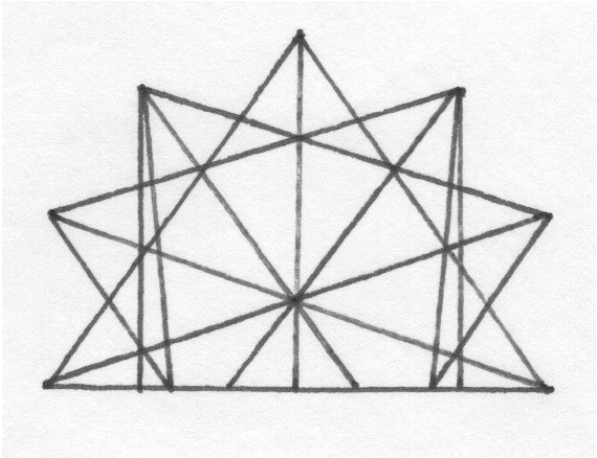
The Modular Keyboard

Novel Tuning Utilities Software for MIDI-Equiped Digital Synthesizers



Siemen Terpstra

www.siementerpstra.com

THE MODULAR KEYBOARD

NOVEL TUNING UTILITIES SOFTWARE
For
MIDI-EQUIPED DIGITAL SYNTHESIZERS

By SIEMEN TERPSTRA

For some years I have been intriqued by the idea of applying 53-Equal-Temperament (Quasi-Just Intonation) to the polyphonic keyboard. This Tuning System allows excellant approximations of 3-Limit and 5-Limit ratios as well as good approximations of many 7-Limit intervals. Moreover, being a closed cyclical system, it allows unlimited modulation to all keys. But how can a system of such complexity be represented on a keyboard in a comfortable, playable manner?

One approach is to design a new keyboard especially for that tuning system. I built a cardboard mock-up of Bosanquet's keyboard in order to feel it under my fingers. (The design specifications are described in Helmholtz--ON THE SENSATIONS OF TONE). I found that it was comfortable for 3-Limit patterns,that is , "Pythagorean" type chords and scales; but it was awkward when playing most 5-Limit (Just Intonation) and 7-Limit patterns. Now some modification of the Bosanquet keyboard may indeed be workable, but I directed my efforts back to the standard keyboard. So many people are accustomed to that design. Can 53-E.T. be adapted to the old, black-and-white ivories?

Basically two solutions to this problem have been tried. The first solution I call the "big spread." The pitches are simply spread along the keys without regard to the usual interval layout. The result is less than two octaves of the scale, since keyboards have at most eighty-eight keys and many have less. This narrow range is musically unacceptable. And to make matters worse, even the closed-position chords involve wide and awkward stretches. So this approach is out.

The second, and most common, solution resigns us to the 12 note limit of the keyboard. We may retune those 12 notes per octave any way we want, but to do it we must stop playing and load up the frequency files of the tuning we wish. Now 53-E.T. offers many ways of tuning the chromatic scale--it offers "modes" of the chromatic scale. So we can play in 53-E.T., but always only in some 12 note subset of the system. Hence we cannot modulate freely at will or take advantage of the wider harmonic implications of the system. To move to a more "distant" key we must stop playing, and load up the new intonations. This solution is therefore also unacceptable.

The MODULAR KEYBOARD offers a more versatile solution. It overcomes the above limitations by using a principle akin to

"bar chords" on the guitar. In order to explain the basis of the design, I must delve a little into the structure of 53-E.T.

This tuning system is fundamentally a scale of commas. Consequently, as an easy preliminary notation, the pitches are numbered from 0 to 52. The pitch numbered 0 (which equals 53) stands for our tuning reference pitch "C." This notation is handy, since it gives the size of any given interval in commas. For example, pitch number 31 (G) stands for the interval of the Pure Musical Fifth (ratio 3:2) and is exactly 31 commas in size. The pitch numbered 17 (E) is the Just Musical Major Third (ratio 5:4) and it is 17 commas in size. The Pythagorean Major Third, which is a comma sharp, has comma number 18. And so on. Those of you interested in questions of notation in regard to 53-E.T. and Just Intonation may refer to my article on notation in INTERFACE--JOURNAL OF NEW MUSIC RESEARCH, Volume 14 (1985), Utrecht, Netherlands.

Just Intonation consists essentially of ratios derived from the 3rd and 5th Harmonics. The 2nd Harmonic is considered a "floating" quantity due to the principle of Octave Equivalence. Ratios using the 7th Harmonic are expressed indirectly through 5-Limit approximations. As a result the system may be presented as a tuning matrix derived directly from the 3 * 5 multiplication table. The primary tuning nucleus is shown in Figure 1.

We establish three tuning axes, and hence six tuning directions. The horizontal axis indicates tuning in Pure Musical Fifths and Fourths. The two directions of this axis show tuning in the Dominant direction and the Sub-dominant direction. The oblique axis pointing upward to the right indicates tuning in Just Musical Major Thirds and Minor Sixths (the 5:4 axis). The third axis points obliquely upward to the left. It indicates tuning in Just Musical Major Sixths and Minor Thirds (the 5:3 axis). Thus, for example, the pitch 31 (G) may be tuned from our reference C by tuning up in pitch a Fifth (3:2) or by tuning down a Fourth (3:4). The downward pointing ratios are bracketed. These fractions may be read directly as frequency ratios, or inverted to indicate ideal string lengths on a monochord. They may also be read directly as Harmonics when actually tuning strings. For example, in order to tune G a pure Fifth above C, form a beatless unison between the 3rd Harmonic of the C string, and the 2nd Harmonic of the G string. Viola players know this well.

This nucleus of tuning procedures may be extended, so that, for example, pitch number 9 (D) can be derived as a 3:2 from G. Or again, pitch 34 (G#) may be derived as a 5:4 ratio above 17 (E). All six tuning directions may be extended indefinitely, theoretically to infinity, but in actual tuning practice there are "natural boundaries" encountered to limit the expansion.

Figure 2 shows the entire field of Quasi-Just Intonation. The natural boundary of the horizontal axis arrives when we encounter the schisma. Tune along the line of fourths-fifths from 0-22-44-13-35 to 4 (the Pythagorean

semi-tone). A boundary is crossed. Now tune from 0-31-9-40 and up a Major Third to-- 4! These two pitches are almost identical. The left-hand side pitch number 4 is a schisma flat of the other pitch 4, which is inside the boundary. Similarly, pitch 49 on the right is a schisma sharp of pitch 49 on the left inside the boundary. Now the schisma is worth about 2 Cents and is generally below our pitch discrimination threshold. This interval is also the difference between the Ditonic comma and the Syntonic comma. The tempering of 53-E.T. eliminates the schisma and uses a "mean" comma midway in size to stand for both types of commas. Hence the boundary to horizontal expansion. Note that any long strand of horizontal tuning leads to a pattern which includes a Just segment. For example, tune 0-22-44-13-35-4-26-48-17. In pure Just Intonation the pitch 17 (E) is a schisma flat of a 5:4. 53-E.T. uses a midway size, about 1 Cent flat of a Just 5:4. Now such temperings are generally below our perception threshold. Hence 53-E.T. is such a good approximation of Pythagorean and Just ratios.

