World Musics and Microtuning

by Brian Lee

The musics of cultures other than the western have one thing in common despite their stunning diversity, they do not use the key system to define their scales.

Even in Europe the key system has only been in use for the last two hundred years. Before that a modal system was used, the eight notes of the diatonic scale that create a different modal feel depending which root note you choose. These "Church modes" like Phrygian, Lydian and Dorian are still in use and still part of our musical vocabulary.

It was only at around the time of J.S.Bach and Rameau that our equal tempered scale became fixed. It did so by compromising the simple rational relationships between notes in order to create a system wherein any one of the twelve notes of the chromatic scale can be used as the starting point for a major or minor scale.

The systems that equal temperament claimed to supersede were the scales built on simple rational relationships discovered by Ling Lun in China (c 2700 BC) and a bit later by Pythagoras in Greece (c 500 BC).

Put in simple practical terms, if you take a stretched string and play it you get a tone. Stop it half way along, you get a tone of twice the frequency (an octave). Divide it by two thirds and you get a tone one and a half (3/2) times the frequency of the whole string (the relationship of a perfect fifth). Divide the string by three quarters you get a tone 4/3 times the frequency (a perfect fourth) and so on. These intervallic relationships are pleasant to the ear and the general rule is the smaller the numbers involved in the ratio, the more pleasant the sound.

It is relatively easy to build a diatonic type scale using intervals of this kind. In fact the ear will naturally lead one towards these simple ratios and produce such a Just Intonation. However, if you want to repeat the same melodic pattern on different degrees of the scale, the same shape will have different intervals. This is the problem that the key system was designed to overcome.

In comparison to the rational system (rational in the sense of using ratios) the equal tempered system requires a sharp intake of breath for the non-mathematician. Look at a guitar fret board. The gaps between the frets get bigger logarithmically. This is to accommodate the key system and allow any note to be used as a tonic. The octave (2/1 in ratio terms) is divided into twelve equal steps, but because there is a geometric relationship between string length and subjective perception of tone, the division is made by taking the twelfth root of two as the factor by which the frequency of one tone is multiplied to reach the next semi-tone up. This relationship cannot be expressed in rational terms. The ear accepts it as near enough and gets used to it.

This system allows us to change key but as far as the ear is concerned it is a compromise. What is lost is the expressive feel that is inherent in the pure ratios.

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Since the beginning of the Romantic period in western art music, the principle aim for many composers has been expression. The flow of tension and relaxation through the relativity of dissonance and consonance. But because the consonance one returns to in equal temperament is not rationally pure, it is fundamentally unsatisfying to the ear. So the composer pushes further and further out into dissonance to make the return to consonance acceptable by contrast. The cadence requires a sense of drama so that you really know it is a cadence. This is typical of the music of late Romanticism But when the consonance is pure then it does not need to be thumped to make it tell, it only needs to be stated and that is enough.

In microtonal music expressive richness is almost unavoidable. The nature of a rationally tuned interval is by its very nature expressive. The structure of a piece using microtonal tuning needs only move to reveal the expression, to allow it through.

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Leaving the system of keys and modulations is like leaving the motorway and heading off cross country. Instead of having only twelve colours in the chromatic paintbox, there are now as many as you want, you decide your scale to express what you feel. But there are certain practical considerations.

The pioneer of the rational tuning revival in the west was the American, Harry Partch whose book "Genesis of a Music" tells the story of his weird and wonderful musical journey. But living in a pre-digital world he had to physically construct the instruments to play the scales . Starting by re-fretting guitars and hacking bits off the reeds of a harmonium, he then built marimba and lyre-like instruments tuned to his own idiosyncratic specifications.

But nowadays we don't have to make such an unholy alliance with the woodwork department, as many of the modern synths have the facility for user programmable scales.

Being digital instruments however, synths will not accept input in ratio terms. They require values in cents. (There are 100 cents to a semi-tone and therefore 1200 to an octave). Below is a short program in Basic to convert ratios to cents courtesy of composer Lawrence Ball.

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10 Print "Input the numerator and denominator of the ratio"
20 Print "and this program will give the cent value"
30 Print
40 Print "numerator": Input A
50 Print "denominator": Input B
60 Let R = A/B
70 Let C = 1200 * LOG(R)/LOG(2)
80 Print "cent value of ratio" A"/"B "is" C
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This program enables us to translate any scale constructed using ratios into a form which is digestible by most synthesisers.

