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The evolution of open-chain enharmonic keyboards *c*1480–1650

Patrizio Barbieri

Only just intonation and meantone enharmonic systems will be taken into account below: these are all open-chain, i.e., non-circulating. The circulating ones, i.e., those based on the many types of Equal Tempered Systems (ETS), have been examined in a previous article.[1]

1. Basic theory: from Pythagorean intonation to sistema partecipato*, later called* meantone

1.1. The Pythagorean system in use up to the 15th century was generated from a chain of perfect 5ths: the customary twelve notes of the octave could be obtained with the scheme illustrated in Table 1, the zero exponents signalling that each successive note has been reached by a pure, that is, a beatless 5th. This scheme produced major 3rds (e.g., C^0-E^0) enlarged by a syntonic comma (ratio 81:80, ≅ 21.5 cents; hereinafter called simply a comma) compared to the consonant ratio 5:4, and minor 3rds (e.g., C^0-$E♭^0$) narrowed by the same amount, with reference to their consonant ratio 6:5.

Table 1 – Pythagorean tuning with harmonic range E♭-G♯

…	$E♭^0$	$B♭^0$	F^0	C^0	G^0	D^0	A^0	E^0	B^0	$F♯^0$	$C♯^0$	$G♯^0$	…

In the Renaissance, when such intervals began to be used harmonically, theoreticians tried narrowing one 5th in each four by exactly a comma, as a means of keeping all the major 3rds and three-quarters of the minor ones consonant. For example, one might narrow the 5ths B♭-F, D-A, and F♯-C♯, obtaining the tuning of Table 2.

1 Patrizio Barbieri, «I temperamenti ciclici da Vicentino (1555) a Buliowski (1699): teoria e pratica ‹archicembalistica›», in: *L'organo* 21 (1983), pp. 129–208.

Table 2 – Typical just intonation

		$C\sharp^{-2}$		$G\sharp^{-2}$		...	
	A^{-1}		E^{-1}		B^{-1}		$F\sharp^{-1}$
F^{0}		C^{0}		G^{0}		D^{0}	
	...		$E\flat^{+1}$		$B\flat^{+1}$		

Here the exponents indicate the cumulative alterations of pitch, in commas, with respect to the Pythagorean scale of Table 1. With this kind of exponential notation one can indicate whether a note is a comma lower or higher than its pitch in Pythagorean intonation, thereby clearly identifying all the possible consonant major and minor triads. For example, in C^{0}-E^{-1}-G^{0}, E must be a comma lower (therefore^{-1}) than its pitch given by Pythagorean intonation (Table 1) in order to be a just major 3rd with C^{0} and a just minor 3rd with G^{0}. Conversely in C^{0}-$E\flat^{+1}$-G^{0}, E♭ must be a comma higher than its Pythagorean pitch for the same reasons (therefore^{+1}). It can also be seen that D has neither the just minor 3rd nor the just 5th above, the dissonances being, respectively, D^{0}-F^{0} and D^{0}-A^{-1}. Moreover, now we have two kinds of tone: major (e.g., C^{0}-D^{0} = 9:8) and minor (e.g., D^{0}-E^{-1} = 10:9). In fact some tones are formed by two just 5ths (C^{0}-G^{0}-D^{0}), while others present one of the two 5ths narrowed by one comma (D^{0}-A^{-1}-E^{-1}).

From the historical perpective, Bartolomeus Ramis de Pareja (1482) was the first theoretician to become aware of the evolution of the intonation towards just ratios.[2] Almost fifty years later, Ludovico Fogliano (1529) is credited with introducing the doubled Ds and B♭s, separated by a comma, in order to supply the just D-A and B♭-F 5ths of the diatonic genus (Table 3).[3]

Table 3 – Fogliano's just intonation (1529)

		D^{-1}		A^{-1}		E^{-1}	B^{-1}
$B\flat^{0}$		F^{0}		C^{0}		G^{0}	D^{0}
							$B\flat^{+1}$

2 On this subject see Mark Lindley, «Fifteenth-Century Evidence for Meantone Temperament», in: *Proceedings of the Royal Musical Association* 102 (1975–76), pp. 37–51. In Italian texts the term «*sintonico*» is usually found where in English one speaks of «just» (intonation or tuning).

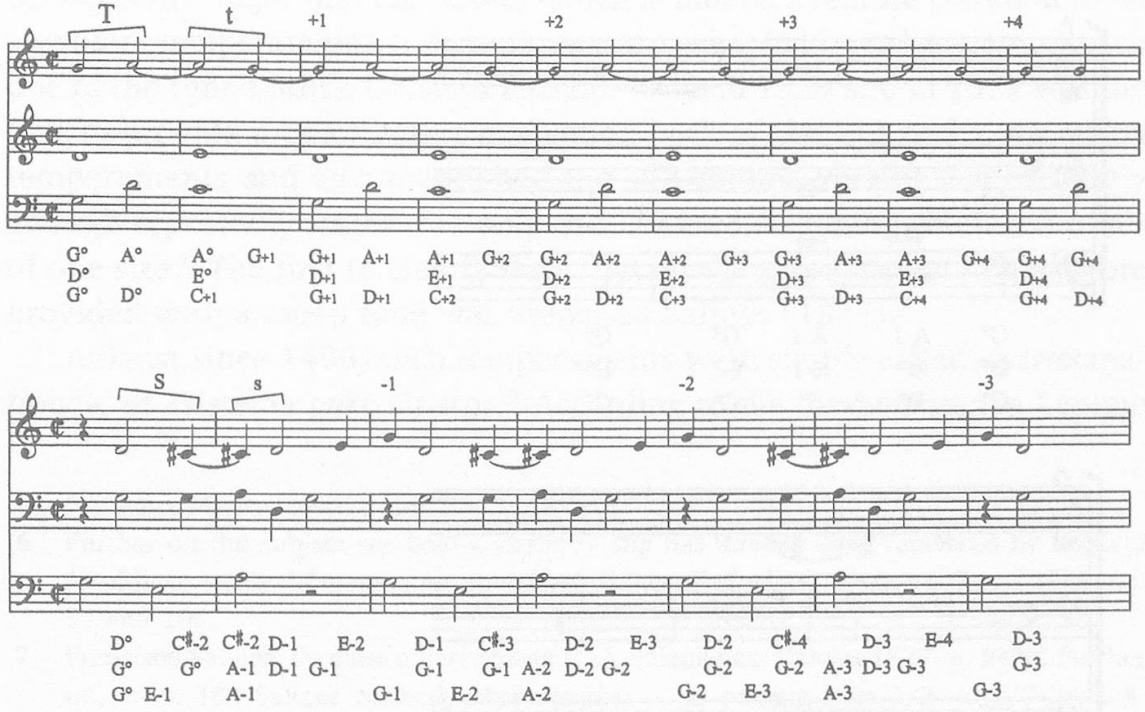
3 Ludovico Fogliano, *Musica theorica* [...], Venezia: De Sabio 1529, fol. 34v; Giovanni Battista Doni, *Annotazioni sopra il compendio de' generi e de' modi della musica* [...], Roma: Fei 1640, p. 40 («conforme all'inventione del Fogliano»).

1.2. The practical problem in performance was to avoid the dissonant, narrowed 5ths, such as D^0-A^{-1}. In vocal intonation this could be obtained by transforming, when needed, the same tone from major to minor or vice versa (e.g., C^0-D^0, C^0-D^{-1}), but, analysed statistically, after a few of these manipulations this could cause a notable pitch alteration, up or down, since commas added might not be compensated by those subtracted. The Venetian mathematician and amateur composer Giovanni Battista Benedetti – in a letter to his friend Cipriano de Rore, published in 1585 – is the first author to draw attention to this pitch shift, providing also two extreme examples of its surprising effects (Ex. 1).[4]

Ex. 1: Giovanni Battista Benedetti (1585): pitch shift due to just intonation. If all intervals are intoned purely the pitch will shift:

(a) upwards by 1, 2, 3, 4 commas, because the upper voice is going up by a major tone (T) and down by a minor one (t).

(b) downwards by 1, 2, 3 commas, because in this case the upper voice is going down by a major semitone (S) and up by a minor one (s)



4 Giovanni Battista Benedetti, *Diversarum speculationum mathematicarum, et physicarum liber*, Torino: Bevilacqua 1585, p. 279. Later on, this pitch shift was also be mentioned by Vincenzo Galilei, *Discorso intorno all'opere di messer Gioseffo Zarlino da Chioggia* [...], Firenze: Marescotti 1589, p. 121. A computer assisted performance of the above examples was provided on the occasion of my paper on «Fretted strings versus vocal intonation: Enharmonic proposals in the Baroque» at the colloquium in Basel.

On the other hand, with regard to keyboard instruments, the problem could be solved in two ways:

1. By splitting the bottom key of the narrowed 5ths into two notes separated by a comma (Ex. 2).
2. By transforming both major and minor tones into a *mean tone* and thus unifying the split keys that are separated by a comma. This could be achieved through one of the many kinds of «meantone» temperament, of which the best known was 1/4-comma meantone (Table 4). This tuning left untempered one of the main intervals of the original just intonation scale, the major 3rd. Instead of narrowing one 5th in each four by a comma (thereby changing it to a dissonant interval), each one of the four 5ths was narrowed by 1/4-comma.

Ex. 2: The same score of Ex. 1, but intoned according to the tuning of Table 2: the pitch will be stable, but a 5th (D^0-A^{-1}) or a 4th (A^{-1}-D^0) will be mistuned by one comma. A solution could be to use the intonation of Table 3, shifting from D^0 to D^{-1} (and vice versa) when necessary.

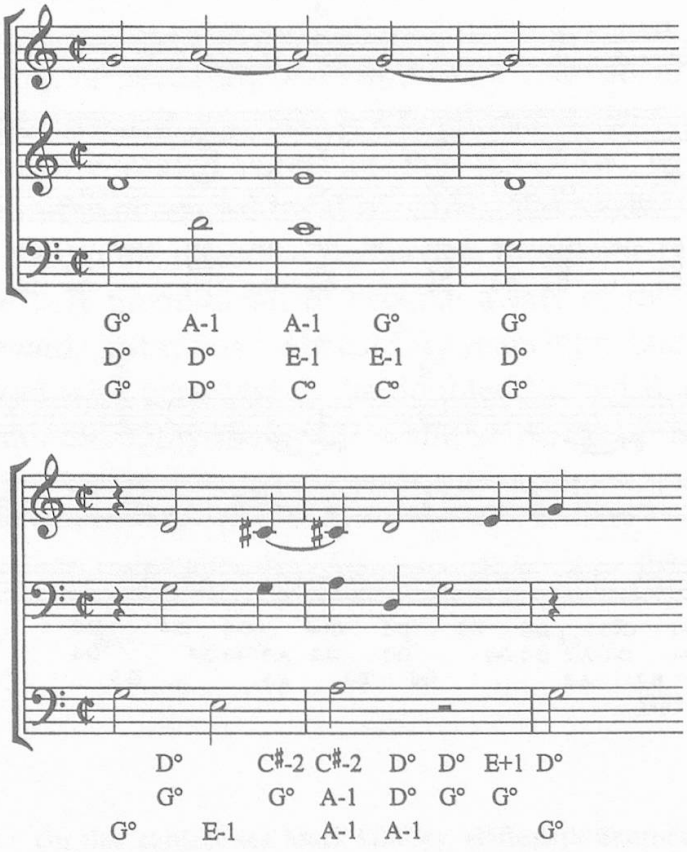


Table 4 – Quarter-comma temperament (meantone)

	$C\sharp^{-7/4}$	$G\sharp^{-2}$	...	
$A^{-3/4}$	E^{-1}	$B^{-5/4}$	$F\sharp^{-6/4}$	
$F^{+1/4}$	C^{0}	$G^{-1/4}$	$D^{-2/4}$	
...	$E\flat^{+3/4}$	$B\flat^{+2/4}$		

1.3. The first theoretician who endeavoured to provide a quantitative interpretation of the 1/4-comma meantone is the above mentioned Ludovico Fogliano (1529). Referring to Table 3 he rather naively unified the two Ds into a single geometrical mean ($D^{-1/2}$), though correctly making use of a graphical construction reported in Euclid's *Elementa*; the same operation was then extended by him to the two B♭s.[5]

Other kinds of meantone, leading to imperfect consonances more or less close to the just ratios, were those narrowing each of the 5ths by 2/7 or 1/3-comma. And even these two provided tones of only one size, that is, a mean between the major and the minor, which is indeed a feature common to all «regular» temperaments (i.e., to those narrowing by the same amount each one of the tuned 5ths). Gioseffo Zarlino – who in 1558 and in 1571 was the first to provide a quantitative evaluation both of the 2/7 and 1/4-comma temperaments and also mentioned the 1/3-comma variant – surprisingly enough repeatedly states that only the 1/4-comma tuning produced tones of one size.[6] The first to clearly state that all the three temperaments were provided with a mean tone was Francisco Salinas (1577).[7]

At least since 1496, such temperaments were simply called «partecipatione», or «sistema partecipato».[8] According to the mathematician Lemme

5 Fogliano, *Musica theorica*, fol. 35v.

6 Further on the subject see below. Zarlino's slip has already been remarked by Roberto Airoldi, *La teoria del temperamento nell'età di Gioseffo Zarlino*, Cremona: Turris 1989, pp. 57 and 106.