The top and bottom of the field is bounded by the Enharmonic Gateway (pitches 11 and 42). Note the tuning progression 11-25-39-0-14-28-42. The whole pattern turns into a "strange loop". When the circle of Fifths for 53-E.T. is laid out, pitches 11 and 42 are at the opposite side as our generator pitch 0. This boundary to the 5:3 axis results in a closed system of 53 pitches per octave.

One more prominant aspect of Just Intonation. Note the four pitches 29-24-7-46 which inhabit all four "corners" of the field. These pitches are the Harmonic Antipodes. Tuning in practically any direction (except the Enharmonic Gateway) brings us to this area. If we consider 0 (C) as our "north pole", then walking in any direction takes us to the "south pole". Note that pitch 24 approximates the 11th Harmonic ratio (11:8) and 29 is the 11th Sub-harmonic ratio (16:11). The cyclical temperament 31-E.T. preserves the Harmonic Antipodes since it orients around the 5:4 axis, but the 19-E.T. system and the 12-E.T. system eliminate it. The 19-E.T. system orients strongly along the 5:3 axis and the Enharmonic Gateway.

There are many other fascinating strucural features to the 53-E.T. system and the other closely related cyclical temperaments, but we do not need them explained here. Only note the highlighted area on Figure 2. The field naturally divides into three regions. The left-hand region contains comma-lowered intervals, and the right-handed region contains comma-raised intervals. In the central region the intervals are not comma-altered. Here is an important key to a clear notation for the system.

It is important to grasp that this field diagram is planimetric. That is, every type of chord or scale has its own "shape" which is intrinsic to it. To modulate patterns we simply shift them around the diagram. For example, every upward-pointing triangle is a Just Major Triad, and every downward-pointing

triangle is a Just Minor Triad. Hence, the graph has sometimes been called the Web of Just Triads. Not only triads, but any harmonic pattern may be visually represented. I have used this field diagram to organize the Modal Tables for the system.

Our interest now is in chromatic scales for our chromatic keyboard. Now there are many ways to tune a chromatic scale in the system--in fact, there are about 36 "best" modal forms for the chromatic scale. Two representative examples are shown in Figure 3 and Figure 4. Beside the field diagram is the natural application to the keyboard.

The Modular Keyboard Software allows me to build any such chromatic scale and store it on Disk to be loaded up at will. But, you ask, how is this any different from the "second" approach described earlier? Here is the new feature.

Once a desired chromatic scale is loaded up from Disk, it becomes a CHROMATIC MODULE which may be instantly shifted anywhere in the whole field (ie. 53 positions). This shift is accomplished by punching the FIELD NUMBER on the computer keyboard. The intonation of the entire music keyboard is shifted instantaniously. For example, if I load up the module which is Figure 3, then press field number 45, the intonation of the keyboard shifts to that shown on Figure 5. Note that in this shift, some pitches changed, and others did not. For example, the pitch 9 (D) did not change. We may shift to closely related harmonic spaces where only one or two pitches change by a comma, or we may jump instantly to "remote" harmonic regions. Hence we have free modulation anywhere in 53-E.T.

Now I have been concentrating on the 53 system, but this software allows me to set up a field of any number of pitches--any division of the octave (up to 53). Thus it will also provide good access to the other good cyclical temperaments--eg. 31-E.T., 19-E.T., and so on. Needless to say, it also ennables me to play in "bizarre" temperaments like 17 or 23. The same set-up applies. A chromatic module is selected which may be shifted anywhere in the system. Generally this module is a segment of the circle of fifths for that particular tuning system. (This was written 1985-or 1986)

Hence this software allows me to explore many harmonic "spaces" both wonderful and wierd! And it allows me to do it in "real time" through my synthesizer. Thanks to some funding through the CANADA COUNCIL, this equipment is now operational. At the present time I'm doing some recording with it.

The main limitation to the design is the restriction to cyclical temperaments only. However, even with this limitation, a vast field is opened up. It is well known that the best cyclical temperaments are 12, 19, 31, 41, 43, 50, and 53. This software has allowed me to personally evaluate these various systems. To my ear, 53 and 31 are the best. The 31 system is especially interesting due to its sonic equivalence to one-quarter comma Meantone tuning. Hence it is very useful for performance of

Renaissance and Baroque music. The "extended meantone" type harmonies of a composer like Gesualdo may be accurately rendered. Thus this software is useful for the performance of "old" music as well as the creation of new forms of harmony.

Figure 1:

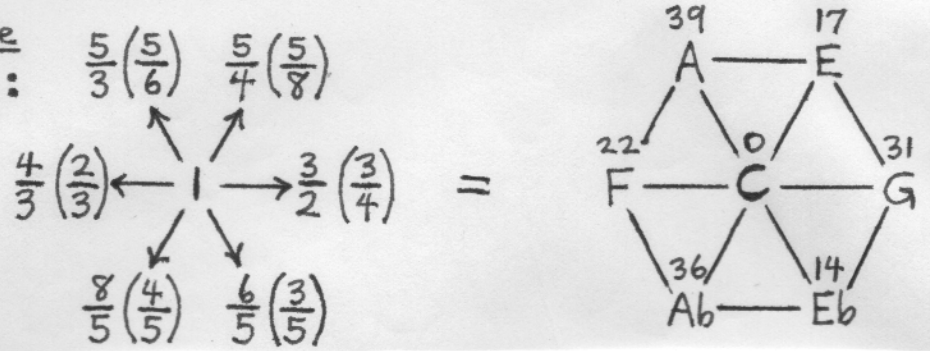


Figure 2:

53-E.T. Field Diagram — Showing Three Regions:

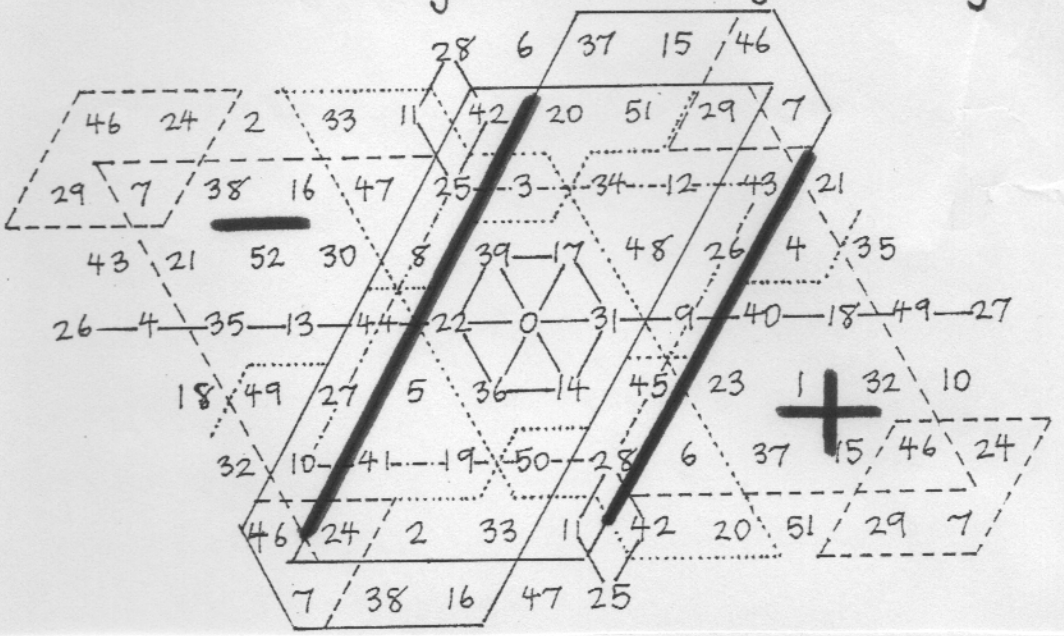


Figure 5:

