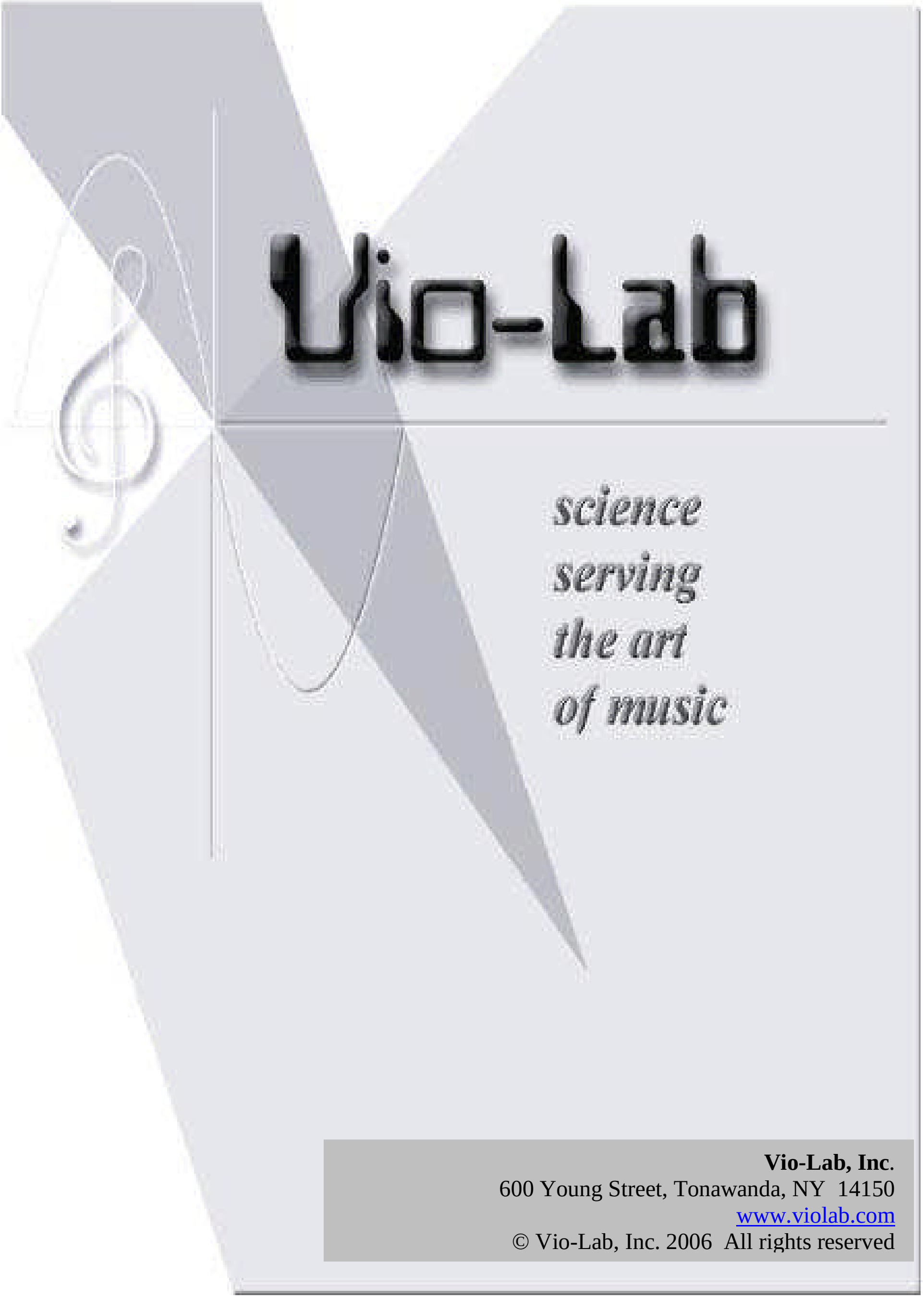

Vio-Lab, Inc.
600 Young Street, Tonawanda, NY 14150
www.violab.com

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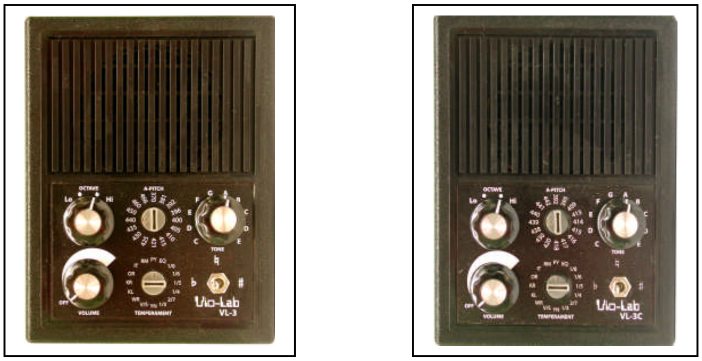

Vio-Lab Models VL-3 and VL-3C

INTRODUCTION

I developed the Vio-Lab *"PitchMan"* Variable Temperament Electronic Tuner to serve the special needs of professional and amateur early music instrumentalists, ensemble leaders, and organ tuners. The design and special features of the *"PitchMan"* evolved from my experience as an acoustician, viol player, and harpsichord tuner, as well as the opinions and suggestions of world-class early music performers and directors. Based upon the premise that good musicianship requires a keen aural sensitivity to pitch and tuning, the *"PitchMan"* uses no visual indicators such as a meter needle or LED array. This manual will teach you how to use your ear in conjunction with the *"PitchMan"* to achieve optimum tuning. By learning and practicing tuning by listening, you will continually refine your ear's pitch discrimination.

The *"PitchMan"* generates a tone quality which is very rich in overtones or harmonics, so that, when combined with the harmonics of the string or pipe being tuned, wave interference ‘beats’ can be clearly heard. Using the procedure detailed in the next section, highly precise tuning can be easily achieved by eliminating these “beats”.

Sixteen A-pitches commonly used in early music and historic performance practice are digitally stored in your *"PitchMan"*, and are referenced to a precision quartz crystal frequency standard for unsurpassed absolute A-pitch accuracy and stability.

The volume control, a feature not found on other electronic tuners, allows optimum loudness setting for individual or group use. To prevent premature battery depletion, your *"PitchMan"* will remain distinctly audible when set to its softest volume level to prompt you to turn it completely off after you have finished tuning.

Foremost, the *"PitchMan"* offers a wide selection of temperaments, which are very subtle variations in interval sizes that, nonetheless, have a dramatic effect on interval and chord consonance. This feature will enable you (and the other instrumentalists in your ensemble) to obtain optimum sonority for a given historical period of music or style of composition. A discussion of the nature of temperament and its application to improve the authenticity of early music playing forms a major portion of this *"PitchMan"* Variable Temperament Tuner Owner's Manual.

Fred Reinagel, M.S.E.E.

GETTING STARTED

Your Vio-Lab *"PitchMan"* can be used in a manner similar to the operation of any number of other electronic tuners on the market. However, as stated, it has additional features, which are of particular importance to the serious early music instrumentalist and historical performance practitioner. Use of these features will be explained in later sections of this manual. This section will tell you how to use your *"PitchMan"* in its most basic mode, which is equal temperament, the octave that starts at middle-C, and A-pitch at 415 Hz, all of which are preset at the factory (see Figure 1).

Figure 1: *"Pitchman"* VL-3 and VL-3C Dials
Figure shows knobs set at Pythagorean (PY) temperament, and A = 440 or A = 439

1. Turn the **TONE** selector control to the pitch name of the string, fret, or pipe to be tuned. Set the accidental control switch appropriately, natural pitches being produced when this switch is in its center position midway between the I and # positions. Pipes or open strings may be tuned in any order; but frets cannot be tuned unless the string being sounded has been precisely tuned as an open string.

2. Rotate the **VOLUME** control clockwise from the **OFF** position until the apparent loudness of the *"PitchMan"* is about the same as the instrument to be tuned. Acuity of pitch perception is usually enhanced at softer levels.