7 Francisco Salinas, *De musica libri septem* [...], Salamanca: Gastius 1577, p. 143ff. Further on, on p. 164 Salinas correctly observes that — in passing from 1/3- to 2/7- to 1/4-comma — the ratio of temperament of the major tone / minor tone tends to 1, through a harmonic progression.

8 See e.g.: Franchino Gaffurio, *Practica musice*, Milano: Lomazzo 1496, fol. ddI^{v} (Lib. III, Cap. III); Fogliano, *Musica theorica*, fol. 35v; Giovan Maria Lanfranco, *Scintille di musica* [...], Brescia: Britannico 1533, pp. 131–136. In this regard it is curious recalling that, according to Giuseppe Unicorno, a mathematician from Bergamo writing in 1598, still in his time some ancient organs were preserving the harsh 3rds and 6ths of their original Pythagorean tuning, being «senza participatione»: Patrizio Barbieri, «An Unknown 15th-century French Manuscript on Organ Building and Tuning», in: *The Organ Yearbook* 20 (1989), pp. 5–20, p. 20.

Rossi (1666), this designation was due to the fact that the systems thus obtained were taking the most advantageous «parts» (i.e., features) from both the Pythagorean (with equal-sized tones) and just intonation (with just 3rds and 6ths).[9] That this kind of temperament was in fact regarded as a true «system» is confirmed by the German Joachim Junge (1587–1657), who lists together the following:

«Scala diatonica vetus» (= Pythagorean)
«Scala diatonica nova» (= Just Intonation)
«Scala diatonica reformata» (= 1/4-comma)[10]

The term «meantone temperament», which today many authors apply only to the 1/4-comma version, is instead of a much later date.[11]

1.4. The above considerations refer only to keyboard instruments. That this tempered intonation could be shared also by unaccompanied singers was highly debated in the late 16th century by Zarlino and Vincenzo Galilei, the former blatantly stating that a strict just intonation was sung, the latter – on the contrary – that just intonation was not strict, but somehow tempered.[12] Without going into detail, it may be noted that Zarlino's position is in any case contradictory. In fact he states that «all» consonances are sung pure, even the comma-affected 5ths, without taking into account that in this way (1) there should have been a more or less marked pitch shift (see Ex. 1), or, (2) if the singers, in order to avoid both the mistuned consonances and the

9 Lemme Rossi, *Sistema musico overo musica speculativa* [...], Perugia: Laurenti 1666, p. 58: «Onde per tor via l'inegualità de' tuoni, si venne a formare un nuovo Sistema, che chiamano temperato, o' participato, participando dell'uno, e dell'altro Diatono esplicati; poiché quanto all'haver'i tuoni eguali è simile al Diatono Ditonieo [= Pythagorean], e nel resto poco si discosta dal Sintono».

10 Joachim Jungius, «Harmonicae definitiones», in: Id., *Praecipuae opiniones physicae* (posthumous work), Hamburg 1679, fol. [B4]v. Junge was a polymath: in 1618 he went to Padova, where he graduated in medicine; Robert Eitner, *Biographisch-Bibliographisches Quellen-Lexicon* V, Leipzig: Breitkopf & Härtel 1901, p. 311.

11 According to Airoldi, *La teoria del temperamento*, p. 8, it seems to have been employed for the first time by Pierre Galin (1818). But it is only with Alexander J. Ellis' famous *Additions* to his English translation of Hermann L.F. Helmholtz, *On the sensations of tone* [...], London: Longmans 1885, p. 433, that the term «meantone» became the standard equivalent of «1/4-comma temperament». On the general application of this term to schemes with tempered major 3rds, see Mark Lindley, *Lutes, Viols and Temperaments*, Cambridge: Cambridge University Press 1984, p. 43.

12 Vincenzo Galilei, *Dialogo della musica antica et della moderna*, Firenze: Marescotti 1581, pp. 30–31; Gioseffo Zarlino, *Sopplimenti musicali* [...], Venezia: De' Franceschi 1588, pp. 130–152, especially p. 148.

pitch shift, had resorted to intoning the comma step (see the double D met with in Ex. 2), the effect should likewise have been unpleasant and troublesome, as Zarlino himself describes in regard to a musical instrument he had had made with split keys separated by a comma (see §3.1 below).[13]

Zarlino's acrimony with his former pupil Galilei was also embittered by the fact that, in the *Dialogo* (1581), the latter had expounded the 2/7-comma temperament without crediting Zarlino for its discovery. The only «new» contribution by Galilei – also this time without mentioning that it was due to another author (Salinas) – is that even in the 2/7-comma version all tones are of the same size, a feature that favoured his assumptions regarding the actual vocal intonation.[14] As for the other details, Galileo's quantitative treatment of temperaments shows that in this field he was not perfectly at ease.[15] Zarlino, on the other hand, never acknowledged his oversight. In the 1589 reprint of the *Dimostrationi harmoniche*, he adroitly corrects the passages containing errors without any warning:[16]

1571 ed.	1589 ed.
[p. 221] così in questo temperamento [2/7-comma] si ritrovano due tuoni l'uno maggiore dell'altro	[p. 200] retiene in sé l'equalità de i tuoni
[p. 266] Et perché quelli [= i tuoni] della partecipatione fatta nelle Istitutioni sono differenti l'uno dall'altro per una settima parte di uno comma	[p. 242] Et perché i tuoni della detta partecipatione dimostrata nelle Istitutioni, non sono differenti l'un dall'altro di proportione

13 Gioseffo Zarlino, *Le istitutioni harmoniche* [...], Venezia: (no publisher) 1558, p. 125 (without the temperament, the comma step should have been used many times, «il che non solamente difficultà al sonatore; ma etiandio poco diletto a gli ascoltanti haverebbe apportato: perché in cotal caso si haverebbe udito un non so che di tristo, che haverebbe fatto non poco fastidio») and p. 127. See also Gioseffo Zarlino, *Dimostrationi harmoniche* [...], Venezia: De' Franceschi 1571, p. 220 («si udiva un non so che di poco buono»).

14 Galilei, *Dialogo*, p. 33.

15 Patrizio Barbieri, «L'accordatura strumentale in Toscana: proposte e contrasti da V. Galilei a Cristofori (c. 1580–1730)», in: *Musicologia humana. Studies in honor of Warren and Ursula Kirkendale*, ed. by Siegfried Gmeinwieser, David Hiley & Jörg Riedlbauer, Firenze: Olschki 1994, pp. 209–232, pp. 212–213. About equal temperament, not only his ideas were not at all clear, but he is also providing tricky numerical calculations: see Airoldi, *La teoria del temperamento*, pp. 142–144.

16 For the 2nd ed. see: Gioseffo Zarlino, *Le dimostrationi harmoniche* [...], in: Id., *De tutte l'opere* [...], vol. II, Venezia: De' Franceschi 1589.

1.5. If in Table 4 we add further tempered 5ths, in order to extend the chain beyond its customary range E♭-G♯, we begin to split the diatonic (i.e., major) semitones into two unequal parts, thus entering into the field of the enharmonic genus (Table 5). In this way we obtain an open chain in which two notes enharmonically equivalent (like G♯-A♭ and D♯-E♭) are separated by the so-called «enharmonic diesis», the flattened note being higher in pitch than its sharpened equivalent. Both in just intonation and 1/4-comma temperament the ratio of frequencies corresponding to this microinterval is 128:125 (≅ 41.1 cents), about a fifth of a tone. In §2 keyboards actually built according to such schemes will be examined.

Table 5 – Meantone tuning extended to the enharmonic (*cimbalo cromatico*)

				E♯			B♯			…		
			C♯			G♯			D♯			A♯
		A			E			B			F♯	
	F			C			G			D		
D♭			A♭			E♭			B♭			
				…			G♭					

1.6. The *partecipationi* we have so far obtained are merely due to the removal of the comma, and therefore to the unification of the split keys that were separated by a comma. If we were to go further along this path, we could remove the enharmonic diesis, therefore unifying enharmonically split keys like G♯-A♭, B♯-C, etc. Thus, we would obtain an equal temperament, in which the octave is divided into 12 acoustically-equal semitones (i.e., semitones with the same frequency ratio), a system nowadays described as ETS 12 (= Equal Tempered System 12). Already in Salinas (1577) we come across this twofold approach to the theory of temperaments, which – according to Lemme Rossi (1666) – is leading to the three classes of keyboards listed in Table 6.[17] However Salinas says that his just intonation keyboard had only three rows of keys, like its tempered version, because he does not count the row of the «commas» (§3.1).

17 Salinas, *De musica*, p. 167; Rossi, *Sistema musico*, pp. 82 and 88.

Table 6 – The three classes of keyboards

System	*Tones*	*Semitones*	*Rows of keys*	*Remarks*
Just inton.	Two sizes	Four sizes	Four: diatonic, sharps, flats, commas	Both tones and semitones of different size
Meantone	One size	Two sizes	Three: diatonic, sharps, flats	Unification of tones only
Equal temp.	One size	One size	Two:diatonic, sharps=flats	Unification both of tones and semitones

Furthermore, it may be observed that:

1. Within the customary range of the eleven tuned 5ths, even meantone tuning can be considered an «equal temperament», having all its harmonic intervals equally tempered.[18]
2. Even dissonant intervals like the «wolf 5th» G♯-E♭ – exceeding the just 5th by a little less than an enharmonic diesis – could have come in handy, being sometimes employed by experienced musicians for special effects: see, e.g., Juan Bermudo (1555) and Bartolomeo Cristofori (1709–10).[19]

2. *Meantone enharmonic keyboards: towards fifths of a tone*

2.1. *From the first split keys up to the* ‹cimbalo cromatico›. The first known example of these extra notes comes from the organ of Cesena cathedral and is dated as early as 1468. In 1480 the new organ of the cathedral of Lucca had its middle octaves furnished with split keys for the E♭/D♯ and G♯/A♭, the customary range E♭-G♯ was thus extended by a 5th at both ends.[20] As we will see in §5.1, expecially the A♭ was needed by church organists. In some cases, according to the choice of the performer, the two split keys could

18 In mid-18th-century this had been already remarked and new temperaments invented also for giving variety to the different keys: Patrizio Barbieri, «Il ‹migliore› sistema musicale temperato: *querelles* fra Estève, Romieu a altri accademici francesi (c. 1740–60)», in: *L'organo*, 27 (1991–92), pp. 31-81, pp. 52 and 57.

19 Juan Bermudo, *Declaracion de instrumentos musicales* [...], Ossuna: De Leon 1555, fol. 47r-v; Barbieri, «L'accordatura strumentale», p. 221 (on Cristofori). See also Doni, *Annotazioni*, p. 173.