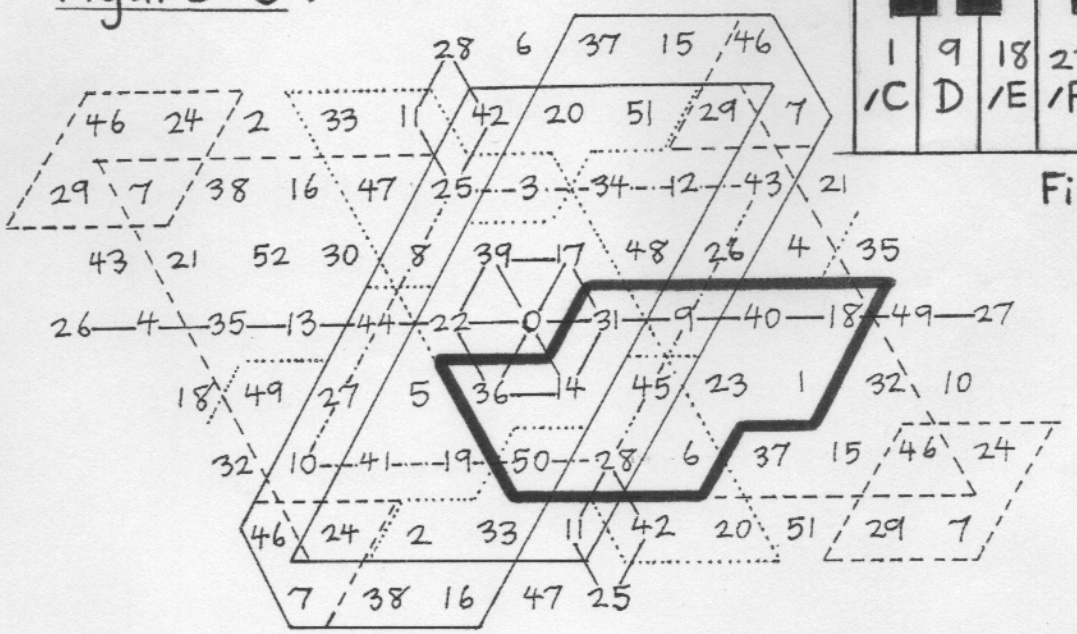


Figure 3 :

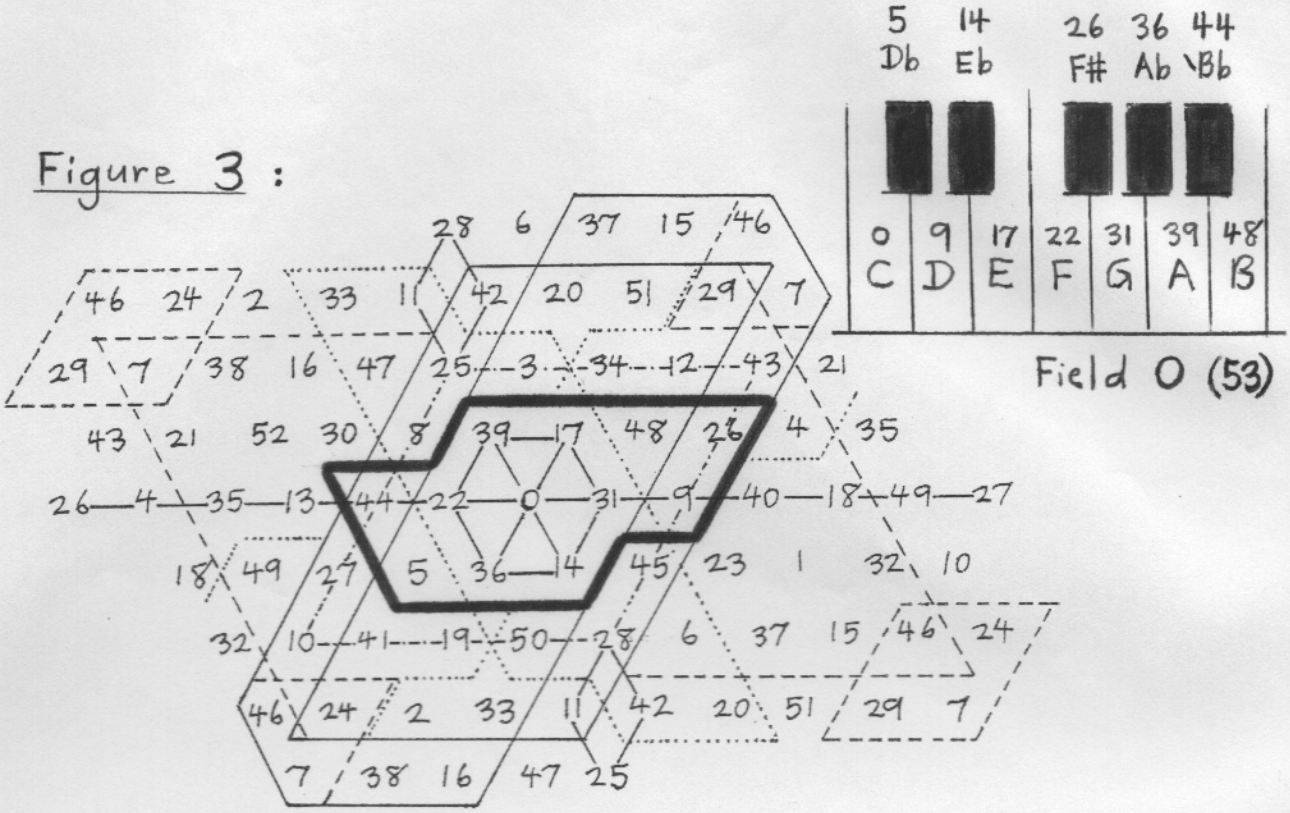
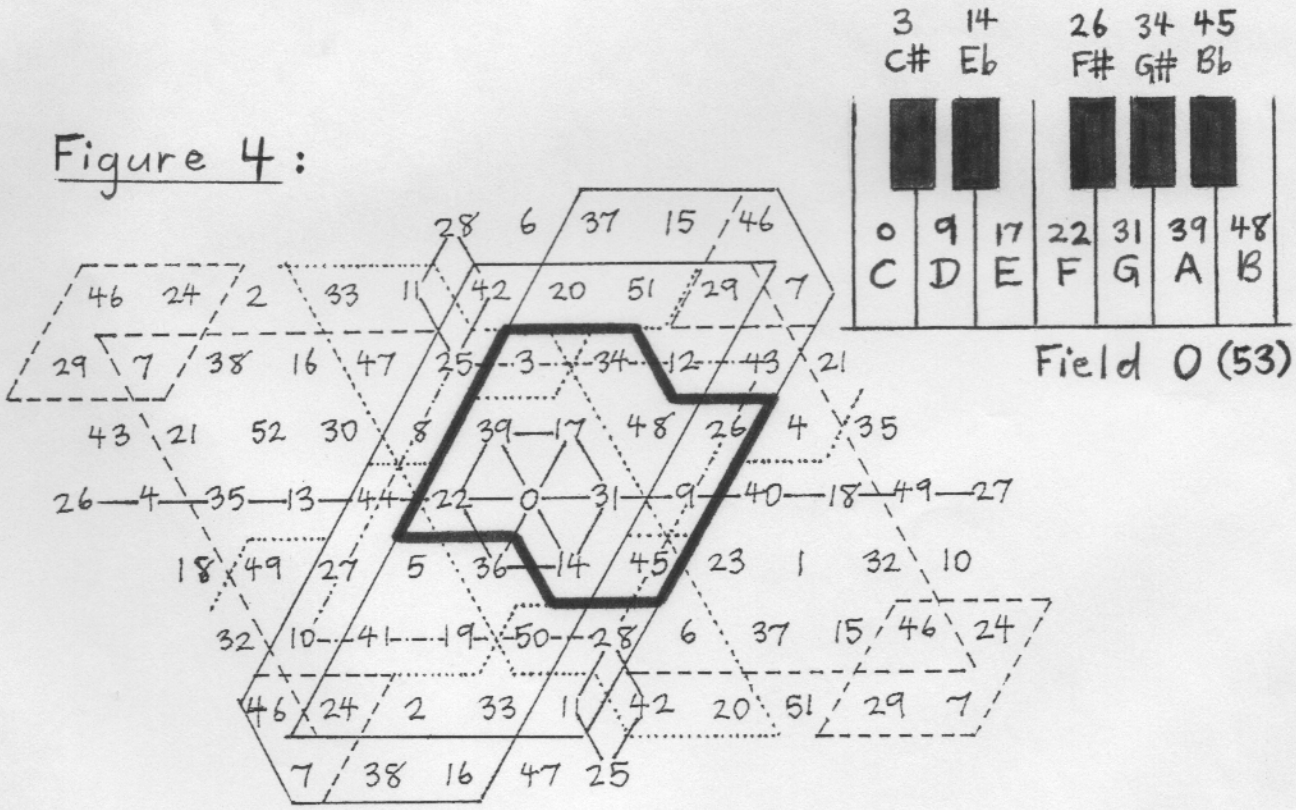