3. Play the pitch to be tuned. For bowed instruments, use a light bow stroke near the bridge. For plucked instruments, pluck the string near the bridge or stopped end. These techniques produce a tone rich in harmonics, which facilitates the ear's ability to perceive small pitch differences.

4. Compare the pitch of the instrument with that of the *"PitchMan"*, and turn the appropriate tuning peg or pin for open string tuning, move the fret, or adjust the length of the pipe to reduce the difference in pitch as much as possible. This is called coarse tuning.

Continued next page

GETTING STARTED cont'd

5. When the difference in pitch is so small that it is not easy to discern whether the instrument's tone is sharper or flatter than that of your *"PitchMan"*, intonation can be further improved by a process called fine-tuning. To do this, play the instrument while carefully listening to the interaction between its sound and that of your *"PitchMan"* adjusted to about the same loudness. By random trial, adjust the peg, fret, pin, or pipe by very small amounts until all wavering or 'beating' of the combined sound completely disappears. If the rate of 'beating' increases, you have adjusted in the wrong direction. (Adequately doped pegs will greatly facilitate tuning of open strings.) A properly fine-tuned pitch should produce a perfectly smooth and even tone when sounded with your *"PitchMan"*. To check fine-tuning for bowed instruments, use a quick, firm bow stroke to set the string in motion, and then lift the bow. As the string 'rings', carefully listen to the composite sound to be sure that not even a very slow waver remains.

6. Set the **TONE** selector and accidental switch to the tone name of the next string, fret, or pipe to be tuned, and proceed with Step 4. (Again, open strings or pipes may be tuned in any order. Frets may also be tuned in any order provided the sounding string has been finely tuned as an open string.)

If your stringed instrument was quite out of tune, or if you are shifting your A-pitch, it will be necessary to coarse-tune the open strings more than once before fine-tuning because changing the tension of each string as you tune will have some effect on the tensions (and, therefore, the pitches) of the strings already tuned. Once correct coarse tuning of all open strings is verified, fine-tuning can be accomplished with only a single tuning per string. As every gut-stringed instrument player knows, however, periodic re-tunings during a session are required, especially after an initial period when strings are 'warming up' to hand temperature and humidity effects. Tuning of frets is normally required only if they have slipped, after installing new strings, or, most importantly, when changing scale temperament or accidental selection. Details on fret tuning are discussed in a later section of this manual.

Tuning a consort of instruments may be expedited by placing your *"PitchMan"* on the floor set to a loud volume, and having all players simultaneously coarsely tune (step 4) to each required tone. (Be sure that the accidental selector switch is in its centered (natural) position for the tuning of open strings.) After all tones are coarse-tuned, fine-tuning can commence. However, only one instrument at a time can be finely tuned (step 5), because the hearing of 'beats' is completely confounded by the introduction of a third tone to the composite sound. It is usually most convenient to have all players, one at a time, finely tune to the same tone name (e.g., all the A strings) before changing the tone selector to the next tone. The method of tuning one instrument to the *"PitchMan"*, and having the rest of the consort tune to that instrument, is not recommended because it allows an additional source of pitch error to enter the ensemble tuning.

OCTAVE SELECTION

With the octave selector set to its right-hand dot position, the *"PitchMan"* can produce all pitches from C| below middle-C to E# one-and-one-half octaves above. Moving the octave selector switch to the left-hand dot and **LO** positions transposes all pitches down one and two octaves, respectively. In its **HI** position, all pitches are transposed up by one octave. However, it is not strictly necessary to set your *"PitchMan"* to the same octave as the pitch being tuned because it is actually the upper harmonics of the instrument and *"PitchMan"* tones which provide the auditory cues required for precise tuning. Octave selection is purely a matter of your personal preference or of convenience.

A-PITCH SELECTION

The A-pitch of your *"PitchMan"* is preset at the factory to 415 Hz (for all temperaments), since this is the most commonly used pitch standard for many early-music instruments.

However, the A-pitch setting may be easily changed to any of 16 values between 370 and 466 (VL-3 model) by turning the **A-PITCH** selector (center, top) of your *"PitchMan"*. The VL-3C model A-pitch values include closely spaced clusters around 415 Hz and 440 Hz to address the needs of some ensemble situations.

All A-pitches (and, indeed, all pitches) are derived from a precision quartz-crystal oscillator and are absolutely accurate to within one-tenth of a cent. (One cent, which is one-hundredth of an equal-tempered semitone, is the smallest pitch difference detectable by the best musical ear.) Select the desired A-pitch and turn the selector knob until the notch in the knob skirt is adjacent to the selected value. The computer chip design of your *"PitchMan"* guarantees the absolute pitch accuracy of 30,720 digitally stored pitches at all times and under all conditions.

TEMPERAMENT SELECTION

The most important feature of your *"PitchMan"*, which distinguishes it from other electronic tuners on the market, is its ability to provide a selection of 17 different scale temperaments. To make best use of this feature, a basic understanding of temperament is required, a subject which many musicians find somewhat mystifying and arcane. I shall attempt, in the next several paragraphs, to provide a lucid explanation of this aspect of musical interval and scale tuning, although I will be the first to admit that a clear understanding might require a few careful readings.

Pure Intervals. First, let me define pure musical intervals as those pairs of tones which have frequency-ratios of small whole numbers or integers. The relationship between intervals and frequency-ratios holds true over the entire audible spectrum, regardless of the absolute frequency values (vibrations per second) of the tones. Figure 2 is a list of recognizable pure intervals of an octave or less and their frequency-ratios.

Continued next page

TEMPERAMENT SELECTION cont'd

For example, if A is 415 Hz (vibrations per second), a pure major 6th below it (C) would be 3/5 of this frequency, or 249 Hz; or a pure minor 6th above it (F) would be 8/5 of 415, or 664 Hz. Psychologically, listeners judge that, when both tones are sounded together, intervals which have frequency-ratios of smaller integers are more harmonious or consonant than intervals having higher integer ratios. When we tune octaves, 5ths, or 4ths by listening to both tones simultaneously, we naturally select pure intervals as being 'correct'. (For those interested in a psycho-acoustic explanation of interval consonance, a detailed discussion is provided in the Appendix.) You may have noticed that many ratios are absent, e.g., 7:4, 9:7, 11:8. These intervals, although they possess the expected degree of consonance, are not recognizable as diatonic intervals (those within the "do, re, mi, fa,…" diatonic scale). In a few cases, more than one ratio is recognized as the same diatonic interval, since these ratios have nearly the same arithmetic values.

To obtain the frequency-ratio of an interval which is the result of a succession of intervals of known ratios, merely multiply their corresponding fractions, the fraction for a descending interval being the reciprocal of the frequency-ratio. For example, an ascending pure major 6th followed by a descending pure major 3rd would be 5/3 x 4/5 = 4/3, which is a pure 4th. The inversion of any interval is the difference between an octave and that interval. Therefore, the frequency-ratio of the inversion of an interval can be calculated by ascending an octave and descending that interval. For example, the inversion of a pure minor 3rd would be 2 x 5/6 = 5/3, which is a pure major 6th.