20 Denzil Wraight & Christopher Stembridge, «Italian Split-Keyed Instruments with Fewer than Nineteen Divisions to the Octave», in: *Performance Practice Review* 7/1 (1994), pp. 150–181, pp. 162 and 169.

be added only on the sharp side of the chain of tempered 5ths, e.g., the keyboard sketched in Fig. 1 by the Dutchman Joannes van der Elst (1657).[21] Moreover, this splitting could involve all the five black keys, bringing the total range to G♭-A♯ (Fig. 2a).[22] With two more extra sharps (between E-F and B-C) the extension could be brought to G♭-B♯, thus obtaining the so-called *cimbalo cromatico* (see Table 5 above). Although this specific designation begins to be found only from 1609 (Ascanio Mayone) onwards, such a kind of keyboard was already known to Vicentino (1555), Zarlino (1558), and Salinas (1577); its keys were arranged in three *ordini*, i.e., rows.[23] On Salinas, see also §3.1 below.

Fig. 1: Joannes van der Elst (1657): Claviarium II (harmonic range E♭-A♯).

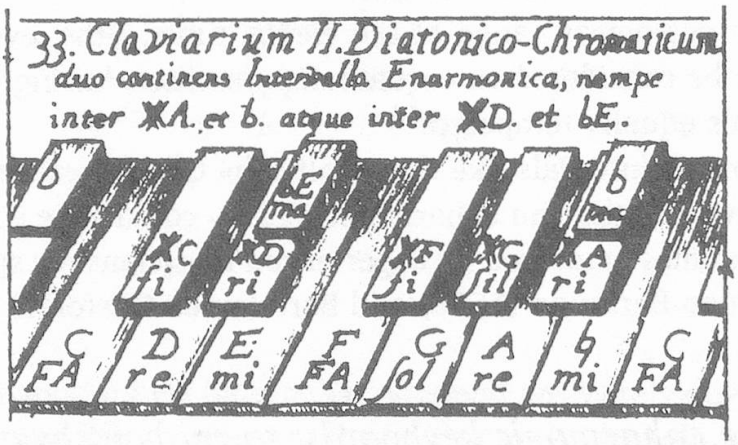
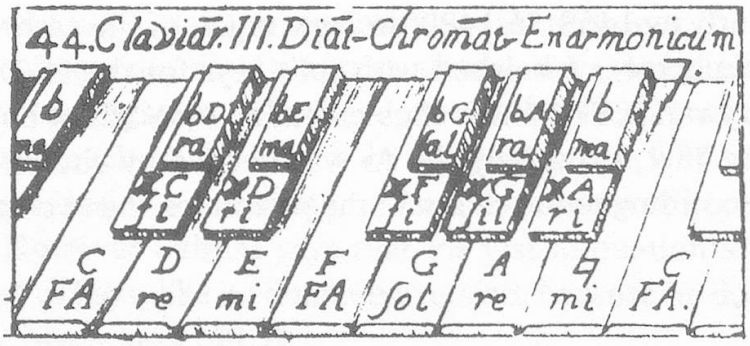


Fig. 2a:
Joannes van der Elst (1657): Claviarium III (harmonic range G♭-A♯).



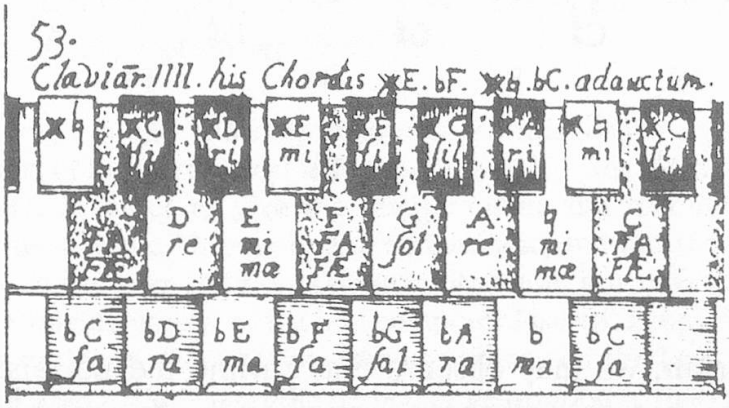
21 Joannes van der Elst, *Notae Augustinianae* [...], Gand: Graet 1657, fig. 33. In Italy, on the contrary, no instrument is known to have had D♯s and also A♯s without also having A♭s: see Wraight & Stembridge, «Italian Split-Keyed Instruments», p. 171.

22 Van der Elst, *Notae Augustinianae*, fig. 44.

23 Beside the contributions by Rudolf Rasch and Denzil Wraight in this volume see Christopher Stembridge, «Music for the *Cimbalo Cromatico* and Other Split-Keyed Instruments in Seventeenth-Century Italy», in: *Performance Practice Review* 5/1 (1992), pp. 5–43; Id., «The *Cimbalo cromatico* and Other Italian Keyboard Instruments with Nineteen or More Divisions to the Octave (Surviving Specimens and Documentary Evidence)», in: *Per-*

In the normal keyboards *all* tones were simply split into a major and a minor semitone. In the *cimbalo cromatico*, on the other hand, *all* major semitones were in their turn split into a minor semitone and an enharmonic diesis. In so doing, apart from the C♭s and F♭s, every diatonic note was thus provided with its sharp and flat. In Fig. 2b van der Elst adds also the missing C♭s and F♭s, bringing the whole range to F♭-B♯.[24]

Fig. 2b:
Joannes van der Elst (1657): Claviarium IV (harmonic range F♭-B♯).



2.2. *From the* ‹cimbalo cromatico› *to the* ‹archicembalo›. Just after presenting an illustration of a harpsichord whose harmonic range is that of a *cimbalo cromatico*, Zarlino adds that in 1548 he had had a harpsichord made – by Domenico da Pesaro, who also happened to be a friend of his – which we now know was a still more complex harpsichord. In fact, according to the 1558 edition of the *Istitutioni harmoniche*, even «all» its minor semitones

formance Practice Review 6/1 (1993), pp. 33–59. On the *cimbalo cromatico* see also Patrizio Barbieri, «La *Sambuca Lincea* di Fabio Colonna e il *Tricembalo* di Scipione Stella. Con notizie sugli strumenti enarmonici del Domenichino», in: *La musica a Napoli durante il Seicento*, ed. Domenico Antonio D'Alessandro & Agostino Ziino, Roma: Torre d'Orfeo 1987, pp. 167–216, pp. 187–190. A *cimbalo cromatico*, with an attempt to calculate its tempered string lengths, is also provided by Michael Keller, *Monochordum* [...], Neisse: Schubart 1636, cap. VI.

24 Van der Elst, *Notae Augustinianae*, fig. 53. The key-disposition of this keyboard somehow recalls the one of Francesco Nigetti's *Cembalo onnicordo* (2nd version, c1644) and Doni's *Cembalo pentarmonico*: Patrizio Barbieri, «Il Cembalo onnicordo di Francesco Nigetti in due memorie inedite di G. B. Doni (1647) e B. Bresciani (1719)», in: *Rivista italiana di musicologia* 22 (1987), pp. 34–113, pp. 59–63.

were split into two parts.[25] Martino Pesenti, who happened to examine this very instrument in Venice (1641), states that it was the first diatonic-chromatic-enharmonic harpsichord ever built (neglecting the *cimbalo cromatico*, whose origin seems to be of a still earlier date). Pesenti's key by key comments yield the division of Table 7.[26]

Table 7 – Tuning of Zalino's harpsichord (Domenico da Pesaro, 1548)

				G𝄪		D𝄪		A𝄪				
			E♯		B♯		F𝄪		C𝄪			
		C♯		G♯		D♯		A♯				
	A		E		B		F♯					
F		C		G		D						
D♭		A♭		E♭		B♭						
				G♭								

About this division, we may observe that Zarlino did not bisect «all» the minor semitones, but only all those formed by the flattened notes present in the *cimbalo cromatico*, i.e., D♭-D, E♭-E, G♭-G, A♭-A, and B♭-B: thus, «all the tones» were split into four (and no longer «all the minor» semitones into two), as Zarlino partially corrects himself in the 1589 ed. of the *Istitutioni*,[27] when he mentions the harpsichord

25 Zarlino, *Le istitutioni harmoniche*, p. 140; Zarlino, *Dimostrationi harmoniche*, p. 235 (where Willaert mentions the 1548 harpsichord «che vi fece Maestro Domenico da Pesaro vostro amico»). See also the contributions by Rudolf Rasch, «Why were enharmonic keyboards built? – From Nicola Vicentino (1555) to Michael Bulyowsky (1699)», and Denzil Wraight, «The *cimbalo cromatico* and other Italian string keyboard instruments with divided accidentals», both in this volume.

26 Martino Pesenti, *Correnti, gagliarde, e balletti diatonici, trasportati parte cromatici, e parte henarmonici* [...], Venezia: Vincenti 1645, introduction, no page number («A professori di musica, per maggior intelligenza»). See also Stembridge, «The *Cimbalo cromatico*», pp. 45–54 (with an English translation of Pesenti's introduction) and Rasch, «Why were enharmonic keyboards built?» (in this volume). – In passing, it should be mentioned that Pesenti himself owned an instrument made by the same harpsichord maker: *L'archivio IRE. Inventari dei fondi antichi degli ospedali e luoghi pii di Venezia*, ed. Giuseppe Ellero, Venezia: IRE 1987, p. 174, year 1645 («caso di testamento fatto da un cieco, Martino Pesenti qu. Giacomo [...] a don Gian Antonio Ferri il suo manacordi [*sic*] Domenico da Pesaro»).

27 Published in: Gioseffo Zarlino, *De tutte l'opere* [...], vol. I, Venezia: De' Franceschi 1589.

1558 ed., p. 140	1589 ed., p. 171
il quale fece Maestro Dominico Pesarese fabricatore eccellente di simili istrumenti; nel quale non solamente li semituoni maggiori sono divisi in due parti, ma anche tutti li minori.	il quale fabricò Maestro Dominico Pesarese, raro et eccellente fabricatore di simili istrumenti; nel quale non solamente i semituoni maggiori sono divisi in due parti, ma anche i minori, di maniera ch' ogni tuono viene a essere diviso in quattro parti

The last mention of this instrument is by Charles Burney, who examined it when in Florence (September 1770):[28]

> At Florence, I found the harpsichord of Zarlino, which is mentioned in the second part of his Harmonical Instructions, p. 140. This instrument was invented by Zarlino, in order to give the temperament and modulation of the three *genera*, the diatonic, chromatic, and enharmonic; and was constructed, under his direction, in the year 1548, by Dominico Pesarese: it is now in the possession of Signora Moncini, widow of the late composer Piscetti. I copied Zarlino's instructions for tuning it, from his own hand-writing, on the back of the foreboard; but I shall reserve them, and the particular description of this curious instrument, for the History of Music, to which they more properly belong.

So, Zarlino's harpsichord was then owned by Maria Rosa Mancini (not «Moncini»), widow of the composer Giovanni Battista Pescetti.[29] It should be mentioned that Pescetti – son of the organ builder Giacinto – in his last years was 2nd organist of the basilica of San Marco, Venice (the same in which Zarlino had been *maestro di cappella*).[30] Though Burney did not keep the promise to publish Zarlino's tuning directions in his *General history of music*, Pesenti's survey fills in this gap, although we still lack a description of its actual key disposition.

In the same passage, Pesenti adds that from 1621 up to 1634 – when in Venice – he usually played and kept in tune a harpsichord made in 1601 by Vito Trasuntino. This instrument was like Zarlino's, but with four more

28 Charles Burney, *The present state of music in France and Italy* [...], London: Becket 1771, pp. 253–254.

29 Mario Fabbri, «Giovanni Battista Pescetti e un concorso per maestro di cappella a Firenze», in: *Rivista italiana di musicologia* 1 (1966), pp. 120–126, p. 124.

30 Sandro Dalla Libera, «Cronologia musicale della Basilica di San Marco in Venezia – IV», in: *Musica Sacra*, series II, 6 (1961), pp. 133–135.