Figure 4 :



THE MODULAR KEYBOARD UTILITIES PROGRAM

Designed for SOUNDCHASER (APPLE) COMPUTER MUSIC SYSTEMS

By SIEMEN TERPSTRA

This software utlilties program modifies the SPECIAL TUNINGS AND PERIODIC WAVEFORMS UTILITIES as well as the TURBO-TRAKS performance software ennabling the SOUNDCHASER synthesizer to execute a powerful Intonations-modification program.

The program allows the synthesizer to realize, in real time, an expanded pitch-field of up to 53 tones per octave. The standard keyboard only allows twelve tones per octave. By means of a CHROMATIC MODULE, the player may shift anywhere in the wider field by pressing the appropriate command on the computer keyboard. The command shifts the Module to the desired region of the wider field, without the need to stop playing and retrieve the new tuning from the Disk Drive. The intonation of the Klavier keyboard is altered instantly as one plays, allowing the player to move into many new harmonic "spaces".

The program allows the player to set up a field of any number of pitches up to a maximum of 53. Once the desired field is established, the player may then choose any type of chromatic scale as his module. The pattern may then be "modulated" anywhere in the pitch field by a simple command during performance.

The reason for setting up[such a program is this: In the One-Quarter Comma Meantone Tuning (for example), the circle of Fifths closes after 31 pitches. Unless one has access to all of these pitches, then certain keys are "good" and certain keys are "wolves". When one sets up the 31-Equal-Temperament field, then one has access to the whole array of pitches which we call the "extended Meantone" tuning. In the 18th Century when this tuning matrix was popular, musicians would stop playing to retune to another region of the circle of fifths (for example, C# is retuned to Db). Keyboards were built with "split" keys so that one had a C# and a Db. This tuning program ennables one to make such modifications instantly without the need to stop playing.

It is well known that the best musical cycles divide the octave into 12, 19, 31, 41, 43, 50, and 53--the best being the 53 cycle. However, this program allows one to set up any cycle, even such bizzare cycles as 17 or 25. The potential for new sonic "spaces" is vast.