OCTAVE	2:1
FIFTH	3:2
FOURTH	4:3
MAJOR SIXTH	5:3
MAJOR THIRD	5:4
MINOR THIRD	6:5
TRITONE	7:5
MINOR SIXTH	8:5
MINOR SEVENTH	9:5
WHOLE TONE	9:8
TRITONE	10:7
WHOLE TONE	10:9
MAJOR SEVENTH	15:8
MINOR SEVENTH	16:9
DIATONIC SEMITONE	16:15
CHROMATIC SEMITONE	25:24

Figure 2: Pure Intervals

The Pythagorean Scale (PY). Let us consider a scale constructed by taking a succession of pure 5ths and 4ths. For example, starting with C, ascend a 5th to G, then down a 4th to D, up a 5th to A, down a 4th to E, up a 5th to B, down a 4th to F#, down another 4th to C#, etc. To obtain flats, we must also start with C and go up a 4th to F, up another 4th to B♭, down a 5th to E♭, etc. The resulting scale is called Pythagorean because it is based on the pure 5th and its inversion, the pure 4th, the integral frequency-ratios of which were deduced 25 centuries ago by the Greek philosopher and mathematician, Pythagoras. It is also called a 'regular' scale tuning because the sizes of the generating intervals (5ths and 4ths) are constant. Two important aspects of the Pythagorean scale are:

1. Tones which we conventionally think of as 'enharmonics' of each other differ by about 1/4 of a semitone; e.g., G# is higher than A♭ by this amount. This is because a succession of six ascending pure 5ths and six descending pure 4ths has a frequency-ratio of $(3/2)^6$ x $(3/4)^6$ which equals 531,441:262,144 (or 2.0272865...: 1) instead of exactly 2:1 for a pure octave. This small interval between 'enharmonic' tones, which has a frequency-ratio of 1.0136433...:1, is called the Pythagorean comma. It is about one ninth of a wholetone interval, or about 23.46 cents.

Continued next page

TEMPERAMENT SELECTION cont'd

2. The major 3rd of the Pythagorean scale, which is obtained by a succession of two ascending pure 5ths and two descending pure 4ths, is badly out of tune (too wide). This is because this interval has a frequency-ratio of $(3/2)^2$ x $(3/4)^2$ or 81:64 (large integers) instead of 5:4. The difference interval between a Pythagorean major 3rd and a pure major 3rd is 81/64 x 4/5 = 81/80 or 1.0125:1, and is called the syntonic comma. For many purposes, the values of the Pythagorean and syntonic commas are close enough (within two cents) to be considered equivalent. When the difference, called an schisma, is significant, the approximation of 11 Pythagorean commas equaling 12 syntonic commas is extremely good.

The Pythagorean minor 3rd is obtained by a succession of two ascending pure 4ths and a descending pure 5th, or $(4/3)^2$ x 2/3 = 32/27, which is equivalent to ascending a pure 5th and descending a major 3rd (3/2 x 64/81). Comparing this to the pure minor-3rd ratio, 6/5, the difference interval is 80/81. Thus, the Pythagorean minor 3rd is also out of tune (too narrow) by a full syntonic comma. A one-comma error (with respect to pure intervals) also exists for Pythagorean major and minor 6ths because they are combinations of Pythagorean 3rds with a pure octave (inversions). In all cases, in fact, the tuning errors of intervals which are inversions of one another are identical (but in opposite senses) because octaves are always tuned pure.

Diatonic and Chromatic Semitones. An important property of scales, in general, is the distinction between diatonic and chromatic semitones. A diatonic semitone, as its name implies, is the interval between the third and fourth (mi-fa) and between the seventh and eighth (ti-do) degrees of the diatonic major scale; e.g., E to F in a C-major scale, F# to G in G-major, or A to B♭ in F-major. Observe that the tone name letters of diatonic semitone notes are always different. On the other hand, a chromatic semitone is that produced by the alteration of a given tone by an accidental sign, e.g., F to F# or B to B♭, thus always retaining the same tone name letter. Equivalently, a diatonic semitone may be defined as the difference interval between a 4th and a major 3rd, and a chromatic semitone as that between a major 3rd and a minor 3rd. Using pure interval frequency-ratios, the diatonic semitone is 4/3 x 4/5 = 16/15; and the chromatic semitone is 5/4 x 5/6 = 25/24, about 37% smaller. However, in the Pythagorean scale, chromatic semitones turn out to be actually *larger* than diatonic semitones by a full comma; or, put another way, Pythagorean chromatic semitones are about 25% larger than Pythagorean diatonic semitones. The intervallic difference between the two types of semitones is called the lesser diesis, which, as you can work out for yourself, is also the difference between three major thirds and an octave for regular scale tunings.

Equal-tempered Scale (EQ). The logically ensuing question is: can anything be done to ameliorate the dissonances of 3rds and 6ths in the Pythagorean scale? The answer is **TEMPERAMENT**: the detuning of pure 4th and 5th intervals by very small but reciprocal amounts (so that in combination they will always equal a pure octave). First, consider narrowing the pure 5th (with the corresponding widening of the pure 4th) by an amount which would eliminate the pitch difference between 'enharmonic' notes. Since there are twelve intervals in the 'circle of 5ths', this amount is exactly 1/12 Pythagorean comma, and produces what we know as the equal-tempered scale. It naturally follows that this scale, which divides the octave into twelve exactly equal semitones, has identically-sized diatonic and chromatic semitones.

Continued next page

TEMPERAMENT SELECTION cont'd

The equal-tempered scale, which is the universally employed modern (Western) music standard, has the advantages of total flexibility of enharmonic key modulations and equal sonority in all keys.

Admittedly, this temperament provides the properties which engendered the evolution of compositional styles and techniques over the past two centuries. And, indeed, the equal-tempered scale is necessary for the proper rendition of much of the music of the encompassed periods, especially keyboard music. However, as we shall see, a large price had to be paid for these advantages.

Narrowing of 5ths by 1/12 Pythagorean comma, or about two cents, is a very small change, and the resulting 4ths and 5ths sound so nearly pure that most musicians are not aware that they are tempered. At the same time, the major 3rd, which is a succession of two ascending 5ths and two descending 4ths, has been improved (narrowed) by 4/12 or 1/3 comma over the badly out-of-tune Pythagorean major 3rd. However, this still leaves the equal-tempered major 3rd 2/3 comma wider than a pure major 3rd, and the minor 3rd 3/4 comma too narrow, both of which remain quite dissonant. Of course, 6ths will have the same amounts of error, but in the opposite senses from their inversions - major 6ths 3/4 comma wide, and minor 6ths 2/3 comma narrow. Why is it that we are not constantly aware of these dissonances when we listen to music rendered in equal temperament? It is because we have been exposed to the equal-tempered scale all of our lives, and have thus 'learned' that this is what 3rds and 6ths 'should' sound like - a condition which the eminent German theorist and acoustician Hermann von Helmholz called the "corruption of the musical ear".

Quarter-comma Meantone Scale (1/4). A great deal of music was written before the universal adoption of equal temperament. This music generally used simple key signatures and was composed without enharmonic modulations. Therefore, when playing such period literature, we can and should consider tempering the 5th to the point where the major 3rd becomes pure. This is achieved by narrowing the 5th by 1/4 syntonic comma, producing the so-called quarter-comma meantone scale. (The term 'meantone' derives from the fact that the whole-tone frequency-ratio is the geometric mean of the pure major 3rd, or $\sqrt{5}:2$.) This was, in fact, the most widely used tuning system during the Renaissance, and composers of the period profited greatly by its ear-pleasing sonorities in the harmonic infrastructure of their music.

Continued next page

TEMPERAMENT SELECTION cont'd

Some of the properties of the quarter-comma meantone scale are that 4ths and 5ths are perceptibly out of tune, but yet are relatively much more consonant than equal-tempered 3rds. Minor 3rds are also in error, being 1/4 comma narrow, since they are the difference between a 1/4-comma narrowed 5th and a pure major 3rd. This is also much better than the 3/4-comma error in equal-tempered minor 3rds. Major triads, although slightly out of tune, have a very rich, blended sonority. Both diatonic and chromatic semitones turn out to be 1/4 comma wider than their corresponding pure tunings. Contrary to the Pythagorean scale, however, diatonic semitones are now *larger* than chromatic semitones by the rather startling amount of 54%. Related to this fact is that 'enharmonic' tones are separated by about twice that of the Pythagorean scale, but in the *opposite* direction. Compared to the previous example given for the Pythagorean scale, G# is almost two commas *lower* than A♭ in the quarter-comma meantone scale, a difference so great that the ear cannot be fooled into perceiving them as enharmonic.