5ths added, two at the top of the chain (A𝄪-E𝄪-B𝄪) and two at the bottom (G♭-C♭-F♭).[31]

At this point a few considerations are unavoidable.

1. If Vito Trasuntino had added three more 5ths at the bottom of the chain, he would have obtained the same harmonic range of Vicentino's *Archicembalo* (Table 8). This seems to be just what Vito himself did in his 31-keys-per-octave *Clavemusicum Omnitonum* (1606), whose actual tuning is in any case hypothetical.[32]

Table 8 – Tuning of Vicentino's (1555) and V. Trasuntino's (1601) harpsichords:
– roman = Trasuntino
– roman + *italic* = Vicentino

						B𝄪								
					G𝄪		D𝄪		A𝄪		E𝄪			
				E♯		B♯		F𝄪		C𝄪				
			C♯		G♯		D♯		A♯					
		A		E		B		F♯						
	F		C		G		D							
D♭		A♭		E♭		B♭								
B♭♭	F♭		C♭		G♭									
		A♭♭		*E♭♭*										

2. In the *Archicembalo*, each of the 5ths was narrowed by an amount very close to 1/4-comma (≅ 1/4.15-comma). In so doing the circle of the 5ths was closed, so that B𝄪 = D♭♭. This led to an octave divided into 31 equal steps, each one being $2^{1/31} \cong 38.71$ cents wide, which Vicentino called «minor diesis» (five of them made up a tone).[33] In 1577 Salinas argued that this could not be possible, since the «enharmonic diesis»

31 Pesenti, *Correnti*, introduction. See also Stembridge, «The *Cimbalo cromatico*», pp. 45–54, and Wraight, «The *cimbalo cromatico*», and Rasch, «Why were enharmonic keyboards built?» (in this volume).

32 In fact the tuning of the «Tetrachordum» (written «trecta cordo» [sic!], a four-string monochord) with the *Clavemusicum* is still unclear: Marco Tiella, «La ricostruzione dell' archicembalo di Nicola Vicentino (1555)», in: *Strumenti e musica*, 33/1 (1980), pp. 82–86, p. 84.

33 Nicola Vicentino, *L'antica musica ridotta alla moderna prattica*, Roma: Barrè 1555, fol. 18: *Diesis minore enarmonico* (e.g. G♯-A♭) vs. *Diesis maggiore enarmonico* (i.e., the minor semitone, like e.g. A♭♭-A♭). The very same terms,with the same meaning, are used by Zarlino, *Dimostrationi harmoniche*, pp. 92 and 90.

128:125 is a rational quantity, while $2^{1/31}$ is irrational. He thus showed himself unable to recognise that – with a slight correction which is almost undetectable to the ear as far as individual consonances are concerned, although not at all negligible as a whole in the long chain of 5ths – 1/4-comma temperament and the ETS 31 were *de facto* the same thing.[34]

3. On this subject, Zarlino was more cautious and never directly criticized Vicentino's tuning from the mathematical and consonance point of view. In fact – in the 1/4-comma temperament, which he seems to prefer – his 1548 bisection of the minor semitones would have yielded Vicentino's «fifths of a tone».[35] In the *Istitutioni*, after mentioning the harpsichord Domenico da Pesaro had made for him, he limits himself to saying that introducing further divisions would have led to useless additions, maybe alluding to Vicentino.[36] Moreover, it should be recalled that he was in close contact with Vincenzo Colombo, a distinguished organ builder operating in Venice, who had made monochords for Zarlino himself, Claudio Merulo, and perhaps Ettore Ausonio, a professional mathematician and also an amateur music theorist of the Venetian environment (Fig. 3):[37] since Colombo had built an *Arciorgano* for Vicentino, it is likely that Zarlino was informed about its tuning.[38]

34 Salinas, *De musica*, pp. 164–166. And this though Salinas were the first to clearly expound the features of the ETS 31. The first author to recognise that the string-lengths of the ETS 31 were very close to those of the 1/4-comma was Lemme Rossi, in 1666: Barbieri, «I temperamenti ciclici», pp. 159 and 181, respectively.

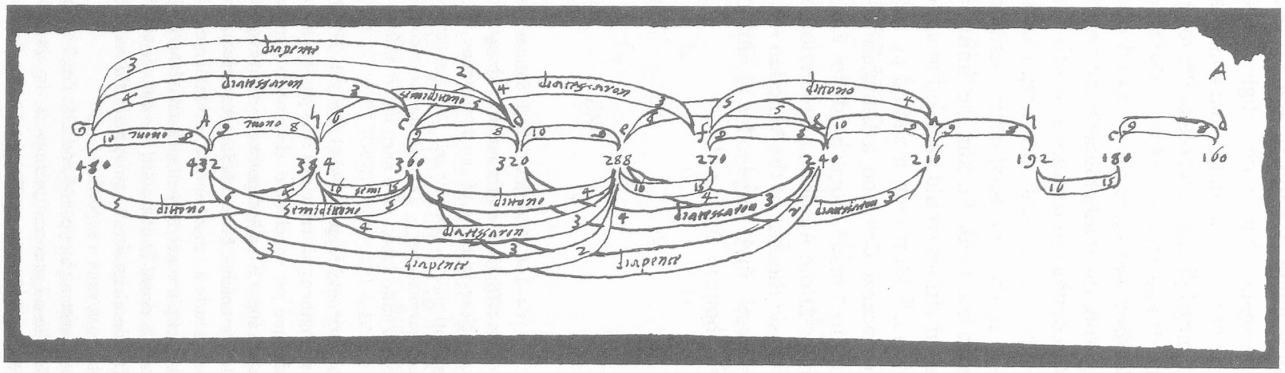
35 Zarlino, *Dimostrationi harmoniche*, p. 221: «Et questo secondo temperamento [i.e., the 1/4-comma] è molto all'udito grato: nè è anco molto difficile da fare: sì come sono gli due altri".

36 Zarlino, *Le istitutioni harmoniche*, pp. 140–141. On p. 172 of the 1589 ed., always of the *Istitutioni*, he even strengthens his criticisms (the phrases in *italic* are not present in the 1558 ed.): «Dirò adunque per concludere, che questo è un'istrumento [i.e., Domenico Pesarese's harpsichord], sopra il quale si potrà essercitare ogni ottimo sonatore, non solamente nell'harmonie diatoniche; ma etiandio nelle chromatiche, et nell'enharmoniche, quando potrà e saprà ridurle à i modi antichi, overamente quando à i nostri tempi potranno riuscir megliori, et più soavi di quello, che si odono in *alcune sgarbate compositioni d'alcuni compositori moderni*. Et dirò anco, che quando si volesse aggiungere al numero delle mostrate chorde alcun'altra chorda; *perciochè molte se ne possono aggiungere*; senza dubbio sarebbe cosa vana e superflua [...]».

37 Zarlino, *Dimostrationi harmoniche*, pp. 146 and 219. Fig. 3 belongs to I-Ma Ms. G.136.Inf.: Ausonius Hector, *Scholia ad musicam pertinentia*, no date, loose sheet (on the back: «Charta datami da Maestro Vincenzo dall'Organi»).

38 Barbieri, «I temperamenti ciclici», pp. 160–161 and 195.

Fig. 3: Manuscript drawing of a diatonic just intonation sent by the organbuilder Vincenzo Colombo to the mathematician Ettore Ausonio (Venice, mid 16th-century): see footnote 37. It refers to the scale C^0-D^0-E^{-1}-F^0-G^0-A^{-1}-B^{-1}-C^0. The string-lengths happen to be the same of Fogliano's *Musica theorica* (1529), to which the final zero has been taken off.



3. Just intonation enharmonic keyboards: Zarlino, Salinas, and Salinas' Franco-Flemish followers

Let us now turn to the harpsichords based on the untempered, just tuning system, a class of instruments – apart from Ban's keyboard – designed for demonstration purposes only, and therefore not for actual practice.

3.1. *Zarlino and Salinas*. Zarlino's writings report that, before 1558, he directed the construction of an «instrument» whose keyboard – covering the usual harmonic range E♭-G♯ – is shown in Fig. 4 and Table 9.[39] It will be noticed that, besides Fogliano's $B♭^{0}$ and D^{-1}, he adds a correct $F♯^{-2}$, but also a harmonically useless $E♭^{0}$.

Fig. 4: Gioseffo Zarlino (1558): just intonation keyboard made under his directions. Maybe with Salinas' instrument, this is the first documented, just intonation keyboard furnished with split keys separated by a comma.

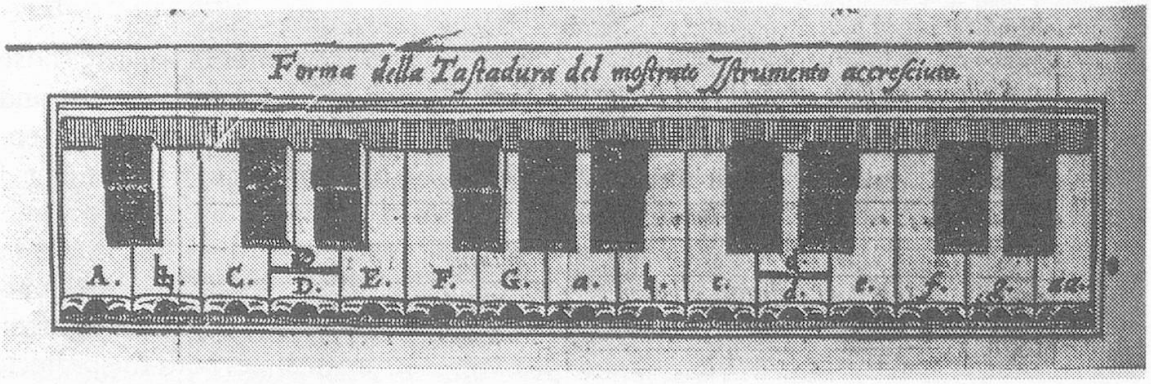


Table 9 – The tuning of Zarlino's just intonation keyboard of Fig. 4

			$F♯^{-2}$		$C♯^{-2}$		$G♯^{-2}$					
		D^{-1}		A^{-1}		E^{-1}		B^{-1}		$F♯^{-1}$		
$E♭^{0}$	$B♭^{0}$		F^{0}		C^{0}		G^{0}		D^{0}			
						$E♭^{+1}$		$B♭^{+1}$				

Salinas' «perfect», just tuning system, on the other side, presents (1) the same harmonic range of the *cimbalo cromatico* ($G♭^{+2}$-$B♯^{-3}$), but untempered, and (2) doubled notes separated by a comma correctly involving the G♭, B♭, D, F♯, and A♯ (see Table 10).[40] Passing to its meantone version, he then unifies these five doubled notes, thus reducing the total number of keys from

39 Zarlino, *Sopplimenti musicali*, p. 156 (illustration and string-lengths). This instrument is already mentioned in Zarlino, *Le istitutioni harmoniche*, p. 127, and Id., *Dimostrationi harmoniche*, p. 220.

40 Salinas, *De musica*, p. 126.

24 to 19 per octave (all the tempered systems he presents through his treatise have this number of keys). He also says that the enharmonic genus is contained in the chain of 5ths G♭-B♯, stressing – in chapter XX – that its number of keys per octave is 24 if untempered, 19 if tempered:[41]

Quo pacto decem et sex soni generis Chromatici, et Enharmonij vigintiquinque instrumenti perfecti, ad tredecim, et viginti imperfecti per Participationem (quam vocant) reducantur. Cap. XX.