The software was designed both to facilitate the performance of "old" music and also to aid in the creation of new forms of music.

```
:ASM

                        *   TUNING FIELDS -CHANGE
                        *
                        * FOR PASSPORT SYNTHESIZER
                        *
                        *THREE TABLES
                        *     -MAIN TABLE: NOTE VALUES FOR
                        *THE TOP OCTAVE. THESE VALUES ARE
                        *ALL THE POSSIBLE VALUES IN AN
                        *OCTAVE OF A GIVEN TUNING. PLUS
                        *AN EXTRA VALUE AT EACH END, FOR
                        *OVERLAP WITH SOME FIELD TUNINGS.
                        *
                        *     -FIELDTABLE: HAS NUMBERS OF
                        *THE 12 NOTE VALUES THAT
                        *COMPRISE THAT FIELD.
                        *
                        *     -KLAVIERTABLE: THE VALUES
                        *ARE STORED WHERE THE KLAVIER
                        *READS THEM. 6 OCTAVES, OF 12 TWO
                        *BYTE VALUES.
                        *
                        *
                        *PROCESS
                        *1 -GET FIELD NUMBER, DISPLAY IT
                        *CHECK IF VALID
                        *
                        *2 -GET START ADDRESS OF PARTI-
                        *CULAR FIELD IN FIELD TABLE.
                        *
                        *3 -GET NUMBER OF FIRST NOTE
                        *VALUE OF THAT FIELD. STORE IN
                        *RESPECTIVE PLACE IN KLAVIERTABLE
                        *DIVIDE VALUE BY 2. STORE IN NEXT
                        *OCTAVE DOWN IN KLAVIERTABLE.
                        *CONTINUE UNTIL ALL OCTAVES DONE.
                        *
                        *4 -GET NUMBER OF NEXT NOTE VALUE
                        *AND PROCEED UNTIL KLAVIERTABLE
                        *FULL.


                        *  SET HI:28144
                        *
                                ORG   $6DFØ
                        MAINTBL =     $6BØØ
                        FIELTBL =     $6B7Ø
                        KLAVTBL =     $576Ø
                        FIELNUM =     $6DED
                        FLDPNTR =     $6DEE
                        KLAPNTR =     $6DEF
                        TUNENUM =     $6B6F
                        KEY     =     $CØØØ
                        STROBE  =     $CØ1Ø
                        LETTR1  =     $411
                        LETTR2  =     $412
                        IOSAVE  =     $FF4A
                        IOREST  =     $FF3F

                        *
6DFØ: EØ C6                     CPX   #$C6
6DF2: FØ Ø1                     BEQ   START
6DF4: 6Ø                        RTS
6DF5: 2Ø 4A FF          START   JSR   IOSAVE
```

```
6DF8: 20 89 6E  64              JSR  GETNUM
6DFB: 60        65              RTS
                66   *
                67   *
                68   *SET FIELNAD TO ADDRESS OF
                69   *START OF DESIRED FIELD
                70   *AND RESET KLAPNTR TO START
                71   *
6DFC: A9 7A     72              LDA  #122
6DFE: 8D EF 6D  73              STA  KLAPNTR
6E01: A9 51     74              LDA  #$51
6E03: 8D 2E 6E  75              STA  FIELNAD+2
6E06: A9 00     76              LDA  #$0
6E08: 8D 2D 6E  77              STA  FIELNAD+1
6E0B: 8D EE 6D  78              STA  FLDPNTR
6E0E: AC ED 6D  79              LDY  FIELNUM
6E11: C0 00     80              CPY  #0
6E13: F0 14     81              BEQ  NXTVAL
6E15: 18        82   LOOP1      CLC                 ;COUNT
6E16: AD 2D 6E  83              LDA  FIELNAD+1      ;THROUGH
6E19: 69 0C     84              ADC  #12            ;FIELDS
6E1B: 8D 2D 6E  85              STA  FIELNAD+1      ;TO
6E1E: AD 2E 6E  86              LDA  FIELNAD+2      ;DESIRED
6E21: 69 00     87              ADC  #0             ;FIELD
6E23: 8D 2E 6E  88              STA  FIELNAD+2
6E26: 88        89              DEY
6E27: D0 EC     90              BNE  LOOP1
                91
                92   *
                93   * FETCH NOTE VALUE
                94   *
6E29: AC EE 6D  95   NXTVAL     LDY  FLDPNTR        ;GET AND
6E2C: BE 70 6B  96   FIELNAD    LDX  FIELTBL,Y      ;SET
6E2F: 8A        97              TXA                 ;2 BYTE
6E30: 0A        98              ASL                 ;POINTER
6E31: AA        99              TAX
6E32: C8        100             INY
6E33: C0 0C     101             CPY  #12            ;DONE?
6E35: F0 34     102             BEQ  DONE
6E37: 8C EE 6D  103             STY  FLDPNTR
6E3A: AC EF 6D  104             LDY  KLAPNTR
6E3D: EE EF 6D  105             INC  KLAPNTR
6E40: EE EF 6D  106             INC  KLAPNTR
6E43: BD 01 6B  107             LDA  MAINTBL+1,X    ;VALUES
6E46: 8D F7 6E  108             STA  NTVAL+1        ;FROM
6E49: 99 61 57  109             STA  KLAVTBL+1,Y    ;MAIN
6E4C: BD 00 6B  110             LDA  MAINTBL,X      ;TABLE
6E4F: 8D F6 6E  111             STA  NTVAL
6E52: 99 60 57  112             STA  KLAVTBL,Y
6E55: 98        113  NXTOCT     TYA
6E56: 38        114             SEC
6E57: E9 18     115             SBC  #24
6E59: 30 CE     116             BMI  NXTVAL
6E5B: A8        117             TAY
6E5C: 20 E6 6E  118             JSR  DIV2           ;DIV /2
6E5F: 99 60 57  119             STA  KLAVTBL,Y      ;FOR
6E62: AD F7 6E  120             LDA  NTVAL+1        ;NEXT
6E65: 99 61 57  121             STA  KLAVTBL+1,Y    ;OCTAVE
6E68: 4C 55 6E  122             JMP  NXTOCT         ;DOWN
                123
                124
                125
                126
                127  *
                128  *SET BOTTOM C AND EXIT
                129  *
```

```
6E6B: A0 18     130 DONE    LDY  #24
6E6D: B9 60 57  131         LDA  KLAVTBL,Y
6E70: 8D F6 6E  132         STA  NTVAL
6E73: B9 61 57  133         LDA  KLAVTBL+1,Y
6E76: 8D F7 6E  134         STA  NTVAL+1
6E79: 20 E6 6E  135         JSR  DIV2
6E7C: 8D 60 57  136         STA  KLAVTBL
6E7F: AD F7 6E  137         LDA  NTVAL+1
6E82: 8D 61 57  138         STA  KLAVTBL+1
6E85: 20 3F FF  139         JSR  IOREST
6E88: 60        140         RTS
                141 *
                142 * GET NUMBER FROM KEYBOARD
                143 *
                144 *
6E89: A9 20     145 GETNUM  LDA  #32
6E8B: 8D 11 04  146         STA  LETTR1
6E8E: 8D 12 04  147         STA  LETTR2
6E91: 2C 10 C0  148         BIT  STROBE
6E94: 20 C9 6E  149         JSR  KPRESS
6E97: 8D 11 04  150         STA  LETTR1
6E9A: 20 DD 6E  151         JSR  NVAL
6E9D: 8D A4 6E  152         STA  MULT+2
6EA0: A2 09     153         LDX  #9
6EA2: 18        154 MULT    CLC
6EA3: 69 00     155         ADC  #0
6EA5: CA        156         DEX
6EA6: D0 FA     157         BNE  MULT
6EA8: 8D F5 6E  158         STA  NUMTEN
6EAB: 20 C9 6E  159         JSR  KPRESS
6EAE: 8D 12 04  160         STA  LETTR2
6EB1: 20 DD 6E  161         JSR  NVAL
6EB4: 8D F4 6E  162         STA  NUM
6EB7: 18        163         CLC
6EB8: 6D F5 6E  164         ADC  NUMTEN
6EBB: CD 6F 6B  165         CMP  TUNENUM
6EBE: 90 05     166         BCC  OK
6EC0: F0 03     167         BEQ  OK
6EC2: 4C 89 6E  168         JMP  GETNUM
6EC5: 8D ED 6D  169 OK      STA  FIELNUM
6EC8: 60        170         RTS
6EC9: 2C 00 C0  171 KPRESS  BIT  KEY
6ECC: 10 FB     172         BPL  KPRESS
6ECE: AD 00 C0  173         LDA  KEY
6ED1: C9 B0     174         CMP  #176
6ED3: 90 0C     175         BCC  WRONG
6ED5: C9 BA     176         CMP  #186
6ED7: B0 08     177         BCS  WRONG
6ED9: 2C 10 C0  178         BIT  STROBE
6EDC: 60        179         RTS
6EDD: 38        180 NVAL    SEC
6EDE: E9 B0     181         SBC  #176
6EE0: 60        182         RTS
6EE1: 68        183 WRONG   PLA
6EE2: 68        184         PLA
6EE3: 4C 89 6E  185         JMP  GETNUM
                186
                187 *
                188 *
                189 *DIVIDE NUMBER IN NTVAL BY 2
                190 *
6EE6: 18        191 DIV2    CLC