Fifth-comma Temperament (1/5). The very large differences in semitone sizes in quarter-comma tuning can sometimes create technical and musical difficulties. These problems can frequently be eased by using lesser degrees of temperament. One attractive candidate is that which would distribute interval-tuning errors (with respect to pure intervals) equally between the 5th and major 3rd. This objective is achieved by fifth-comma temperament since the major 3rd would be corrected by 4/5 of its original full-comma Pythagorean tuning error. (The major 3rd is always changed by four times the change in the 5th because it is the result of a succession of four scale-generating intervals.) In this scale, 4ths and 5ths are slightly better (by 1/20 comma) than in quarter-comma temperament, and the 1/5-comma error in the major 3rd produces a very nearly pure interval as compared to the equal-tempered major 3rd which is 2/3 comma wide. The minor third is 2/5 comma narrow, a little worse than quarter-comma temperament, but yet substantially more consonant than the 3/4-comma error in equal temperament. Since both major 3rds and 4ths are wide by 1/5 comma, the diatonic semitone has no error. The chromatic semitone is 3/5 comma wide, but closer in size to the diatonic semitone, the latter now being about 34% larger than the former. Indeed, as we continue to reduce the amount of 5th tempering (widening toward pure), the difference between the two types of semitones will become less and less, until it disappears when equal temperament is reached. Compared to the nearly two-comma disparity in quarter-comma temperament 'enharmonic' tones, fifth-comma temperament considerably reduces this difference to about 1.2 commas.

Continued next page

TEMPERAMENT SELECTION cont'd

Sixth- and Eighth-comma Temperaments (1/6 and 1/8). These lesser degrees of temperament provided on your *"PitchMan"* are closer to equal temperament than the above, but yet provide some degree of improvement in sonority for music written in simple keys. Sixth-comma tuning was espoused by Gerle, a 16th century lutenist, and by Silbermann, who was a keyboard instrument maker who pioneered the development of the forte-piano. Since it is not clear whether Silbermann based his temperament upon the syntonic or Pythagorean comma, the latter version is also included under 'well' temperaments (see section on 'Circular or Well Temperaments'). These temperaments can be useful for compositions which have occasional wider harmonic excursions from their home keys, but which, on the whole, sound more satisfying using a heavier-than-equal temperament. These temperament choices may also provide a good means for you and your consort group to gradually acclimate your ears to unfamiliar scale tunings as you progress from equal temperament to the more heavily tempered (but more sonorous) tunings suitable for a large share of early music literature. Eighth-comma temperament is also frequently chosen for instruments of the lute family, and is therefore often useful when playing in mixed consorts with these instruments.

Two-Seventh- and Third-comma Temperaments (2/7 and 1/3). These heavier-than-quarter-comma temperaments are provided on your *"PitchMan"* because they have some historical and theoretical importance. The former, attributed to Zarlino, is that which produces equal - yet acceptably small - errors in major and minor thirds. The latter, proposed by Salinas, achieves minor 3rds and major 6ths which are pure. However, it is more remarkable in that it produces a closed scale of 19 steps per octave where, for example, B# is enharmonic with C♭, and no consonant interval has an error exceeding 1/3 comma. By using the **ACCIDENTAL** selector switch, all 19 pitches are available on your *"PitchMan"*. The disparity between diatonic and chromatic semitones for these tunings is even more pronounced than for quarter-comma tuning. This is likely to be perceived as gross 'out-of-tune'ness' of melodic lines to our modern ears which are inured to equal temperament. On the other hand, 'meantone' scales do represent another musical palette of tonal colors which have an exotic charm endowed by the very fact of their strangeness.

Regular Temperaments. The temperaments discussed so far are classified as 'regular' temperaments because all like-spelled intervals are exactly the same size. This is particularly meaningful for fretted instruments because regular temperaments can be perfectly realized with straight frets, which are parallel to each other and perpendicular to the strings. When tuning a standard keyboard instrument to a regular temperament, you must decide whether a chromatic (black) key will be a flat or a sharp since they have different pitches (except for equal temperament). This results in one misspelled 5th on the keyboard (and, of course, its inversion) being badly out of tune. This is called the 'wolf' interval, and is usually placed between G# and E♭. (Eighth-comma tuning produces a 'wolf' having a marginally tolerable error of 3/8 comma.) The existence of this so-called 'wolf' is why these tunings are non-circular - the sequence of 5ths (except for equal and third-comma temperaments) does not close on itself, i.e., is not a circle of 5ths. Since each chromatic key must be tuned as *either* a flat *or* a sharp in non-circular temperaments, only eight properly spelled (and therefore properly tuned) major triads can be realized on a 12-key-per-octave keyboard. Since your *"PitchMan"* has *all* single flats and sharps, you are at liberty to place the 'wolf' interval wherever you desire in the sequence of 5ths as dictated by the key and harmonic compass of the composition(s) to be rendered.

Continued next page

TEMPERAMENT SELECTION cont'd

To provide an overall understanding of regular temperaments, Figure 3 shows the error for various intervals as the 5th is progressively narrowed from pure to 1/3 comma narrower than pure. The lesser diesis interval, which is a measure of the difference between diatonic and chromatic semitones, vanishes for equal temperament. This occurs for a temperament of 1/11 syntonic comma, which (by sheer mathematical serendipity) is equivalent to 1/12 Pythagorean comma. All regular temperaments on your *"PitchMan"* use the indicated fraction of the syntonic (not the Pythagorean) comma. They are selected by the **TEMPERAMENT** switch code assignments from **0** to **7**, and increase in degree of temperament as the code number increases. Temperament selection is made in the same manner as A-pitch selection by turning the selector knob until the notch in the knob skirt is adjacent to the selected temperament. This is indicated by the fraction of syntonic comma, or the abbreviations defined on pager 15-17.

To summarize this discussion of regular temperaments, may I suggest to you a few demonstrations using your *"PitchMan"* to illustrate the principal effects of tempering? Recalling that the pitch of **A** is the same for all temperaments, listen to what happens to the pitch of the **F** tone, which is a major 3rd below **A**, as you sequence the **TEMPERAMENT** selector clockwise from **PY** to **1/3**. Notice that pitch of **F** becomes sharper by very small increments as the major 3rd progresses from being one-comma wide to 1/3-comma narrow. This phenomenon is even more dramatic when listening to **D|** which is two major 3rds below **A**, because the total pitch change is more than half a semitone. The same effects can be observed for **C#** and **E#** which are one and two major 3rds above **A**, respectively, except their pitches will become flatter as you sequence the **TEMPERAMENT** selector clockwise from **0** to **7.**

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TEMPERAMENT SELECTION cont'd