In which way the 16 sounds of the chromatic genus and the 25 of the enharmonic, in the perfect instrument, can be reduced to 13 and 20, respectively, in the imperfect one, through the so-called temperament. Chapter XX. [Salinas divides the C-to-C octave, counting twice the C]

During his stay in Rome (c1538-58) he also had had made an enharmonic keyboard instrument. In fact – alluding to the organ of Santa Maria Novella, Florence, furnished with split keys only for the G♯/A♭ and E♭/D♯ – he says:[42]

Et plurima instrumenta Musica ex his, quae per alba, et nigra plectra pulsantur, secundum hoc genus disposita sunt (qualia memini me audire Florentiae) sed omnium perfectissimum est, quod ego Romae faciendum curavi et hîc habeo Salamanticae. In quo utrumque reperitur instrumentum, tam perfectum, quam id, quo utimur, imperfectum; et alterius ad alterum potest fieri collatio: et in utroque tria melodiarum genera maxima cura, atque diligentia perfectissime demonstrantur.

Many musical instruments, among those which are played pressing their white and black keys, present this genus [i.e. the enharmonic] (of this type I remember I listened to in Florence). But the most perfect of all is the one I had had made in Rome, which now I have here in Salamanca. In this one can be found together the two instruments, i.e. both the perfect, and the one we are using, the imperfect; and each one can be compared with the other, and both of them show – with the highest perfection, and with the greatest exactness and care – the three genera of melody.

As recalled above (§2.2), Salinas did not approve of Vicentino's *Archicembalo* (whose building, he observes, had started less than forty years before). He says that «he tried many times» to put into practice this kind of tuning, but – outside the harmonic range G♭-B♯ (the same as the *cimbalo cromatico*, we can add) – his attempts were unsuccessful. In fact his problems begin

41 Salinas, *De musica*, pp. 146–162 (chapter XX on p. 151).

42 Salinas, *De musica*, p. 127; reference to Santa Maria Novella organ on p. 80. On his stay in Rome see José Maria Àlvarez Pérez, «El organista Francisco de Salinas. Nuevos datos a su biografia», in: *Anuario musical* 18 (1963), pp. 21–44, p. 22.

just «in the row they call the 4th», and so he stresses once again that the enharmonic genus starts from the G♭ and «ends» («*terminatur*») in the B♯. Certainly he made some mistakes in tuning the 4th and 5th orders, because he concludes:[43]

Quae quoniam plus nimio non meas solum, sed omnium etiam aures offendebat, cognovi, huiusmodi temperamentum ab omni harmonica ratione, tam perfecti, quam participati instrumenti prorsum abhorrere: et mutavi consilium. Nam in tribus primis ordinibus accomodavi temperamentum instrumenti participati, et in tribus supremis perfecti; sonis C litera signatis fixis manentibus, et ad unisonantiam temperatis, quo ex utriusque collatione posset (ut Ptolomaeus ait) legitimum ab spurio, et imperfectum a perfecto discerni.

As it was highly upsetting not only my own, but also the ears of all the other people, I realized that such a tuning was absolutely far away from all harmonic ratios, both of the perfect and of the tempered instrument: so I changed my mind. In fact in the first three rows I set the tuning of the tempered instrument, while in the three upper [rows, the tuning of] the perfect one. The sounds marked with the letter C were fixed and tuned in unison, so that in comparing the two [keyboards] one could see (as Ptolemy says) the difference between the just from the false, and the perfect from the imperfect.

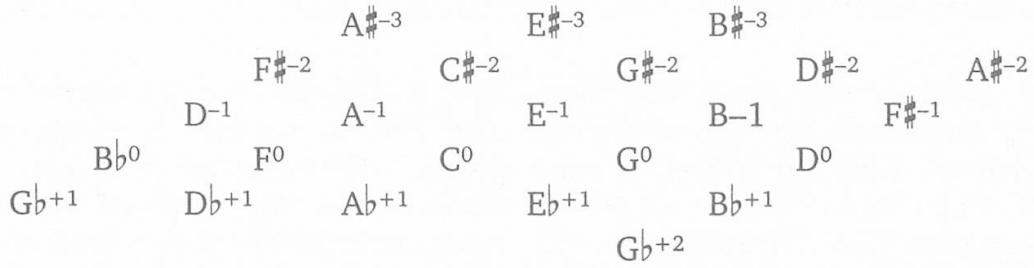
So, this multitone harpsichord was still furnished with two keyboards and three rows of keys in each one of them, like the *Archicembalo*. It was offering the above mentioned «perfect» just tuning system in the upper keyboard (Salinas says that even this one presented «three rows» of keys, thus not counting the row of the commas). The «three rows» of the lower one – like in Vicentino's instrument – were instead providing its tempered equivalent, the «imperfect instrument» (i.e. the *cimbalo cromatico*). Recalling that – among the three meantone temperaments mentioned in §1 above – he judged the 1/4-comma to be «much more suited to keyboard instruments», the tuning of his version of the *archicembalo* can be reconstructed (Table 10).[44] Being the Cs of the two keyboards in unison, he could thus present listeners with the difference between all the «perfect» and «imperfect», i.e. pure and tempered, intervals of his own enharmonic system. In

43 Salinas, *De musica*, pp. 164-166. On p. 85 he says that on the instrument he had had made in Rome both the major and the minor tone could be heard.

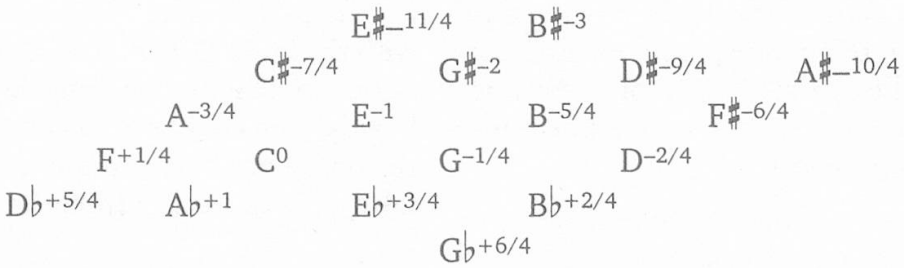
44 Salinas, *De musica*, p. 154, title of chapter XXII: «De tertio instrumentorum imperfectorum temperamento [i.e. the 1/4-comma], quod multo quam duo superiora [i.e. the 2/7- and 1/3-comma], et intellectu facilius, et instrumentis accomodatius esse videtur». And again, p. 154: «Videtur, etiam ad instrumentis fabricandis accomodatius».

Table 10 – Tuning of Salinas' double harpsichord (*c*1538–58)

UPPER KEYBOARD: 3 ROWS:
«Instrumentum perfectum»



LOWER KEYBOARD: 3 ROWS
«Instrumentum imperfectum» or «participatum»



1618 Vicente Espinel reports that he saw Salinas playing it in Salamanca, «working wonders» with his hands.[45]

3.2. *Galeazzo Sabbatini*. Following in the steps of Vicentino's «fifths of a tone», a still more complex keyboard – somehow based on the untempered division of the octave up to the enharmonic diesis, and in some places going even further – is the harpsichord by Galeazzo Sabbatini, furnished with 38 keys per octave. Its string lengths are provided by Kircher's *Musurgia* (1650). Anyway these are not fully reliable, and this is indirectly confirmed by the fact that, a few years later, Sabbatini described its tuning in a table, now lost, attached to a letter to Kircher himself (1653). Likewise lost is a manuscript treatise

45 Vicente M. Espinel, *Vida de Marcos de Obregòn*, ed. Samuel Gili Gaya, Madrid: Espasa-Calpe 1940, II, p. 158: « Yo lo vi tañer el instrumento de tecla que dejò en Salamanca, en que hacìa milagros con las manos; pero no le vi reducillo a que voces humanas le ejecutasen, habiendo en el coro de Salamanca en aquel tiempo grandes cantores de voces y habilitad, y siendo maestro aquel grande compositor Juan Navarro».

by Sabbatini – the *Scintille armoniche* –, dealing with his and others' enharmonic keyboards, as well as related compositional practice.[46]

3.3. *Mersenne, Descartes, Ban, and van der Elst.* Apart from some experiments involving the ETS 19, 24, and 31,[47] the multitone keyboards mentioned in §2 were not used in France. Starting with Mersenne (1636), we only come across a few modifications of Salinas' «perfect» system, some with a few ones removed.

Table 11 – Two proposals for «improving» Salinas' system:
– roman = Salinas (1577)
– roman + bold = Mersenne (1636-7)
– roman + bold + *italic* = Albertini (before 1636)

															A♯$^{-3}$			E♯$^{-3}$				B♯$^{-3}$			
		A^{-2}			*E*$^{-2}$			*B*$^{-2}$			F♯$^{-2}$			C♯$^{-2}$			G♯$^{-2}$			D♯$^{-2}$			A♯$^{-2}$
F^{-1}			–			G^{-1}			D^{-1}			A^{-1}			E^{-1}			B^{-1}			F♯$^{-1}$		
		A♭^{0}			E♭^{0}			B♭^{0}			F^{0}			C^{0}			G^{0}			D^{0}			
						G♭$^{+1}$			D♭$^{+1}$			A♭$^{+1}$			E♭$^{+1}$			B♭$^{+1}$						
																	G♭$^{+2}$							

Let us begin with those presenting extra notes added (Table 11). Mersenne's *clavier parfait* (Fig. 5) is merely Salinas' «perfect system» enlarged by adding two more tones, both harmonically useless (G^{-1} and E♭^{0}).[48] Though the E♭^{0} turns out to be the same as in Zarlino's (Table 9), the true reason for these doubled notes separated by a comma will be seen below. The *Harmonie universelle* also reports a still more enlarged Salinas' system, up to 31 notes per octave, without any mention of its inventor.[49] According to a manuscript treatise by Juan Carmuel Lobkowitz (1606–1682), this was due to a certain «Albertinus nobilis italus» (also its string lengths are labelled:

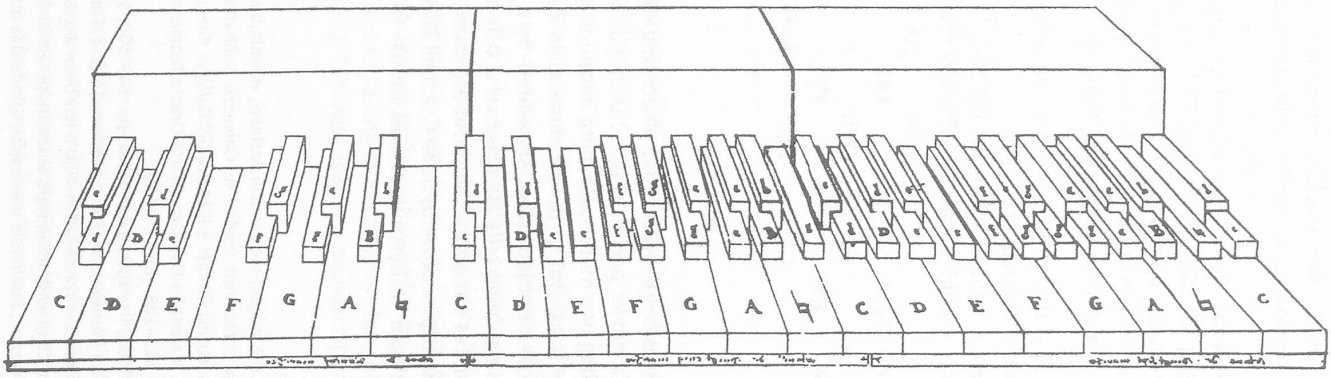
46 On the subject see Patrizio Barbieri, «Cembali enarmonici e organi negli scritti di Kircher. Con documenti inediti su Galeazzo Sabbatini», in: *Enciclopedismo in Roma Barocca. Athanasius Kircher e il Museo del Collegio Romano tra Wunderkammer e museo scientifico*, ed. Maristella Casciato, Maria Grazia Ianniello & Maria Vitale, Venezia: Marsilio 1986, pp. 111–128, pp. 118–125.

47 Barbieri, *I temperamenti ciclici*, pp. 149–150, 153, 156, 173–175.

48 Marin Mersenne, *Harmonie universelle* [...], Paris: Cramoisy 1636, «Traité des instrumens à chordes», pp. 354–356. Fig. 5 has been drawn from the facsimile edition of Mersenne's own copy, with autograph annotations: Paris: C.N.R.S. 1965, III, manuscript table.