6EE7: 6E F7 6E  192         ROR  NTVAL+1
6EEA: AD F6 6E  193         LDA  NTVAL
6EED: 6A        194         RORA
6EEE: 69 00     195         ADC  #$0
```

```
6EF0: 8D F6 6E   196             STA  NTVAL
6EF3: 60         197             RTS
                 198  *
6EF4: 00         199  NUM        BRK
6EF5: 00         200  NUMTEN     BRK
6EF6: 00         201  NTVAL      BRK              ;DIV
6EF7: 00         202  END        BRK              ;ACCU


--End assembly--

264 bytes

Errors: 0


Symbol table - alphabetical order:

   DIV2     =$6EE6      DONE     =$6E6B   ?  END      =$6EF7      FIELNAD =$6E2C
   FIELNUM  =$6DED      FIELTBL  =$6B70      FLDPNTR  =$6DEE      GETNUM  =$6E89
   IOREST   =$FF3F      IOSAVE   =$FF4A      KEY      =$C000      KLAPNTR =$6DEF
   KLAVTBL  =$5760      KPRESS   =$6EC9      LETTR1   =$0411      LETTR2  =$0412
   LOOP1    =$6E15      MAINTBL  =$6B00      MULT     =$6EA2      NTVAL   =$6EF6
   NUM      =$6EF4      NUMTEN   =$6EF5      NVAL     =$6EDD      NXTOCT  =$6E55
   NXTVAL   =$6E29      OK       =$6EC5      START    =$6DF5      STROBE  =$C010
   TUNENUM  =$6B6F      WRONG    =$6EE1


Symbol table - numerical order:

   LETTR1   =$0411      LETTR2   =$0412      KLAVTBL  =$5760      MAINTBL =$6B00
   TUNENUM  =$6B6F      FIELTBL  =$6B70      FIELNUM  =$6DED      FLDPNTR =$6DEE
   KLAPNTR  =$6DEF      START    =$6DF5      LOOP1    =$6E15      NXTVAL  =$6E29
   FIELNAD  =$6E2C      NXTOCT   =$6E55      DONE     =$6E6B      GETNUM  =$6E89
   MULT     =$6EA2      OK       =$6EC5      KPRESS   =$6EC9      NVAL    =$6EDD
   WRONG    =$6EE1      DIV2     =$6EE6      NUM      =$6EF4      NUMTEN  =$6EF5
   NTVAL    =$6EF6   ?  END      =$6EF7      KEY      =$C000      STROBE  =$C010
   IOREST   =$FF3F      IOSAVE   =$FF4A
```

```
  REM  ***EQ. TUNING4Ø***
1Ø  HIMEM: 16ØØØ: GOTO 5ØØØØ: REM                                    ** SUBRO
    UTINES **
1Ø9  REM  --FORMATTING--
11Ø N$ =  RIGHT$ (SP$ + NM$,M3): RETURN
12Ø N$ =  RIGHT$ (SC$ + FE$,M2): RETURN
199  REM ----MODULE SORTING----
2ØØ OP = M1:DV = .5: FOR N = M1 TO 12: ON IR(N) < DV GOSUB 2Ø2:DV = IR(N)
    : NEXT : GOTO 2Ø3
2Ø2 OP = N:N = 12: RETURN
2Ø3 NN = M1: FOR N = OP TO 12:KR(NN) = IR(N):FI(NN) = FF(N):NN = NN + M1:
     NEXT : FOR N = M1 TO OP:KR(NN) = IR(N):FI(NN) = FF(N):NN = NN + M1:
     NEXT
2Ø5  IF ET(FE) = KR(FK) THEN  RETURN
2Ø6  IF ET(FE) = KR(FK + M1) THEN IR(QQ) = KR(M1):FF(QQ) = FI(M1): FOR N =
    M1 TO 11:KR(N) = KR(N + M1):FI(N) = FI(N + M1): NEXT :KR(12) = IR(QQ
    ) * M2:FI(12) = FF(QQ) + TN: RETURN
2Ø7  IF ET(FE) = KR(FK - M1) THEN IR(QQ) = KR(12):FF(QQ) = FI(12): FOR N =
    M2 TO 12:KR(N) = KR(N - M1):FI(N) = FI(N - M1): NEXT :KR(12) = IR(QQ
    ) / M2:FI(12) = FF(QQ) - TN: RETURN
2Ø8  PRINT B$: INVERSE : PRINT "CHECK !": PRINT : PRINT "MODULE MAY NOT B
    E ARRANGED PROPERLY !!": NORMAL : GET A$: RETURN
499  REM  ----MAKE FIELDS----
5ØØ JD = M1: FOR N = QQ TO 12:ND =  ABS (ET(FE) - ET(MO(N))): ON ND < JD GOSUB
    5Ø2: NEXT : GOTO 5Ø6
5Ø2 JD = ND:FK = N: RETURN
5Ø6  FOR N = M1 TO 12:JV = ET(FE) * ET(MO(N)): ON JV > M2 GOSUB 5Ø8:JD =
    M1: FOR A = QQ TO TN + 4:ND =  ABS (ET(A) - JV): ON ND < JD GOSUB 5Ø
    9: NEXT :IR(N) = ET(JC):FF(N) = JC: NEXT : GOSUB 2ØØ: GOTO 515
5Ø8 JV = JV / M2: RETURN
5Ø9 JD = ND:JC = A: RETURN
515  GOSUB 93Ø: PRINT : FOR A = M1 TO 12:NM$ =  STR$ (A): GOSUB 11Ø: PRINT
    N$") "KN$(A)"= "KR(A);: HTAB 2Ø: PRINT " -FIELD "FI(A): POKE FT,FI(A
    ):FT = FT + M1: NEXT
517  RETURN
599  REM  ---FIELD LIST----
6ØØ  GOSUB 971: GOSUB 92Ø: PRINT :LK =  PEEK (KB): FOR N = QQ TO TN + 4:N
    M$ =  STR$ (N): GOSUB 11Ø: PRINT N$") "ET(N): ON  PEEK (KB) = ZZ GOSUB
    6Ø5: NEXT : POKE 35,24: RETURN
6Ø5  POKE KS,QQ: GET A$: ON A$ = "Q" GOTO 6Ø9:LK =  PEEK (KB): RETURN
6Ø9 N = TN + 4: RETURN
699  REM  ----PRINTER ON/OFF----
7ØØ TI$ = "OUTPUT TO: (P)RINTER OR (S)CREEN : ": GOSUB 978: HOME : IF A$ <
     > "P" THEN  RETURN
71Ø  PRINT D$;"PR#1":FL = M1: RETURN
72Ø  IF FL = M1 THEN  PRINT D$;"PR#Ø":FL = QQ: RETURN
721  RETURN
799  REM   ----INPUT CHECK----
8ØØ  ON  VAL (A$) > TN + 4 OR  VAL (A$) < QQ GOTO 8Ø2: ON  ASC (A$) > 58 OR
     ASC (A$) < 48 GOTO 8Ø2: ON  ASC ( RIGHT$ (A$,M1)) > 58 OR  ASC ( RIGHT$
    (A$,M1)) < 48 GOTO 8Ø2: ON  LEN (A$) > M2 GOTO 8Ø2:IE = QQ: RETURN
8Ø2 IE = M1: RETURN
9ØØ  REM   --TITLES--
92Ø TI$ = "FIELD RATIOS FOR TUNING: " +  STR$ (TN): GOSUB 972: RETURN
93Ø TI$ = "TUNING: " +  STR$ (TN) + "  -FIELD " +  STR$ (FE) + " = " + KN
    $(FK): GOSUB 972: RETURN
971  HOME : INVERSE : VTAB 23: PRINT  SPC( 4Ø): VTAB 23: PRINT "(SPACE)ST
    OP -(Q)UIT": POKE 35,22: NORMAL : VTAB 21: RETURN
972  POKE 34,M1: HOME : INVERSE : VTAB M2: PRINT  SPC( 4Ø): VTAB M2: PRINT
    TI$: POKE 34,M2: NORMAL : RETURN
978  POKE 35,24: VTAB 23: INVERSE : PRINT  SPC( 4Ø): VTAB 23: PRINT TI$;:
     GET A$: PRINT : NORMAL : RETURN
979  POKE 35,24: VTAB 23: INVERSE : PRINT  SPC( 4Ø): VTAB 23: PRINT TI$;:
     INPUT A$: NORMAL : RETURN
98Ø  HOME : VTAB 1Ø: PRINT "JUST A SEC": RETURN
```

```
982  FLASH : HTAB 2: PRINT "INSTALLED TUNING TABLE NOT OF CURRENT": HTAB
```

```
5300  GOSUB 8000: GOTO 2000
5499  REM ---QUIT TABLE?---
5500  POKE KS,QQ: GET A$: ON A$ = "Q" GOTO 5509: RETURN
5509 FE = TN: POP : GOTO 2000
7999  REM
8000  REM
8001  REM *** SAVE TO DISK ***
8002  REM
8010 EF = 8010:TI$ = "SAVE TUNING TABLE: " +  STR$ (TN): GOSUB 972: VTAB
     10: PRINT "WILL BE SAVED AS:": PRINT : HTAB 13: PRINT "TUNING TABLE.
     "TN$
8012  IF TA <  > TN THEN  GOSUB 982: GOTO 8900
8020 EF = 8010:TI$ = "(S)AVE TO DISK  (C)HANGE NAME  (Q)UIT": GOSUB 978: ON
     A$ = "Q" GOTO 8900: ON A$ = "C" GOTO 8024: ON A$ = "S" GOTO 8050: GOTO
     8020
8024 TI$ = "ENTER NEW NAME : ": GOSUB 979: ON A$ = "" GOTO 8010:TN$ = A$:
      GOTO 8000
8050  PRINT D$;"BSAVE TUNING TABLE."TN$",A$6B00,L$2F0": GOTO 8000
8900  REM   ---RETURN---
8901 EF = QQ: RETURN
10000  REM
10001  REM  ** MENU **
10002  REM
10010  POKE 34,QQ: HOME : INVERSE : PRINT  SPC( 40): VTAB M1: HTAB 16: PRINT
     "MAIN MENU":TI$ = "EQUAL TEMPERED TUNINGS  -NOW " +  STR$ (TN): GOSUB
     972: VTAB 5: PRINT "(T)UNING SETUP": PRINT
10012  PRINT "(S)AVE TUNING TABLE": PRINT : PRINT : PRINT "(P)RINTOUT": PRINT
     : PRINT "(B)OOT TURBO-TRACKS": PRINT : PRINT "(CTRL-Q)UIT TO BASIC":
     TI$ = "DESIRES? "
10013  VTAB 22: HTAB 5: PRINT "('ESCAPE' RETURNS TO THIS MENU)":TI$ = "DE
     SIRES? ": GOSUB 978
10020  ON A$ = "P" GOTO 20000: ON A$ = "T" GOTO 2000: ON A$ = "B" GOTO 13
     000: ON  ASC (A$) = 17 GOTO 10030: ON A$ = "S" GOSUB 8000: GOTO 1000
     0
10030  PRINT  FRE (QQ): POKE 34,QQ: PRINT : END
13000  REM
13001  REM  ** BOOT TURBO **
13002  REM
13010 TI$ = "BOOT TURBO-TRAKS": GOSUB 972: VTAB 10: FLASH : PRINT "CURREN
     T TUNING TABLE WILL BE LOST": NORMAL : PRINT : PRINT : PRINT "SAVE T
     UNING FIRST ?":TI$ = "SAVE TUNING  -(Y / N): ": GOSUB 978
13012  IF A$ = "Y" THEN  GOSUB 8000: GOTO 13018
13015  ON A$ <  > "N" GOTO 10000
13018 TI$ = "BOOT TURBO-TRAKS": GOSUB 972: VTAB 10: PRINT "INSERT TURBO-T
     RAKS DISK":TI$ = "TURBO-TRAKS IN ?  -(Y)ES  (Q)UIT ": GOSUB 978: ON
     A$ = "Y" GOTO 13020: ON A$ = "Q" GOTO 10000: GOTO 13018
13020  PRINT D$;"PR#6": END
19000  REM
19001  REM  ** ERROR **
19002  REM
19010  HOME : PRINT B$: FLASH : VTAB 10: PRINT "ERROR -CANNOT COMPUTE": NORMAL
     :EE =  PEEK (222)
19012  IF EE = 4 THEN  PRINT "DISK IS WRITE PROTECTED -SILLY!": PRINT : PRINT
     "TRY A DISK THAT ISN'T"
19013  IF EE = 9 THEN  PRINT "THIS DISK IS FULL": PRINT : PRINT "-WOULD Y
     OU LIKE TO INITIALIZE A NEW DATA DISK ?": GOTO 19060
19014  IF EE = 10 THEN  PRINT "A LOCKED FILE WITH THIS NAME ALREADY ON DI
     SK.": PRINT : PRINT "-MAYBE RENAME THIS FILE ?"
19017  IF EE = 8 THEN  PRINT "I/O ERROR": PRINT : PRINT "-DISK NOT INITIA
     LIZED, DRIVE DOOR OPEN,  BAD DISK ETC"
19049  GET A$
19050  ON EF = 8010 GOTO 8010: GOTO 10000
19059  REM  ---INIT---
19060 TI$ = "INITIALIZE A NEW DISK ? (Y/N):": GOSUB 978: ON A$ = "Y" GOTO
     19065: ON A$ <  > "N" GOTO 19060
19061  GOTO 19050
```