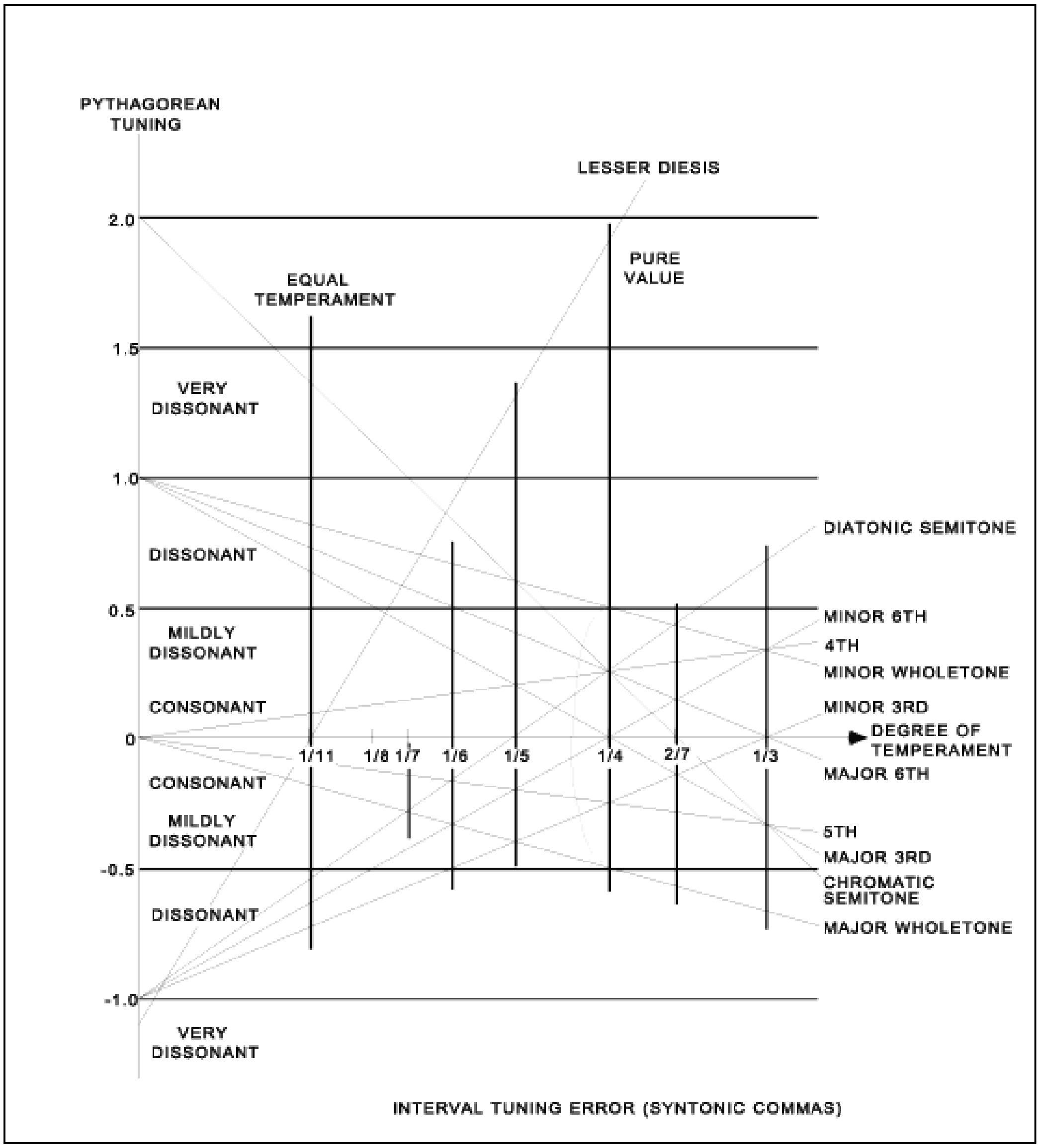

Figure 3: Interval Tuning Error (Syntonic Commas)

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TEMPERAMENT SELECTION cont'd

In another demonstration, listen to the diatonic semitone interval by alternating the TONE selector control between **E** and **F**. Notice that this interval becomes wider and wider as you sequence the TEMPERAMENT control from **0** to **7**. In a similar manner, toggling the ACCIDENTAL selector switch between its center (natural) and **#** positions, the chromatic semitone from **A** to **A#** can be heard to become narrower and narrower over the same sequence of temperaments.

Circular or 'Well' Temperaments. To deal with the problems of 'wolf' intervals and unusable triads on keyboard instruments, late renaissance and early Baroque theorists devised many keyboard tunings which used variously tempered (narrowed) 5ths between some or all of the 'white' keys, and somewhat wider (frequently pure or occasionally wider than pure) 5ths between the remaining keys. This approach was able to avoid the 'wolf' fifth, and make more triads usable. Some triads, however, would necessarily be more dissonant than equal-tempered triads. Your *"PitchMan"* incorporates nine historical non-equal 'well' temperaments which are selected by the TEMPERAMENT selector code assignments from **8** to **F**, and increase in degree of irregularity as the code character increases.

Young I (YN). This 'well' temperament, considered by Barbour an "excellent irregular temperament", uses 5ths in the C-G-D-A-E sequence narrowed by 3/16 syntonic comma, and those in the F#-C#-G#-EI-BI tuned pure. The remaining 5ths are equal in size and turn out to be very close to 1/12 syntonic comma narrow. Only one of the 12 major 3rds is as bad as Pythagorean (a full comma wide), and four others are worse than equal-tempered, all being located in the more remote key signatures. The distribution of sonorities is symmetrical, C-major being the best, and three sharps or flats being almost exactly equal temperament. Because of its complexity, this temperament was difficult to set by ear, and therefore historically not widely used. Now, with your *"PitchMan"*, you can take advantage of its beneficial qualities.

Vallotti/Silbermann (V/S). These temperaments are based on 1/6 Pythagorean comma temperament. In both cases, 5ths in the F-C-G-D-A-E-B sequence are narrowed by 1/6 comma. In the Vallotti tuning (lately 'rediscovered' by Van Biezen), the remaining six 5ths in the circle are pure, and are given on your *"PitchMan"* with the ACCIDENTAL selector in the I position. In this case, major3rds in keys of five or more accidentals are Pythagorean, and two others are worse than equal-tempered. This is also a symmetrical tuning with F-, C-, and G-major triads all being twice as good as equal temperament. Vallotti tuning is well suited to much early and middle Baroque literature, and is the choice of many ensembles which combine viols and keyboard instruments. The Silbermann scale, selected when the ACCIDENTAL selector is in the sharp # position, continues to narrow 5ths into the chromatic tones by 1/6 comma. Following the variant indicated by Klop, BI-EI is *widened* by 1/6 comma to reduce the 'wolf' to 1/2 comma, and make the EI tone more usable as a D#. Seven inner major keys have equally 'good' major 3rds 1/3 comma wide. Outer key signatures are very piquant to the point of being unusable.

Continued next page

TEMPERAMENT SELECTION cont'd

Werckmeister III (WR). This famous temperament is based on 1/4 syntonic comma temperament. The 5ths in the C-G-D-A sequence are narrowed by 1/4 comma, and those in the descending C-F-Bl-El-G#-C#-F# sequence and E-B are all pure. This leaves the B-F# 5th narrowed by 5/16 Pythagorean comma because it includes the schisma difference between syntonic and Pythagorean commas. In this case, three major 3rds are Pythagorean, and four others are just slightly worse than equal-tempered. Major triads on C, F, and B are more sonorous than for Vallotti tuning, the latter commending this temperament for pieces in E-minor.

Kellner's Proposed J.S. Bach (KL). This temperament is based on a multi-disciplinary research effort by H.A. Kellner in the 1970/80's. It is similar to Werckmeister III, except it uses 1/5 Pythagorean comma temperament and extends the contiguously tempered sequence of 5ths to E. Major 3rds on C, G, D, and A are slightly better than in Werckmeister at the expense of all others, except those on Ai, Di, and F# which are Pythagorean in both cases.

Kirnberger III (KR). This temperament uses 5ths narrowed by 1/4 syntonic comma in the C-G-D-A-E sequence of the inner part of the circle of 5ths. The syntonic comma is chosen to preserve the purity of the C-E major 3rd. The result is two major 3rds in the outer keys being Pythagorean and three others nearly so. Two are slightly worse than equal-tempered, and the inner keys are very good.

Temperament Ordinaire (OR). This designation applies to a number of variations of 'well' temperament which were very popular in France in the late Renaissance and early Baroque periods. The genre is characterized by 5ths in the inner part of the circle tempered 1/4 to 1/6 comma, gradually widening toward the outer part of the circle until the two outermost 5ths are wider than pure. Since exact descriptions are not historically documented, I have attempted to construct a 'middle-of-the-road' version. The *"PitchMan"* realization of this temperament uses integral multiples of 1/15 Pythagorean comma, with 5ths in the C-G-D-A-E-B sequence narrowed by 3/15 or 1/5 comma. B-F# is narrowed by 2/15 comma, while F-C and F#-C# are each narrowed by 1/15 comma. C#-G# and F-Bi are pure, and Bi-Ei-G# are widened by 2/15 comma. This tuning results in three major 3rds being worse than Pythagorean, and two between Pythagorean and equal-tempered. The rest are better than equal-tempered with inner keys being very good, favoring keys with sharps.