49 Mersenne, *Harmonie universelle*, «Traité des instrumens à chordes», p. 357.

Fig. 5: Marin Mersenne, undated manuscript drawing attached to his own copy of the *Harmonie universelle* (1636). In the present article this sketch is published as it would be seen in mirror image; Mersenne's original was drawn as it would have been cut on a copper plate for printing. It shows three different C-to-C octaves in just intonation:
Left («octave de dix-neuf marches»), i.e., the same division that was put into practice by Joan Albert Ban (1639) in his harpsichord. However, Ban followed almost the same key disposition shown by Mersenne on p. 352 of the *Harmonie universelle* («Traité des instrumens à chordes»). It is merely Salinas' division from which six keys have been removed.
Centre («octave de vingt-cinq marches»), i.e., the same «instrumentum perfectum» designed and put into practice by Francisco Salinas.
Right («octave de vingt-sept marches»), i.e., Mersenne's «clavier parfait». It is the same Salinas' «perfect instrument» enlarged by the addition of two more tones, both harmonically useless.



«Scala Musicae Panharmonicae ad mentem Albertini»).[50] As shown in Table 11, Albertini's five extra notes are similarly useless.

Unlike the above enlarged schemes, of more practical use seem to have been keyboards in which some notes of Salinas' perfect system were removed. If reduced to only 18 keys per octave, we have a keyboard illustrated by Mersenne himself in the *Harmonie universelle* and also in his manuscript additions to this treatise (Fig. 5 above). In October 1639 the very same keyboard was put into practice by Joan Albert Ban, in Haarlem (Table 12).[51] Ban got to know about Mersenne's division through René Descartes and – always on Descartes' advice – also published some music based on the shades of this just tuning.[52]

Table 12 – Ban and Descartes keyboards:
– roman = Ban (1639)
– roman + *italic* = Descartes (1639–46)

			F♯$^{-2}$		C♯$^{-2}$		G♯$^{-2}$		D♯$^{-2}$				
G^{-1}		D^{-1}		A^{-1}		E^{-1}		B^{-1}		F♯$^{-1}$			
	B♭^{0}		F^{0}		C^{0}		G^{0}		D^{0}				
		D♭$^{+1}$		A♭$^{+1}$		E♭$^{+1}$		B♭$^{+1}$					

According to Ban himself, his «perfect keyboard» («*volmaekte Klaeuwier*») was copied several times by others.[53] One of these copies can now be traced: according to the above mentioned manuscript by Caramuel, who in those years spent some time in Flanders, a harpsichord with a tuning that turns out to be the same was one kept in the «treasure» (i.e. Wunderkammer) of a certain «Prince of Rosemberg» (it is labelled «De Rosembergi Abaco»).[54]

Ban's keyboard was based on the C-to-C octave. Mersenne offers also a second version of this very same division, based on the F-to-F octave, thus

50 Barbieri, «Cembali enarmonici», p. 118; Id., «Juan Caramuel Lobkowitz (1606–1682): Über die musikalischen Logarithmen und das Problem der musikalischen Temperatur», in: *Musiktheorie* 2 (1987), pp. 145–168, p. 158.

51 Ban's instrument presents almost the same key disposition printed in Mersenne, *Harmonie universelle*, «Traité des instrumens à chordes», p. 352. In Fig. 5 Mersenne, perhaps for the player's convenience, shifted one of the two comma-splitted Ds in the row of the black keys.

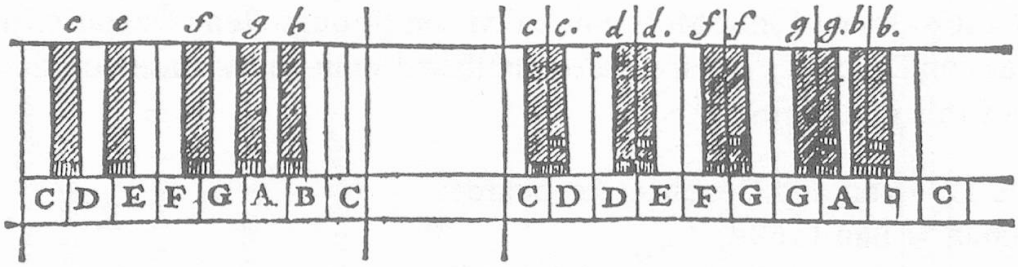
52 For a thorough survey on the subject see Rudolf Rasch, «Ban's intonation», in: *Tijdschrift van de Vereniging voor Nederlandse Muziekgeschiedenis*, 33 (1983), pp. 75–99.

53 Rasch, «Ban's intonation», pp. 82–83.

54 Barbieri, «Cembali enarmonici», p. 117; Id., «Juan Caramuel Lobkowitz», p. 157.

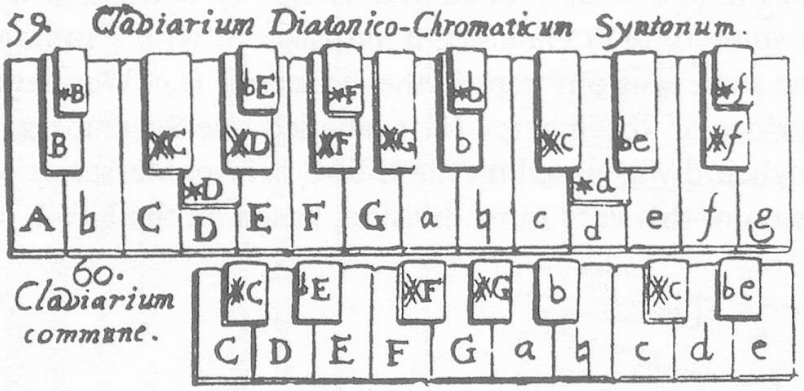
lowering by a 5th its harmonic range ($G\flat^{+1}$-$G\sharp^{-2}$) as well as the three doubled notes separated by a comma ($E\flat^{+1}/E\flat^{0}$, G^{0}/G^{-1}, B^{-1}/B^{-2}).[55] Descartes – in a letter of July 1643 – presented Ban's C-to-C keyboard, but inexplicably with both D^{-1} and G^{-1} present (see Fig. 6, Table 12, and Mersenne's Table 11).[56]

Fig. 6: René Descartes (1643): proposal of a (harmonically useless) G^{-1} added to Ban's keyboard.



Ban's keyboard seems to have been well known by another Dutch theorist: in fact the *Claviarium Diatonico-Chromaticum Syntonum* by Joannes van der Elst (1657) turns out to have the same tuning, apart from having had both the A♭ and D♭ removed (Fig. 7).[57] Johann Voigt Moritz – dealing

Fig. 7: Joannes van der Elst (1657): Ban's keyboard with both A♭ and D♭ removed (compared to a common 12-note one).



55 Mersenne, *Harmonie universelle*, «Traité des instrumens à chordes», pp. 352–353.

56 Fig. 6 has been drawn from René Descartes, *Epistolae* [...], ed. Clerselier, III, Amsterdam: Tip. Blaviana 1683, p. 387. On the subject see: *Oeuvres de Descartes*, ed. Charles Adam & Paul Tannery, IV, Paris: Cerf 1901, pp. 678–683; Rasch, «Ban's intonation», p. 92 (also on an enlarged version of Descartes' keyboard proposed by Pieter Hellingwerf, Amsterdam 1718), and – especially on Descartes' letter – Rasch, «Why were enharmonic keyboards built?» (in this volume).

57 Fig. 7 has been drawn from Van der Elst, *Notae Augustinianae*, fig. 59 and 60. See also Rasch, «Ban's intonation», p. 92.

with the «Anatomia claviaturae chromaticae, et diatonicae, et partim enharmonicae» – in 1719 added an A♯$^{-2}$ to Ban's division on the other side of the chain of 5ths.[58]

Table 13 – Giovanni Valentini's (?) keyboard

				F♯$^{-2}$		C♯$^{-2}$		G♯$^{-2}$		D♯$^{-2}$			
					A^{-1}		E^{-1}		B^{-1}				
		B♭^{0}		F^{0}		C^{0}		G^{0}		D^{0}			
G♭$^{+1}$		D♭$^{+1}$			A♭$^{+1}$		E♭$^{+1}$						

As far as just intonation keyboards are concerned, without any doubt Fogliano and Salinas chose the most rational pattern. To abandon it meant to obtain Mersenne's useless additions or, from bad to worse, unplayable keyboards like the one of Table 13, which offers highly dissonant major and minor triads on D. Caramuel ascribes this keyboard to a «Valentinus Archimusicus Caesareus» (probably Giovanni Valentini, Kapellmeister at the Viennese court of Ferdinand III, a composer himself). He adds that it was also adopted by a certain «Cunradus organista apud Bavaros» (maybe Caspar Conrad, organist in Öttingen, Bavaria). Anyway one could also imagine some oversight by Caramuel in reporting its string lengths, it being highly improbable that a musician like Valentini would approve a harpsichord providing such dissonant chords.[59]

4. The problem of fretted instruments

In lutes and viols, enharmonic notes raised problems – both of feasibility and performance – still worse than those already met with in keyboard instruments. Some brief considerations are presented below regarding the three possible classes of fretting arrangements.

58 Johann Voigt Moritz, *Conclave thesauri magnae artis musicae* [...], Praga: Labaun 1719, pp. 43–44 (anyway, Ban is not mentioned).

59 Barbieri, «Cembali enarmonici», p. 117; Id., «Juan Caramuel Lobkowitz», p. 157. Besides, Giovanni Valentini was the author of an «enharmonic» sonata a 5: Warren Kirkendale, *Emilio de' Cavalieri «Gentilhomo romano». His life and letters, his role as Superintendent of all the arts at the Medici Court, and his musical compositions. With addenda to ‹L'Aria di Fiorenza› and ‹The Court Musicians in Florence›*, Florenz: Olschki 2001 (= Historiae Musicae Cultores 86), p. 154.

4.1. *Just intonation.* Apart from a semi-just fretting experimented with by Thomas Salmon (1688–1705), a true just intonation seems to have been put into practice only on Giovanni Battista Doni's set of «prepared» viols (1636–40).[60] Joan Albert Ban too seems to have adapted a lute (and maybe also a viol) with his just intonation fret arrangement.[61] It may be observed that, in the case of the lute, the space between two frets yielding doubled notes (separated by a comma) would have been only a few millimetres, depending on the part of the neck on which they were placed.

4.2. *Meantone.* In such temperaments there are two kinds of semitone, major (e.g. G-A♭) and minor (e.g. G-G♯), their difference being equal to the enharmonic diesis (i.e., G♯-A♭): therefore mistuned octaves of the type G♯-A♭ are always to be feared in meantone-tuned fretted instruments (Table 14).

