is because it's what they're used to (conditioning) and because they've never heard an acoustically pure major third (ignorance). They're convinced that the ET major third must be the proper sound because it's what modern – and therefore obviously more enlightened – theorists have devised (delusion), and they wouldn't want to change because it would be too much trouble (convenience). Mostly, they don't want to think about it (oblivion). As convenient as it may be, it's time for modern musicians to think about this and, where appropriate, make some changes." Ross W. Duffin

If what I want to implement can become a reality, perhaps convincing others will be its biggest challenge. There, inevitably, would be concerns about our existing acoustic fixed pitched instruments becoming "period" instruments. It is, however, the mechanical challenges that place it on the endangered list.

Any concern that the computer becomes "too perfect" with its intonation prowess and not be convincing as "human music" should not be of concern. The physical feeling of enjoying harmonious sounds will prevail.

We must appreciate the aesthetics of harmony and nature and the resonance of sympathetic vibrations. Vibrations are vibrations. Out of tune is out of tune. In tune is in tune. Tuning is big!

As the great Nelson Mandela once said, "It always seems impossible until it's done."

Table of Intervals in Cents

Interval	Example	Ratio	Just	ET	Bach WT	Sixth-Comma	55-Division
Minor Semitone	C–C♯	135:128	92.2	100	94-110	88.6	87.3
Major Semitone	C–D♭	16:15	111.7	100	94-110	108.2	109.1
Minor Tone	C–D	10:9	182.4	200	196-204	196.7	196.4
Major Tone	C–D	9:8	203.9	200	196-204	196.7	196.4
Diminished 3rd	C♯–E♭	256:225	223.5	200	196-204	216.3	218.2
Augmented 2nd	C–D♯	75:64	274.6	300	294-306	285.3	283.6
Minor 3rd	C–E♭	6:5	315.6	300	294-306	304.9	305.4
Major 3rd	C–E	5:4	386.3	400	392-406	393.5	392.7
Diminished 4th	C–F♭	32:25	427.4	400	392-406	413.4	414.6
Augmented 3rd	C–E♯	125:96	478.5	500	496-502	482.1	480.0
"Perfect" 4th	C–F	4:3	498.04	500	496-502	501.6	501.8
Augmented 4th	C–F♯	45:32	590.2	600	594-608	590.2	589.1
Diminished 5th	C–G♭	64:45	609.8	600	594-608	609.8	610.9
"Perfect" 5th	C–G	3:2	701.96	700	698-704	698.4	698.2
Augmented 5th	C–G♯	405:256	794.1	800	794-808	787.0	785.4
Minor 6th	C–A♭	8:5	813.7	800	794-808	806.5	807.3
Major 6th	C–A	5:3	884.4	900	894-906	895.1	894.6
Augmented 6th	C–A♯	225:128	976.5	1000	996-1004	983.7	981.8
Minor 7th (lesser)	C–B♭	16:9	996.1	1000	996-1004	1003.3	1003.6
Minor 7th (greater)	C–B♭	9:5	1017.6	1000	996-1004	1003.3	1003.6
Major 7th	C–B	15:8	1088.3	1100	1094-1106	1091.9	1090.9
Diminished 8ve	C–C♭	256:135	1107.8	1100	1094-1106	1111.4	1112.7
Augmented 7th	C-B♯	2025:1024	1180.4	1200	1200	1180.4	1178.2
8ve	C–C	2:1	1200.0	1200	1200	1200.0	1200.0

Notes: As with the two Ds and the two B♭s, there are other possible Just ratios for some of these intervals: for example, 25:24 for a smaller minor semitone (70.7c), 25:16 for an augmented fifth (772.6c), and 125:64 for an augmented seventh (1158.9c). In this table I have given intervals that come closer to our usual scale.

BIBLIOGRAPHY

J. Bruce Gatchell – interviews and conversations

Ross W. Duffin (2007) *How Equal Temperament Ruined Harmony (and Why You Should Care).* W.W. Norton & Company, Inc. ISBN 978-0-393-06227-4

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[i] Cartoon drawing by Ryan Gatchell (2019)

[ii] Elephant cartoon drawing by Philip Neuman in Ross W. Duffin (2007) How Equal Temperament Ruined Harmony (and Why You Should Care). W.W. Norton & Company, Inc. ISBN 978-0-393-06227-4

[iii] 1995 Schott Musik International, Mainz, Friede auf Erden (Peace on Earth) Arnold Schoenberg opus 13

[iv] Circle of Pure Fifths by Ross W. Duffin

[v] Table of Intervals in Cents by Ross W. Duffin (2007) How Equal Temperament Ruined Harmony (and Why You Should Care). W.W. Norton & Company, Inc. ISBN 978-0-393-06227-4