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There are many different ways of constructing a rational scale. The way that Pythagoras used was to take the perfect fifth (3/2) and put another perfect fifth on top of it (9/4 or to put it back within an octave 9/8) which gives a major second. The next step gives 27/16 (a major sixth), then 81/64 (a largish major third), then 243/128 (a major seventh), then 729/512 (an augmented fourth). You can of course build downwards as well. The inverse interval of a perfect fifth (3/2) is the perfect fourth (4/3) and the others become 16/9. 32/27, 128/81, 256/243 etc.

Putting these intervals in sequence you get the following scale:

NOTE	RATIO	CENT VALUE
C	1/1	0
C#	256/243	90.2
D	9/8	203.9
D#	32/27	294.1
E	81/64	407.8
F	4/3	498
F#	729/512	611.7
G	3/2	702
G#	128/81	792.2
A	27/16	905.9
A#	16/9	996
B	243/128	1109.8

This is a typical Pythagorean scale. All the intervals are in the form of (3/2) to the power of n or (2/3) to the power of n. This is a simple procedure but it does create some pretty hefty numbers in the name of mathematical purity. Also it illustrates another principle - the highest prime number used in the scale is three. In fact it is a scale constructed solely of ratios using multiples of two's and three's.

Ling Lun's system follows the same route but goes beyond the 729/512, eventually reaching the dizzy heights of 177147/131072 for F. Classical Chinese and Japanese music still use this basic way of making scales. Further west, some Arabic scales use pure Pythagorean ratios to construct their scales. Arabic mathematics can be seen at its most creative in the lute tunings of the middle ages while Europe was in the Dark Ages.

Compare the following diatonic scale:

NOTE	RATIO	CENT VALUE
C	1/1	0
D	9/8	203.9
E	5/4	386.3
F	4/3	498
G	3/2	702
A	5/3	884.4
B	15/8	1088.3

Here we have used smaller numbers to construct the scale, but the highest prime is five. Take a simple diatonic melody and try it in the pure Pythagorean scale and then in the Just Diatonic scale and then go back to Equal Temperament and see if there is a difference in feeling. By changing the tuning of the notes only by a few cents you may not notice a difference in an individual interval but you may find a subtle change in the overall feel of the scale. According to some tuning practitioners, scales based on ratios only using multiples of threes and twos create a distant cool feel, whereas introducing ratios including five and its multiples generates a more emotional feel. Quite generally the major third (5/4) is experienced as having a happy feel and the minor third (6/5) a melancholic feel. In equal temperament, major third of 400 cents is quite wide of the pure rational major third of 5/4 (386.3 cents) and because of this, just intonation is more clearly expressive than equal temperament.

Here is another scale, a rational chromatic scale as used by Robert Rich, an American minimalist composer on his album "Geometry".

NOTE	RATIO	CENT VALUE
C	1/1	0
C#	16/15	111.7
D	9/8	203.9
D#	6/5	315.6
E	5/4	386.3
F	4/3	498
F#	7/5	582.5
G	3/2	702
G#	8/5	813.7
A	5/3	884.4
A#	9/5	1017.6
B	15/8	1088.3

You will notice that the F# in this scale is a 7/5 and uses a higher prime number than we have used before. Each higher prime is, as far as the ear is concerned, a journey further up the harmonic series. 7/5 is the ratio between the seventh and fifth harmonic of any tone. As a prime number cannot be made by multiplying other numbers together, it introduces a new feel to the music when it is used in a scale. But if you wish to stay within the limit of five there is the choice to use the composite ratios 64/45 or 45/32.

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Let's look at another way of building rational scales. This method was made explicit by Kathleen Schlesinger in her book "The Greek Aulos". In her research, she measured the positions of holes in flutes from many cultures around the world from Inca, to Eastern European to Eskimo and found a common pattern within the diversity of the scales. The same principle can of course be applied to strings and as we used strings as our previous example we shall do so again.