Table 14 – Meantone tuning on a lute in D

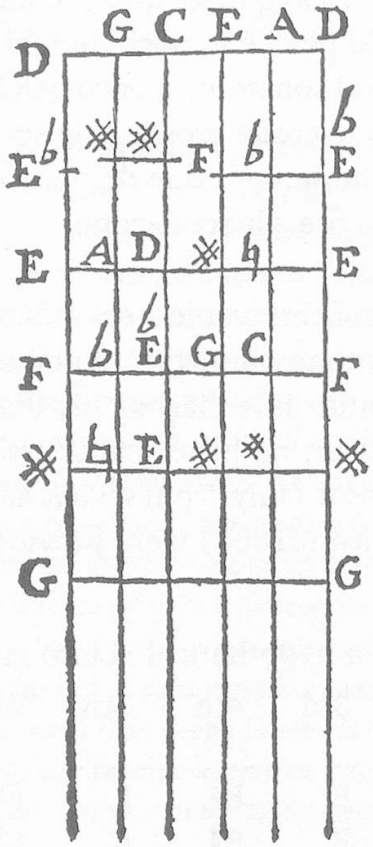
open string	1st	2nd	3rd	4th	5th	6th	7th	8th	fret
D^{treble}	E♭	E	F	F♯	G	G♯	A	B♭	
A	B♭	B	C	C♯	D	D♯	E	F	
E	F	F♯	G	G♯	A	A♯	B	C	
C	D♭	D	E♭	E	F	F♯	G	A♭	
G	A♭	A	B♭	B	C	C♯	D	E♭	
D^{bass}	E♭	E	F	F♯	G	G♯	A	B♭	

In order to avoid such drawbacks, lutes and viols sometimes were provided with a few *tastini*, i.e., short ivory frets not crossing the whole neck. In De Chales' (Fig. 8), A♭ and D♭ are thus turned into G♯ and C♯, which according

60 On Salmon, see Lindley, Lutes, pp. 68–69; Patrizio Barbieri, «Conflitti di intonazione tra cembalo, liuto e archi nel ‹concerto› italiano del Seicento», in: *Studi Corelliani.* IV, ed. Pierluigi Petrobelli & Gloria Staffieri, Firenze: Olschki 1990, pp. 123–153: 132-4. On Doni: Patrizio Barbieri, «Gli strumenti poliarmonici di G.B. Doni e il ripristino dell'antica musica greca (c.1630–1650)», in: *Analecta musicologica* 30 (1998), pp. 79–114, p. 84; Martin Kirnbauer, «‹Wherein the most compleat Harmony was heard›: The Viola da Gamba in Chromatic and Enharmonic Music in Seventeenth-Century Rome», in: *The Italian Viola da Gamba. Proceedings of the International Symposium on the Italian Viola da Gamba, Magnano 29 April – 1 May 2000,* ed. by Susan Orlando, Solignac: Editions Ensemble Baroque de Limoges & Torino: Manzoni 2002, pp. 34–51; see also the contribution by Martin Kirnbauer in this volume.

61 Rasch, «Ban's intonation», pp. 82–83.

Fig. 8: Claude-François Milliet de Chales (1674): «common» fretting for a viola da gamba, with tastini at the position of the 1st fret.



to him was the «common» tuning and fretting.[62] Besides De Chales, Doni too confirms that such *tastini* were mainly placed at the position of the first fret, in order to narrow the major semitone.[63] At this place on a viola da gamba neck, the space corresponding to the enharmonic diesis would not be at all negligible, being around two centimetres. In any case, Doni himself stresses that the non-uniformity of gut-strings and their inharmonicity seriously hindered the perfect intonation of such notes:[64]

62 Claude-François Milliet de Chales, *Cursus seu mundus mathematicus*, III, Lyon 1674, pp. 37–38: «varie a variis ad concentum revocant chordae; commune tamen illius systema proferam divisionemque manubrij».

63 Doni, *Annotazioni*, p. 29: «Quelli che aggiungono un tastino alle viole, lo sogliono mettere immediatamente dopo il capotasto».

64 Giovanni Battista Doni, *Compendio del Trattato de' generi e de' modi della musica*, Roma: Fei 1635, pp. 45–46. On the above problem of inharmonicity in instruments with fingerboards see Patrizio Barbieri, «The inharmonicity of musical string instruments (1543-1993). With an unpublished memoir by J.-B. Mercadier (1784)», in: *Studi musicali* 27/2 (1998), pp. 383–419, pp. 407–412.

> per mezzo di questi instrumenti [Doni's *viole diarmoniche*] si potranno far sentire cotali melodie nella loro perfettione; il che non riesce ne' comuni quando bene vi s'aggiunga qualche mezzo tasto che divida ogni semituono maggiore, sì perché in pochi luoghi servono, et gl'altri recano impedimento notabile al sonatore; sì anco perché calcandosi egualmente, et al medesimo segno le corde grosse, e le sottili, non egualmente alterano il suono; né anche sempre due d'una istessa grossezza tastate nel medesimo sito, parimente s'inacutiscono.

If extra gut frets – crossing the whole neck – had been added in order to divide all the major semitones into the minor ones and the enharmonic diesis, the performer would have had at his disposal the range of notes shown in Table 15. However, no historical source ever mentions what we could call a *liuto cromatico*! Only Doni's *Violone panarmonico* and Pietro Salvetti's *Lirone enarmonico* (*c*1668) were provided with a few frets of this kind.[65]

Table 15 – The tuning of a hypothetical «Liuto cromatico»

open string	1st	2nd	3rd	4th	5th	6th	7th	fret
D^{treble}	D♯	E♭	E	E♯	F	F♯	G♭	
A	A♯	B♭	B	B♯	C	C♯	D♭	
E	E♯	F	F♯	F♯♯	G	G♯	A♭	
C	C♯	D♭	D	D♯	E♭	E	E♯	
G	G♯	A♭	A	A♯	B♭	B	B♯	
D^{bass}	D♯	E♭	E	E♯	F	F♯	G♭	

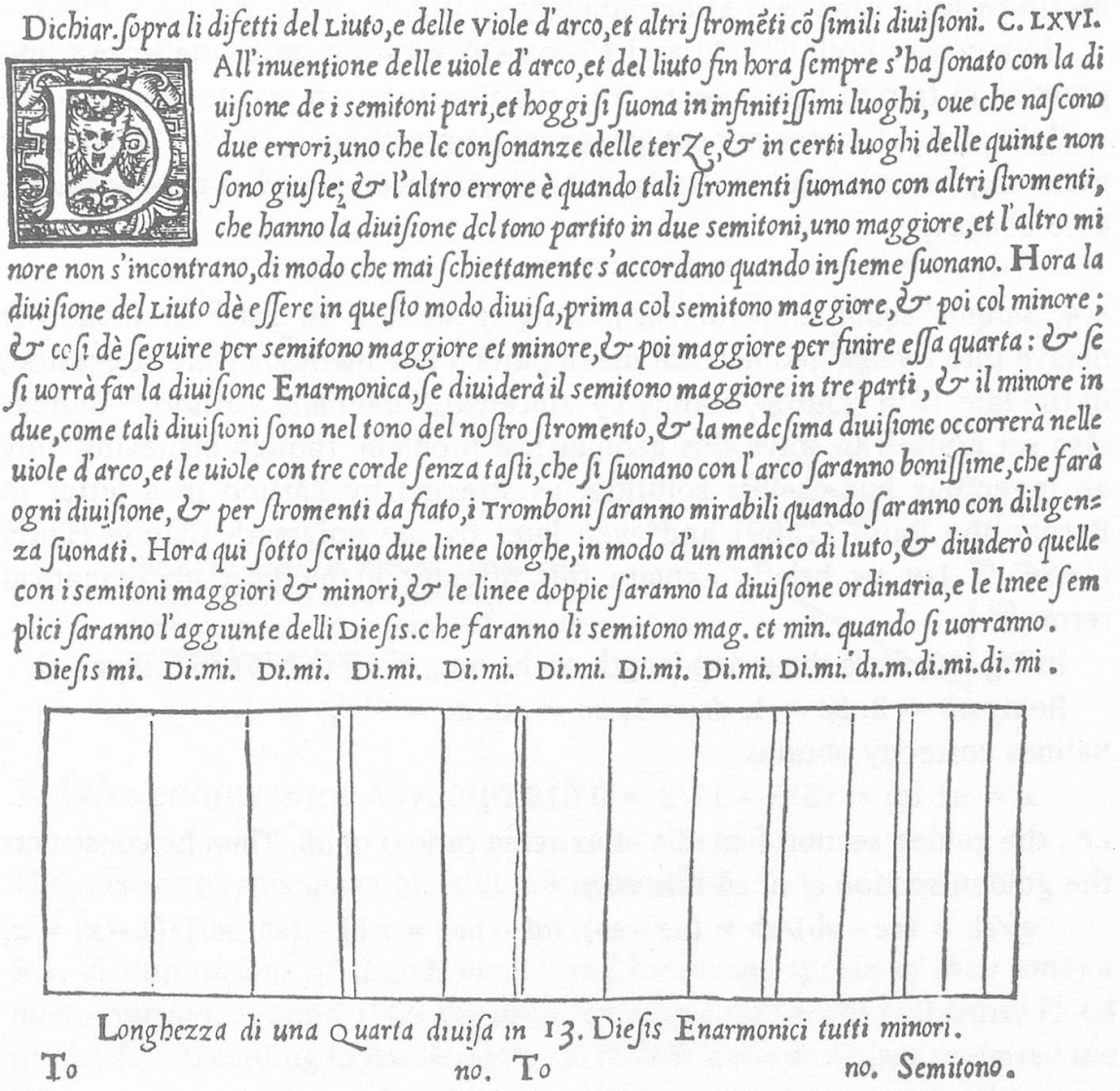
Table 16 – Vicentino's proposal for tuning a lute with his ETS 31

open string	1st	2nd	3rd	4th	5th	6th	7th	8th	fret
D^{treble}	E♭♭	D♯	E♭	D♯♯	E	F♭	E♯	F	
A	B♭♭	A♯	B♭	A♯♯	B	C♭	B♯	C	
E	F♭	E♯	F	G♭♭	F♯	G♭	F♯♯	G	
C	D♭♭	C♯	D♭	C♯♯	D	E♭♭	D♯	E♭	
G	A♭♭	G♯	A♭	G♯♯	A	B♭♭	A♯	B♭	
D^{bass}	E♭♭	D♯	E♭	D♯♯	E	F♭	E♯	F	

65 Barbieri, «Gli strumenti poliarmonici», pp. 91, 102, 110 (on Doni); Id., «L'accordatura strumentale», pp. 227–232 (on Salvetti).

4.3. *Equal Tempered Systems*. In 1555 Nicola Vicentino suggested tuning a lute like his *Archicembalo* (Fig. 9).[66] Thus, all the minor semitones of Table 15

Fig. 9: Nicola Vicentino (1555): proposal for a lute fretting according to his Equal Tempered System 31.



Dichiar. ſopra li difetti del Liuto, e delle Viole d'arco, et altri ſtromẽti cõ ſimili diuiſioni. C. LXVI.

All'inuentione delle uiole d'arco, et del liuto fin hora ſempre s'ha ſonato con la diuiſione de i ſemitoni pari, et hoggi ſi ſuona in infinitiſſimi luoghi, oue che naſcono due errori, uno che le conſonanze delle terze, & in certi luoghi delle quinte non ſono giuſte; & l'altro errore è quando tali ſtromenti ſuonano con altri ſtromenti, che hanno la diuiſione del tono partito in due semitoni, uno maggiore, et l'altro minore non s'incontrano, di modo che mai ſchiettamente s'accordano quando inſieme ſuonano. Hora la diuiſione del Liuto dè eſſere in queſto modo diuiſa, prima col semitono maggiore, & poi col minore; & coſi dè ſeguire per semitono maggiore et minore, & poi maggiore per finire eſſa quarta: & ſe ſi uorrà far la diuiſione Enarmonica, ſe diuiderà il semitono maggiore in tre parti, & il minore in due, come tali diuiſioni ſono nel tono del noſtro ſtromento, & la medeſima diuiſione occorrerà nelle uiole d'arco, et le uiole con tre corde ſenza taſti, che ſi ſuonano con l'arco ſaranno boniſſime, che farà ogni diuiſione, & per ſtromenti da fiato, i Tromboni ſaranno mirabili quando ſaranno con diligenza ſuonati. Hora qui ſotto ſcriuo due linee longhe, in modo d'un manico di liuto, & diuiderò quelle con i semitoni maggiori & minori, & le linee doppie ſaranno la diuiſione ordinaria, e le linee ſemplici ſaranno l'aggiunte delli Dieſis. che faranno li semitono mag. et min. quando ſi uorranno.

Dieſis mi. Di.mi. Di.mi. Di.mi. Di.mi. Di.mi. Di.mi. Di.mi. Di.mi. di.m.di.mi.di.mi.

Longhezza di una Quarta diuiſa in 13. Dieſis Enarmonici tutti minori.