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19065  HOME : VTAB 10: PRINT "INITIALIZE NEW DISK:": PRINT : HTAB 20: PRINT
     "-INSERT NEW DISK":TI$ = "READY ?  -(Y)ES (Q)UIT ": GOSUB 978: ON A$
      = "Q" GOTO 19050: ON A$ <  > "Y" GOTO 19065
19070  PRINT : PRINT D$;"INIT X": GOTO 19050
20000  REM
20001  REM  ** PRINTER **
20002  REM
20010  POKE 34,QQ: HOME : INVERSE : PRINT  SPC( 40): VTAB M1: HTAB 17: PRINT
     "PRINTOUT":TI$ = "FOR TUNING: " +  STR$ (TN): GOSUB 972
20012 TI$ = "(T)UNING T(A)BLE (F)IELD (S)YNTH  (ESC)": GOSUB 978:AA$ = A$
     : ON  ASC (AA$) = 27 GOTO 10000: ON AA$ = "C" GOTO 20300: ON AA$ = "
     M" GOSUB 20500: ON AA$ = "Z" GOSUB 20400
20013  ON AA$ = "A" OR AA$ = "S" OR AA$ = "F" OR AA$ = "T" GOTO 20015: GOTO
     20010
20015  GOSUB 700: ON AA$ = "S" GOTO 20020: ON AA$ = "F" GOTO 20050: ON AA
     $ = "T" GOTO 20100: ON AA$ = "A" GOTO 20200
20018  GOSUB 720: GOTO 20012
20019  GOTO 20012
20020  REM ---SYNTH VALUES-----
20021  HOME :TI$ = "CURRENT SYNTH VALUES": GOSUB 972: PRINT " #  ADDRESS
     VALUE": POKE 34,3
20022 N =  - M1: FOR A = 22368 TO 22514 STEP M2:N = N + M1:KN =  PEEK (A)
      +  PEEK (A + M1) * BY:NM$ =  STR$ (N): GOSUB 110: PRINT N$" "A"
     "KN: IF  PEEK (KB) = ZZ THEN  POKE KS,QQ: GET A$
20023  NEXT : ON FL = M1 GOSUB 20018: GET A$: GOTO 20018
20049  REM ---FIELD---
20050 TI$ = "ENTER FIELD #: ": GOSUB 979: ON A$ = "" GOTO 20000: GOSUB 80
     0: ON IE = M1 GOTO 20050:FE =  VAL (A$): GOSUB 930: GOSUB 980: GOSUB
     500: GOTO 20018
20099  REM ---TUNING RATIOS---
20100 TI$ = "RATIOS FOR TUNING: " +  STR$ (TN): GOSUB 972: FOR A = QQ TO
     TN + 4:NM$ =  STR$ (A): GOSUB 110: PRINT N$" "ET(A): IF  PEEK (KB) =
     ZZ THEN  POKE KS,QQ: GET A$
20104  NEXT : PRINT : GOTO 20018
20199  REM  ---TUNINGTABLE---
20200 TI$ = "TUNINGTABLE FOR TUNING: " +  STR$ ( PEEK (TM)): GOSUB 972: PRINT
     "VAL ADDRESS": POKE 34,3:FT = 27504
20201  IF TA <  > TN THEN  GOSUB 982: GOTO 20018
20202  IF  PEEK (TM) > TN THEN  VTAB 10: PRINT "NO VALID TUNING TABLE LOA
     DED": GET A$: GOTO 20018
20203  FOR A = M1 TO  PEEK (TM): PRINT "FIELD "A: FOR AA = M1 TO 12:NM$ =
      STR$ ( PEEK (FT)): GOSUB 110: PRINT N$" "FT:FT = FT + M1: IF  PEEK
     (KB) = ZZ THEN  POKE KS,QQ: GET A$: IF A$ = "Q" THEN 20018
20204  NEXT : NEXT : GET A$
20210 MT = 27392:TI$ = "MAINTABLE FOR TUNING: " +  STR$ ( PEEK (TM)): GOSUB
     972: PRINT "#  VALUE  ADDRESS"
20211  FOR A = M1 TO  PEEK (TM) + M2:NM$ =  STR$ (A): GOSUB 110:A2 =  PEEK
     (MT) +  PEEK (MT + M1) * BY: PRINT N$" "A2" "MT:MT = MT + M2: IF  PEEK
     (KB) = ZZ THEN  POKE KS,QQ: GET A$
20212  NEXT : GOTO 20018
40997  REM
40998  REM  **** INIT ****
40999  REM
50000  ONERR  GOTO 19000
50005  HOME : VTAB 10: INVERSE : PRINT  SPC( 40): VTAB 10: HTAB 9: PRINT
     "EQUAL TEMPERED TUNINGS": NORMAL
50010 M1 = 1:M2 = 2:QQ = 0:JV = QQ:JD = QQ:ND = QQ:JC = QQ:M3 = 3:BY = 25
     6:ZZ = 160:RN = .5:CV = 8581.5:KB = 49152:KS =  - 16368:KN = QQ:TN =
     QQ:TC = QQ:EF = QQ:TR = QQ
50012  DIM ET(60): REM  EQUAL TUNING RATIOS (FIELDS) + 4 AT END
50035  DIM MO(13): REM NUMBERS OF THE    FIELDS IN THE TUNING MODULE
50036  DIM JR(13): FOR N = QQ TO 12: READ JR(N): NEXT : REM   JUST RATIOS