Eighteenth-century Italian (IT). This temperament uses 5ths narrowed by 1/4 syntonic comma (11/48 Pythagorean comma) in the C-G-D-A-E sequence of the inner part of the circle of 5ths. 5ths in the C-F-Bi-Ei-Ai sequence are *widened* by 1/12 Pythagorean comma, leaving the remaining four 5ths 5/48 Pythagorean comma narrow. This temperament has pronounced irregularity with four major 3rds close to Pythagorean or worse. However, inner key signatures are very good, favoring those with sharps.

Continued next page

TEMPERAMENT SELECTION cont'd

Rameau (RM). This temperament, the most irregular of the 'well' temperaments furnished with your *"PitchMan"*, uses 5ths narrowed by 1/4 syntonic comma in the F-C-G-D-A-E-B sequence of 5ths. Thus, major triads in F, C, and G are tuned exactly as in quarter-comma meantone. 5ths in the B-F#-C#-G# sequence are tuned pure, resulting in gradually worsening major 3rds as more sharps are added to the key signature. Although not quite as good as in equal temperament, E - and B-major are quite usable. Going the other way around the circle, F-Bi-Ei 5ths are *widened* by 1/4 Pythagorean comma, causing flatted keys to deteriorate rapidly. In fact, keys with more than two flats are essentially unusable. On the other hand, what would have been an almost two-comma 'wolf' between Ei and G# in quarter-comma meantone has been completely tamed to the point of being 1/8 comma narrow.

To summarize the essential qualities of the irregular circular temperaments available on your *"PitchMan"*, the chart provided in Figure 4 shows the tuning errors of all major 3rds in each of the nine historical 'well' temperaments. This chart can provide a quick comparison of the 'flavoring' difference between temperaments, and can provide guidance in selecting a temperament propitious for the key signature(s) and tonal compass of the literature being performed.

WHEN TO USE WHICH TEMPERAMENTS

In general, the older the period of composition, the greater is the degree of tempering which can be successfully utilized. For example, almost all Henrician, early Elizabethan and contemporary continental music from the Flemish, German, Italian, and Spanish schools sounds best in quarter-comma meantone temperament. Later Elizabethan and Jacobean period music, because of its more complex harmonic schemes and further excursions into secondary keys, more readily lends itself to fifth- or sixth-comma temperament. The choice among regular temperaments is best decided by examining the specific composition to see if and how often 'enharmonic' tones (other than melodic passing notes) are required in different major triad chords. In the case of music for fretted instruments, determine whether 'enharmonic' tones can be executed with a reasonable combination of fret placement and fingering (see below).

Some consort music may require the use of a 'well' temperament. Daring composers of the Jacobean period wrote some experimental compositions (many of them in the Hexachord Fantasy genre) that modulate over such a wide range of keys that only a circular temperament works well. As mentioned above, early to middle Baroque music is likely to be better served by one of the 'well' temperaments, considering that a keyboard instrument is usually included in the continuo. Selecting an appropriate 'well' temperament should consider the key signature of the piece(s), the extent of harmonic excursions, and the nature of any enharmonic modulations. Further guidance on temperament selection is given below in the discussion on viol and lute fret placement.

Continued next page

WHEN TO USE WHICH TEMPERAMENTS cont'd

When playing with a keyboard instrument, the stringed instruments should be tuned to the temperament of the keyboard (which, hopefully, is appropriately tempered for the music to be performed). Concluding this section, I would like to emphasize that viols and lutes tuned by ear (open strings and frets) using pure 4ths, 5ths, and octaves will be tuned Pythagorean, which is *never* the best choice for *any* type of multi-part instrumental music. Out of this fact arises the unique utility of the *"PitchMan"* Variable Temperament Tuner.

CONSONANCE OF MAJOR 3RDS ON

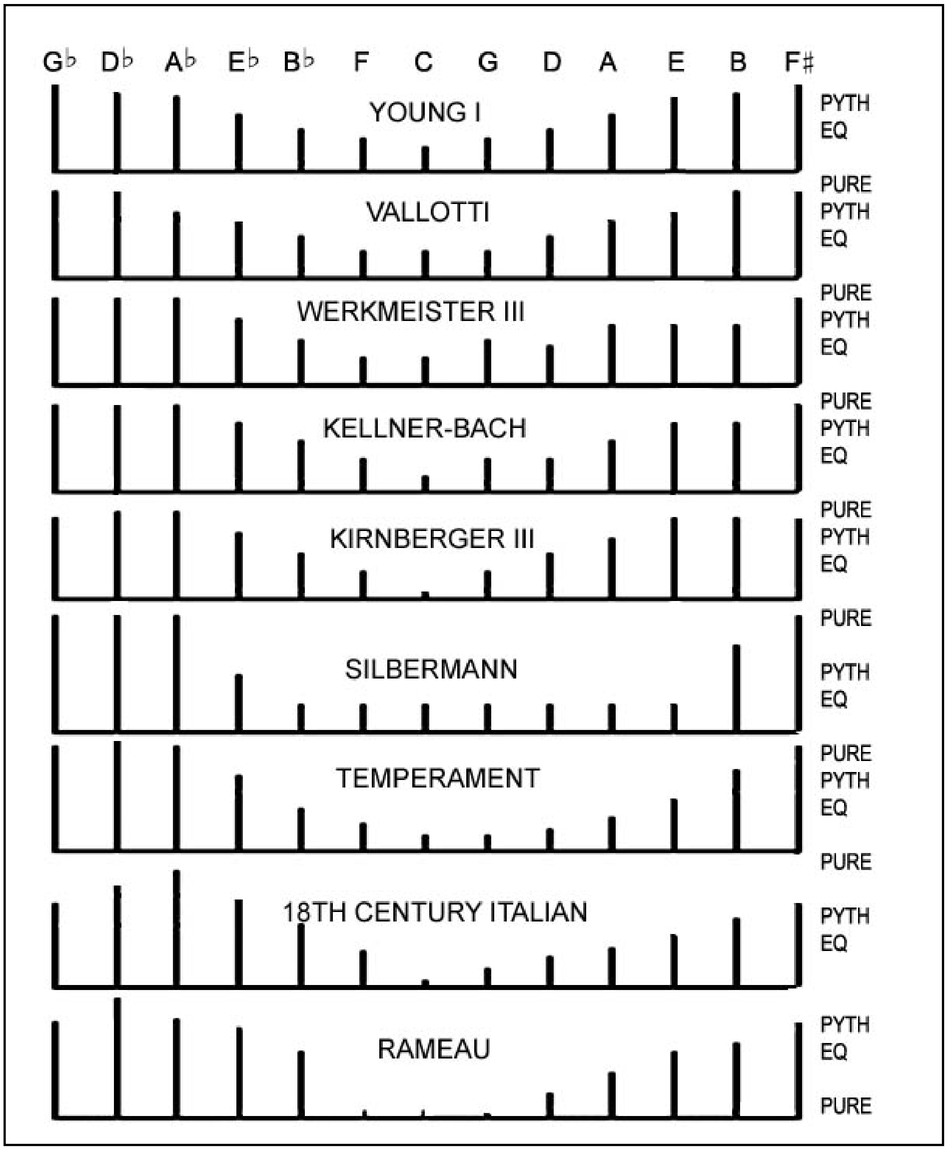

Figure 4: Tuning Errors of All Major 3rds

THE EFFECT OF TEMPERAMENT OF FRET PLACEMENT

If you tune your viol or lute in equal temperament, the placement of the frets will be straightforward and non-problematical. Each fret will be located very nearly 1/18 of the distance from the previous fret (or nut) to the bridge (although you would actually adjust the frets using your *"PitchMan"*, not with a tape measure). When a given fret produces a chromatic or ‘black’ note on one or more strings, those notes serve equally well as flats or sharps; e.g., the third fret on the fourth string of a bass or viol is an equally ‘good’ D# or E♭ in equal temperament. As demonstrated above, however, this is not true for any other choice of regular temperament. (I will not take up the case of so-called ‘split fret’ practice in this tutorial.) To help visualize the following discussion, the diagram provided in Figure 5 shows the nominal note positions for heavier-than-equal regular temperaments for standard viol sizes and string tuning. Although lutes have more frets, similarity in tuning schemes allows the following detailed discussion for viols to be generalized for lute fret placement. Frets which are likely candidates for shifting, depending on key signature and use of accidentals in a given composition, are shown for both possible positions. Note: This chart is not accurately proportioned, and the relative distances between ‘enharmonic’ pairs increases as the amount of tempering increases.