Take an even number like 16 and mark off the length of the string into sixteen equal parts. You don't even need a ruler to do it, just another piece of string which you halve repeatedly to make your marks on the sound board. If I stop the string at the first mark I am letting 15/16ths of the string vibrate, at the second stop 14/16ths, at the next 13/16ths and so on. If 15/16ths of the string is vibrating, I get a tone 16/15 times higher than the open string and so on. So my scale looks like this:

16/16 16/15 16/14 16/13 16/12 16/11 16/10 16/9 16/8

Some of these ratios can be simplified as follows:

NOTE	RATIO	CENT VALUE
16/16	1/1	0
16/15	16/15	111.7
16/14	8/7	231.2
16/13	16/13	359.5
16/12	4/3	498
16/11	16/11	648.7
16/10	16/10	813.7
16/9	16/9	996.1
16/8	2/1	1200

Quite a wild little scale from humble beginnings. What's familiar is the 16/15 (minor second), the 4/3 (perfect fourth), the 8/5 (minor sixth) and the 16/9 (minor seventh). But the rest is uncharted territory. Not only have we got a nine note scale without a perfect fifth, we've also got a couple of new prime numbers to contend with, 13 and 11. A long way from western diatonic or chromatic tonality.

But how on earth can such a scale be used apart from for melodic doodling? One way of structuring a piece of music is to choose one note in such a scale as a tonic drone. This way is used in bagpipe music from Scotland to the Balkans and beyond. It is also the basis of classical Indian Raga music. Accompany with percussion and you are making music from a totally different scale. Try a different note of the scale as the drone and see what difference that makes. See what triads you can use.

Let's try a different number to divide the string into. Kathleen Schlesinger refers to this as the Modal Determinant (MD). Here's MD 22.

22/22 22/21 22/20 22/19 22/18 22/17 22/16 22/15 22/14 22/13 22/12 22/11

Now let's simplify the ratios and filter out prime numbers over 11 in the denominator:

NOTE	RATIO	CENT VALUE
22/22	1/1	0
22/21	22/21	80.5
22/20	11/10	165.0
22/19		
22/18	11/9	347.4
22/17		
22/16	11/8	551.3
22/15	22/15	663.0
22/14	11/7	782.5
22/13		
22/12	11/6	1049.4
22/11	2/1	1200

and we have a scale typical of many Inca flutes.

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Indonesian gamelan music takes another approach to tuning. The resonance of gongs and bells produces a rich complex of overtones whose maths requires at least degree level to understand. (Bessel functions anyone?) Suffice it to say that the harmonics of a gong or a bell are not in whole number ratios to the fundamental (if a bell can even be said to have a fundamental). For practical purposes, if I have a chromatic set of tubular bells for example, and attempt to play a fast melodic passage, I end up with a jangle of clashing overtones. The Indonesian solution is to tune the gongs of a gamelan avoiding whole number ratios. This enables a gamelan orchestra to play fast polyphonic passages without overtone clashes.

Research by Dutch ethnomusicologist Jaap Kunst in Indonesia has shown that each village tunes its gamelan slightly differently since the aim of avoiding ratios can be accomplished with different tuning solutions. One way for us to imitate this on a synth is to divide the octave into 7 equal steps on the white notes (the pelog scale) and five equal steps on the black notes (the salendro scale).

PELOG

NOTE	CENT VALUE
I	0
II	171
III	343
IV	514
V	686
VI	857
VII	1029

Similar scales are also found in Burma and Thailand.

SALENDRO

NOTE	CENT VALUE
I	0
II	240
III	480
IV	720
V	960

These scales do not work in a harmonic sense as ratio based scales. Rather they are best used for sequencing patterns in the same pulse at different speeds.

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As we have noted before, digital technology obviates the need for carpentry. With it we can generate and perfect sounds that would otherwise take years of experimentation building instruments thereby saving time and quite a few trees. Through this technological access to other tuning systems we can also travel to other cultures and historical periods.

As western culture spreads, the equal temperament system of tuning spreads with it. This is having a devastating effect on many traditional musical ecologies. For example in India, only the ragas that approximate to equal temperament can be played on western instruments such as guitars, saxes and pianos. The same is happening in Turkey, Iran and countless other countries. Synthesisers and digital technology offer a way of keeping alive traditional tunings and thereby much of the musical richness of our planet. They open doors to new worlds of musical possibilities and maybe point the way to new musical futures.

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