50037  DATA  1 ,1.06666667,1.125,1.2,1.25,1.33333333,1.40625,1.5,1.6,1.66
     666667,1.77777778,1.875,2
50038  DIM IR(13): REM   INTERIM RATIO STORAGE
```

```
50039  DIM KR(13): REM   KEY RATIO -SET FOR EACH FIELD
50040  DIM KN$(13):KN$(0) = "C ":KN$(1) = "D'":KN$(2) = "D ":KN$(3) = "E'
     ":KN$(4) = "E ":KN$(5) = "F ":KN$(6) = "F#":KN$(7) = "G ":KN$(8) = "
     A'":KN$(9) = "A ":KN$(10) = "B'":KN$(11) = "B ":KN$(12) = "C "
50045  DIM FI(53): DIM FF(53): REM     FIELD AND INTERIM FIELD NUMBERS
50050 MT = 27392:FT = 27504:FM = 28141:TM = 27503:TU = 00
50051  REM     START ADDRESSES FOR MAINTABLE & FIELDTABLE. ADDRESSES FOR
     FIELNUM $ TUNENUM. TUNING # VAR
50053 SP$ = "    ":SC$ = "00":D$ =  CHR$ (4):B$ =  CHR$ (7):IE = 00
50095  GOTO 10000
60000  PRINT  CHR$ (4);"PR#1": LIST : PRINT  CHR$ (4);"PR#0"
60001  REM
60002  REM  PROGRAM BY A.NIEMANN
60003  REM
60004  REM  RUN 60000 TO PRINTOUT LISTING
```

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