In some cases, a given fret produces only ‘white’ notes, and thereby would not be a candidate for shifting. This is because the enharmonics of ‘white’ notes (e.g., F♭ and B#) are almost never encountered in pre-18th century music in a harmonic context. As seen in the diagram, these cases consist of the fifth and seventh fret on treble and bass viols, and the second and seventh fret on tenor viols.

The next category consists of those frets which produce chromatic or ‘black’ notes on only one or two strings. These are the second and third frets on trebles and basses, and the fourth and fifth on tenors. If the fret is placed to properly tune the ‘white’ notes, the ‘black’ notes will be F#, C#, B♭, and E♭. You will recognize these as the altered notes of ‘inner’ key signatures, and the occurrence of their ‘enharmonics’ (G♭, D♭, A#, and D#, respectively) as the 3rd of major triads is rare. The one exception is the D# in the B-major triad as the dominant of E-minor (as in Simpson’s No. XI of *The Division Viol*). On treble and bass viols, the D# alternative for the third fret, fourth string E♭ is an awkward third-position fourth finger on the fifth string. Moving the third fret toward the nut to produce a D# would detune all the ‘white’ notes on that fret to their sharped ‘enharmonics’, most probably an unacceptable solution. Equal temperament, the dissonances of which are less objectionable in minor key modality, is probably the best choice in such instances.

Since no frets sound just three ‘white’ notes, the next case to consider is those frets which produce only one or two ‘white’ notes. Those are the first and fourth frets for trebles and basses, and the third and sixth frets for tenors. For these frets, one can consider sacrificing the ‘white’ note tuning to gain needed ‘black’ notes for a given key or composition. For example, when playing in sharped key signatures, the first fret on trebles and basses can be moved toward the nut to provided needed sharps at the expense of changing the third string F to an E#. However, the fourth-string fifth-fret F is a readily available substitute for the few times it may be needed.

Continued next page

THE EFFECT OF TEMPERAMENT OF FRET PLACEMENT con't

The last category consists of those frets which produce no 'white' notes, but either all sharps or all flats: the sixth on trebles and basses, and the first on tenors. In general, a good rule seems to be to set the first fret to provide the most frequently occurring 'black' notes in a piece, and the sixth fret to the opposite chromatic species if needed. For example, when playing in flatted keys, place the first fret toward the bridge for flats, and the sixth fret toward the nut for lower string F#s or C#s. (Keep in mind that, except for Pythagorean and equal temperaments, the sharped spelling of 'enharmonic' pairs is always lower in pitch that the corresponding flat.)

In the final analysis, the only sure guide for fret positioning and temperament selection is a careful examination of the piece to be played. At first, assume quarter-comma temperament, place lower frets (those nearer the nut) to produce the sharps or flats in the key signature, upper (those nearer the bridge) frets to cover needed accidentals, and determine if and in what context unplayable notes exist. Try to resolve conflicts with alternate fingering, while preserving as much tempering as possible since this will maximize sonority. Equal temperament should be used only as a last resort (e.g., for Tomkins' Fantasia No. X for three viols). I would like to emphasize again that most consideration should be given to maximize the sonority of the more frequently used sustained major triads (in any of their inversions or positions); least critical, from an intonational standpoint, are more rapid *passaggio* notes. Once you have determined the best temperament and fret settings for a given piece, make a record of them on your music so you won't have to re-analyze the piece at some later time.

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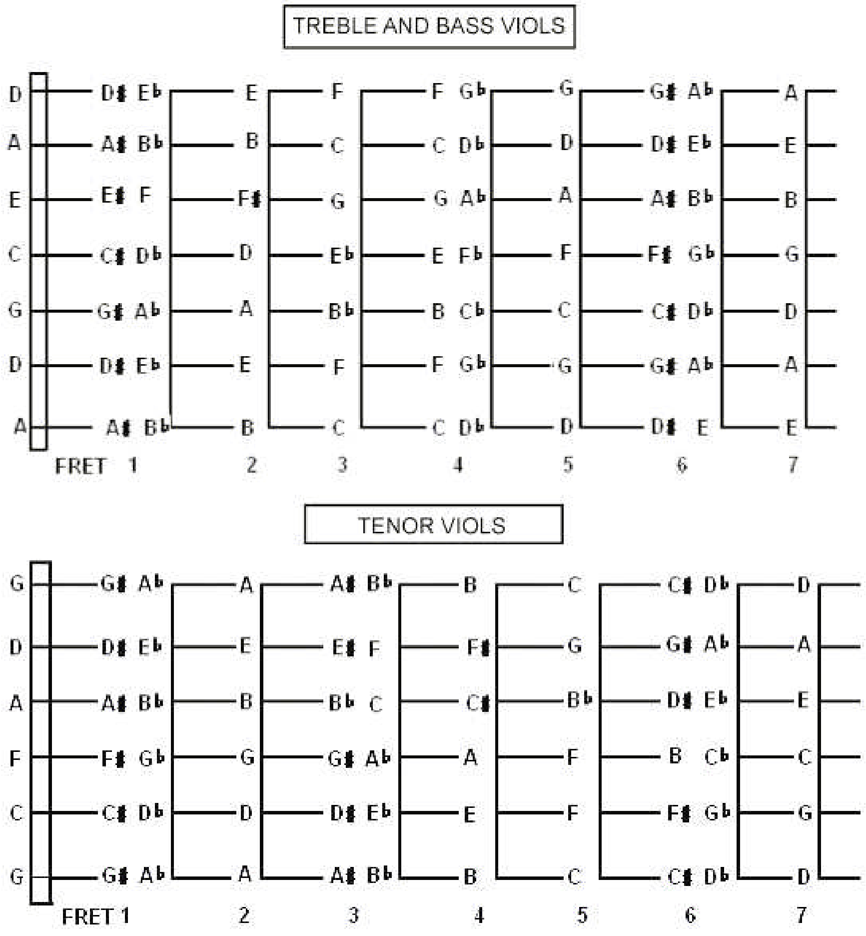
THE EFFECT OF TEMPERAMENT OF FRET PLACEMENT con't



FRET 4

Figure 5: Nominal Note Positions for Heavier-Than-Equal Regular Temperaments

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THE EFFECT OF TEMPERAMENT OF FRET PLACEMENT con't

In the above discussion, only regular scale tunings were considered. For these, the frets are always (at least, theoretically) perfectly straight and perpendicular to the strings because like intervals are always exactly the same size. This is not true for irregular circular temperaments. For this category, frets can only be placed at positions and angles to minimize tuning errors. The availability of all chromatic pitches on the *"PitchMan"* will greatly facilitate the determination of best fret placement for 'well' temperaments. For a good discussion of fret positions for the case of Vallotti temperament, see Elizabeth Liddle's Appendix on viol tuning in *Play the Viol* by Alison Crum (Oxford University Press 1989).

HOW TO REPLACE THE BATTERY

When the maximum volume of your *"PitchMan"* becomes weak, or when its tone and/or pitch becomes erratic, it is time to replace the 9-Volt battery.

1. To gain access to the battery compartment, place your thumb on the ridged pad located on the upper back panel.

2. Press the pad inward and, at the same time, slide the battery access cover upward. If the access cover remains fast, increase thumb pressure until latch release is affected.

3. Shake the old battery from its compartment into the upturned palm of your hand, and unsnap the connector, being careful not to exert excessive tension on the battery connector wires.

4. Replace the expended battery with a high-energy alkaline 9-Volt transistor battery, fully mating the snap connector.

5. Thread the connector wires back into the unit through the battery compartment slot, and gently reseat the new battery into the compartment.

6. To replace the battery cover, fit it into its frame engaged to about 3/4 closed. Press the cover inward and slide it downward until it is latched as indicated by a snapping sound.

APPENDIX

A PSYCHO-ACOUSTIC EXPLANATION OF INTERVAL CONSONANCE AND DISSONANCE

When we hear a sound, portions of the cochlear membrane in our inner ear sympathetically vibrate and convert the sound to neural impulses which are sent to the brain via the auditory nerve. This membrane is highly frequency selective so that, when we hear a pure tone (like that of a tuning fork), only a very small region of this membrane is stimulated. We perceive this sound as being musical with a clearly defined pitch. On the other hand, when we hear a sound which is a composite of a very large number of random frequencies, like that of a jet engine, we perceive the sound as unmusical with no identifiable pitch. We describe such a sound as noise, and are likely to characterize it as being unpleasant.

A tone produced by a vibrating string or column of air is not a pure tone because those physical structures are capable of supporting vibrational modes at many frequencies simultaneously. However, those frequencies are specifically related to a primary lowest resonant frequency, called the fundamental, in that they are integral (whole number) multiples of that fundamental frequency. This family of frequencies consisting of the fundamental and integral multiples thereof (variously called partials, overtones, or harmonics) is called the harmonic series. Surprisingly, our psychological perception of a sound consisting of even a large number of harmonic series components is that of a *single* musical tone having a pitch corresponding to the fundamental frequency. Although individual harmonics are not perceived as separate tones, their relative strengths impart the attribute of ‘timbre’ which distinguishes one type of musical instrument from another. Thus, we may conclude that, when the cochlear membrane is stimulated at a number of localized points which correspond to a harmonic series, the brain perceives an integrated or ‘blended’ sensation having a clearly defined unique musical pitch.

Let us next consider what happens when the ear is stimulated simultaneously by two pure tones of arbitrary frequencies. The ear is constructed to sense sound intensities over a huge dynamic range (sound at the threshold of pain has about one trillion times the power of the softest perceptible sound). The ear's physical mechanism compresses its response to sound intensity in a non-linear fashion so that each time the sound power is doubled, we hear only a fixed increment of loudness increase (logarithmic response). Whenever two pure tones are ‘mixed’ together in a non-linear device, such as the ear, two additional tones are generated whose frequencies are at the sum and the difference of the original tone frequencies, but at lower intensities. Secondarily, these new tones will mix with the original tones and each other to produce even more tones at yet lower intensities, and so on. Giuseppi Tartini became aware of the primary frequency difference tone when two tones are simultaneously played (as in double stops), and based his method of violin intonation on them. Therefore, primary frequency difference tones are sometimes referred to as ‘Tartini’ tones.

Continued next page

APPENDIX con't

Now, what happens if a complex tone (fundamental frequency plus harmonics) excites a non-linear device? All of the component frequencies will form sum and difference tones with each other, but because the harmonic series consists of integral multiples of the fundamental, *all sum and difference frequencies will be in the original harmonic series.* For example, if a complex tone has a fundamental of 100 Hz (vibrations per second) and harmonics at 200 Hz, 300 Hz, 400 Hz, etc., then for any pair of these frequencies, the sum and difference frequencies will be some integral multiple of 100 Hz. Thus, the basic structure, and therefore primary musical perception, of a complex tone is not altered by the non-linearity of our ears.

Next, consider the ear's response to two complex tones which are an octave apart, the most consonant of musical intervals. The frequency-ratio of the fundamental components of those complex tones is 2:1. Thus, the fundamental of the upper tone is at the frequency of the second harmonic of the lower tone; and, indeed, every harmonic of the upper tone coincides with an even-numbered harmonic of the lower tone. Again, this produces the perception of highly fused sound where, if the octave is perfectly tuned, it may be difficult to perceive that two separate tones are being sounded. If we expand this case to include any interval where the upper tone's fundamental frequency is any harmonic frequency of the lower tone, the harmonic series of the lower tone is always preserved. This is the basis of mixture stops on a pipe organ which synthesize artificial tone qualities by employing ranks of pipes tuned to pure harmonics of the eight-foot ranks.

Moving on to the interval of a perfect 5th, where the frequency-ratio of the fundamentals is 3:2, we see that the difference tone between them would be 1 (ratio-wise) or an octave below the lower tone's fundamental. In addition, the sum and all combinatorial tones of the harmonics of the original tones would be some integral multiple of this primary difference frequency. So, the cochlear pattern for the interval of a 5th is still basically the structure of a harmonic series, even though the fundamental frequency of this series is missing from the original stimulus tones. Consistent with this is the fact that the second, fourth, sixth, etc. harmonics of the upper tone are coincident with the third, sixth, ninth, etc. harmonics of the lower tone, respectively. For example, a 5th consisting of middle-C at 250 Hz and the G above at 375 Hz would produce a frequency 'comb' with component tones spaced 125 Hz apart. Hence, we may conclude that the psychological quality of interval consonance is maintained for combinations of complex tones where the cochlea is stimulated a comb of points along its length corresponding to equally-spaced frequencies, provided those points are not too close to each other.

As the integers of an interval's frequency-ratio become larger and larger, the derivative fundamental of the combinatorial harmonic series becomes lower and lower in frequency, the frequency comb spacing becomes closer and closer, and the psychologically perceived degree of consonance becomes less and less. When the spacing becomes less than about 25 Hz, listeners judge the sound as no longer consonant, but begins to sound dissonant. Physiologically, this corresponds to the condition where regions of cochlear response begin to overlap and interfere with each other. On the other hand, when the spacing decreases below about 5 Hz, the points of cochlear stimulation begin to coalesce, interference effects decrease, and the sensation of dissonance transitions back toward consonance. This is why slightly detuned pure intervals, such as the 5ths in the range of temperaments discussed above, are judged to be quite consonant.

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APPENDIX con’t

As a concluding example, let us compare the cases of pure and Pythagorean major 3rds with the lower note being middle-C at 256 Hz (frequency chosen for mathematical convenience). In the former instance, E would be 5/4 x 256 Hz = 320 Hz; and the difference frequency (320 - 256) is 64 Hz, a tone exactly two octaves below middle-C and above the 25-Hz threshold of dissonance. In addition, the fifth harmonic of C and the fourth harmonic of E are coincident (do not ‘beat’) at 1280 Hz. In the Pythagorean case, E would be 81/64 x 256 Hz = 324 Hz. The resulting difference frequency, 324 - 256, or 68 Hz, which corresponds to the C# almost two octaves below middle-C, a tone which is not a sub-harmonic of either primary tone. Even more damaging to the degree of consonance of the Pythagorean major 3^{rd} is the interaction of the fifth harmonic of C at 1280 Hz and the fourth harmonic of E at 1296 Hz which will beat and mix to form a difference tone at 16 Hz. Also, in general, the frequencies at which many other secondary tone-mixing combinations occur will be multiples of 16 Hz, a spacing where cochlear stimulation interferences result in the sensation of a high degree of dissonance.

WARRANTY & FACTORY SERVICE

Limited Warranty and Factory Service

The *“PitchMan”* tuner is covered by a one year warranty. If the unit malfunctions at any time due to component failure or workmanship defect, you may return it to Vio-Lab, Inc. for repair. Vio-Lab, Inc. will also repair damage not covered under warranty on a time and materials basis, the estimate for which will be supplied at no cost.

Enclose the unit in adequately protective packing material, place in a hard box, and send via US Mail or United Parcel Service (UPS). Vio-Lab, Inc. will pay return postage only if unit is under warranty.

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