To no. To no. Semitono.

would have been bisected, giving rise to octaves divided into 31 acoustically equal «fifths of a tone» (Table 16). As shown above (§2.2), this particular kind of equal temperament (ETS 31) provided almost pure major thirds (e.g. E𝄫-G♭, D♯-F𝄪, D𝄪-A𝄫=F𝄪𝄪). Furthermore – unlike the tunings of Table 14 and 15, which are not Equal Tempered Systems – it offered the performer the possibility of shifting the pitch of a chord merely by shifting

66 Vicentino, *L'antica musica*, fol. 146v. About the «Diesis enarmonici minori» see note 33 above.

his hand, without changing the relative position of the fingers. Also the tuning of Table 15, if put into practice with a meantone tuning practically coincident with the 1/3-comma (1/2.98-comma), would provide a particular kind of equal temperament, the ETS 19, whose octaves are divided into 19 acoustically equal «thirds of a tone» (and so the lonely F𝄪 on the 4th fret would turn into a common G♭).

In any case both ETS 31 and 19 were awkward systems, never put into practice in fretted instruments. The simplest solution was to resort to the well known 12-notes-per-octave equal temperament (ETS 12), merely removing the enharmonic diesis (see Salinas' second level of temperament, §1.6 above).

4.4. *Salinas' equal-temperament fretting of the lute.* In order to divide the octave into twelve geometrical mean parts a few methods were suggested, in the late 16th century, mainly by Vincenzo Galilei and Zarlino.[67] Salinas also set himself to solve this geometrical problem, though achieving only an ingenious but useless solution, as stressed by Zarlino in a letter to Bernardino Baldi (1589) and even later by the polymath Claude Hardy (1636).[68] Let us briefly explain this attempt in modern mathematical terms.[69]

In Fig. 10, ab is the string-length of the lute, from nut (b) to bridge (a).

Being $ab = 2$, $bc = 1$, $dc = 1$, $ae = ad$, $ac = 5^{1/2}$,

Salinas correctly obtains

$$x = ae/ab = (5^{1/2} - 1)/2 = 0.618...,$$

i.e., the golden section («media et extrema ratio») of ab. Then he constructs the golden section ef of eb this way:

$$ef/eb = (ae - eb)/eb = (ae - eb)/(ab - ae) = x\,[1 - (eb/ae)]/(1 - x) = x,$$

67 Lindley, *Lutes*, pp. 21 and 24–26. On the use of the mesolabium for this purpose (as suggested by Zarlino) and of the proportional reduction compass (according to Galilei's rule) see Patrizio Barbieri, «Il mesolabio e il compasso di proporzione: le applicazioni musicali di due strumenti matematici (1558-1675)», in: *Musica, scienza e idee nella Serenissima durante il Seicento*, ed. Francesco Passadore & Franco Rossi, Venezia: Fondazione Levi 1996, pp. 201–220, pp. 201–207 and 219–220.

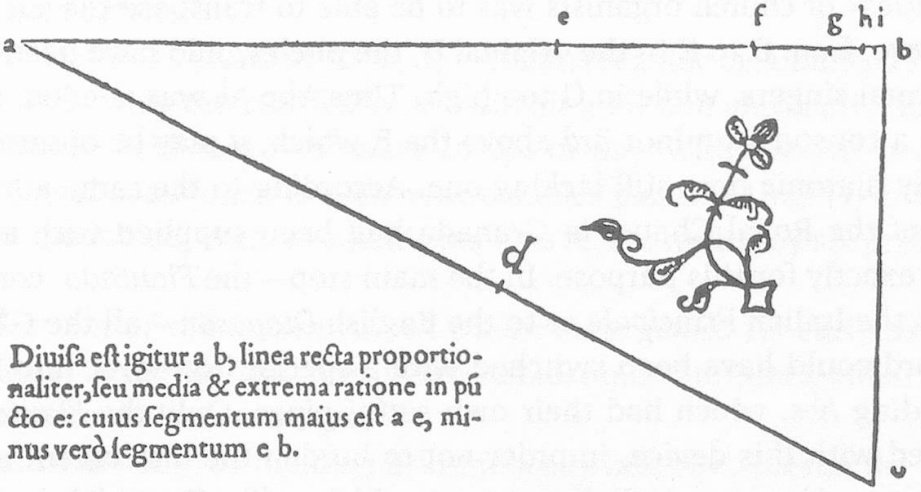
68 On Zarlino see Bernardino Baldi, *Vite inedite di matematici italiani* [...], ed. Enrico Narducci, Roma: Tipografia delle scienze matematiche e fisiche 1887, p. 171 (*Bullettino di bibliografia e di storia delle scienze matematiche e fisiche*, XIX, July-November 1886, off-print). On Hardy: Mersenne, *Harmonie universelle*, «Traité des intrumens à chordes», pp. 224–225. Claude Hardy belonged to Mersenne's entourage, and also left a manuscript French translation of Zarlino's *Istitutioni harmoniche*: Marin Mersenne, *Correspondance* [...], ed. by Cornelis de Waard, I, Paris: Presses Universitaires de France 1945, pp. 187–188.

69 Salinas, *De musica*, p. 173.

being, but *only* for a golden section, $ae/ab = eb/ae = x$. Salinas then applies the same division to *fb*, *gb*, *hb*, etc.

Thus, the above construction is valid only for the golden section, and not for all the other possible ratios (like $1:2^{1/12}$, needed for the ETS 12). Although only approximate, a working method – still based on the golden section – for applying equal temperament to the neck of a lute was devised by William Brouncker in 1653.[70]

Fig. 10: Francisco Salinas (1577): proposal for a lute fretting according to a progression based on the golden section



5. *Why enharmonic keyboards?*[71]

The answer to this question is at least threefold.

5.1. *Transpositions of church modes and increasing spread of their «major mode» version.* Around 1500 the usual harmonic range was still either E♭-G♯ or A♭-C♯.[72] According to Ramis de Pareja (1482) some musicians preferred the G♯ because it was good for «Landino's» cadential progressions of the type b-g♯^{1} → a-a^1.[73] In 1555 Juan Bermudo reported that «some barbarian performers» («algunos barbaros tañedores») modified the melodic pattern of the 1st mode by introducing the so-called «diatessaron intenso» (D-E-F♯-G / A-B-C♯-D) and the same «species» of 4th was also applied to the 4th mode (E-F♯-G♯-A). Their explanation was that in this way both «sounded bet-

70 Lindley, *Lutes*, pp. 33–36.

71 See also Rasch, «Why were enharmonic keyboards built?» (in this volume).

72 On the problem see: Lindley, «Fifteenth-Century Evidence», pp. 46–47; Wraight & Stembridge, «Italian Split-Keyed Instruments», pp. 163 and 171.

73 Lindley, «Fifteenth-Century Evidence», p. 47.

ter».[74] Indeed the modern «major mode» was already beginning to extend its domain into the modes based on all the diatonic notes of the octave, strengthening the need of the above mentioned three sharps. Turning to the E♭, on the other side of the chain of 5ths, we may observe that (1) in *fugato* counterpoint the «diatonic» note B♭ needed the 5th below or 4th above, and (2) there being no church mode on the B, the D♯ – according to Pietro Aron (1529) – was «little used» (and so the B was the only diatonic note which did not require the major 3rd upwards).[75] However, we may add that a D♯ would be needed for the cadences in the pieces in E.

As far as the A♭ is concerned, Bermudo relates that «one of the great necessities» of church organists was to be able to transpose the 1st mode a 3rd above, from D to F. In the original D, the pitch would have been too low for normal singers, while in G too high. Thus, the A♭ was needed, in order to give a consonant minor 3rd above the F, which, it may be observed, was the only diatonic note still lacking one. According to the same author, the organ of the Royal Chapel in Granada had been supplied with a special device exactly for this purpose. In the main stop – the *Flautado*, corresponding to the Italian *Principale* or to the English *Diapason* – all the G♯s of the keyboard could have been switched with a special iron lever into the corresponding A♭s, which had their own set of pipes. Only the *Flautado* was provided with this device, in order not to burden the instrument with too many pipes. Also in some Italian organs, which unlike Granada's instrument were equipped with split keys, the pipes for the extra semitones were only supplied for one or two stops.[76]

It is worth recalling that a revival of Granada's solution was recorded in mid-18th-century England, where some instruments were equipped with keyboards of the normal type, but with the possibility of shifting the eleven-5ths compass by hand-operated stops. For example, the harpsichord Kirkman made to plans by Robert Smith, or the famous organ installed at the Found-

74 Bermudo, *Declaracion*, fol. 67r.

75 Pietro Aron, *Toscanello in musica* [...], Venezia: De Vitali 1529, cap. 40: the black key between D and E is tuned as an E♭ instead than a D♯, «because of the organists, who prefer to give the 3rd minor to the C, than the 3rd major to the B, being the B little used by them».

76 Bermudo, *Declaracion*, fol. 89v; Wraight & Stembridge, «Italian Split-Keyed Instruments», pp. 170–171. The above mentioned practice is documented in the following two Italian organs. (1) Mesagne (Brindisi), instrument built by Tommaso Mauro for the «Chiesa Collegiata» (1648): ten stops, but «eight semitoni spezzati»(D/F♯, E/G♯, plus six unspecified enharmonic splittings) only for the *Principale 8'* and *Flauto in ottava fusulato*; see Luisa Cosi, «Organi e organari in terra d'Otranto nei secoli XVII e XVIII», in: *Musicisti nati in Puglia ed emigrazione musicale tra Seicento e Settecento*, Roma: Torre d'Orfeo 1988, pp. 117–138, p. 127. (2) Florence, Cathedral (1649): «tasti rotti» only for the *Principale*; see Barbieri, «Il Cembalo onnicordo», p. 67.

ling Hospital in London (1768), again inspired by the theories of Smith, who had died only a few months earlier. On this second instrument the player could opt for any one of the three harmonic ranges: E♭-G♯ (the common one), F-A♯, or D♭-F♯.[77] By the end of the century the same idea was extended to pianos, which used more convenient pedal levers and adopted solutions similar to those being applied to harps in the same period. The following instruments are particularly relevant in this connection:

- Charles Clagget's *Royal Teliochordon* (1790–91), which was a device that could also be applied to grand pianos so that by using two extra pedals, the normal range E♭–G♯ could be supplemented with five further sharps or five further flats.[78]
- William Hawkes's piano of 1808, 1/6-comma regular meantone, 17 notes per octave, with the possibility of switching all five chromatic notes of its (normal) keyboard into either sharps or flats with just one pedal.
- Lastly David Loeschmann's even more complex piano of 1809 (1/4-comma regular meantone, with 24 sounds per octave, controlled by six pedals).[79]

5.2. *The revival of the ancient Greek enharmonic genus*. As early as 1666 Lemme Rossi remarked that during the Renaissance the Greek enharmonic had been restored in two stages:[80]

1. The «ancient» one, by dividing arithmetically into two «diesis» the minor semitone of the three tetrachords of the Greek Perfect System: B-C-D-E, E-F-G-A, and A-B♭-C-D. The quartertones B×, E×, A× thus obtained did not give rise to any consonant chord, so maybe they were employed only melodically, as ornamentations or *portamento* effects. It is in this way that they were treated by Emilio de' Cavalieri and by the Roman papal singers in the first half of the 17th century.[81]

77 Alexander C.N. Mackenzie of Ord, *Keyboard temperament in England during the eighteenth and nineteenth centuries*, Unpublished Thesis, University of Bristol, September 1979, pp. 94–95.

78 Charles Clagget, *The Royal Teliochordon Stop*, London [1791].

79 Henry Liston, *An essay on perfect intonation*, Edinburgh 1812, pp. 141–142; Mackenzie of Ord, *Keyboard temperament in England*, pp. 180–181. It is worth recalling that, still in 1885, the English concertina was tuned in meantone (= 1/4-comma temperament), and its harmonic range had 14 notes, from A♭ to D♯: Helmholtz, *On the sensations of tone*, p. 434 (*Addition* by A.J. Ellis).

80 Rossi, *Sistema musico*, pp. 76–78.

81 Kirkendale, *Emilio de' Cavalieri*, p. 156; Patrizio Barbieri, «Violin intonation: a historical survey», in: *Early music* 19/1 (1991), pp. 69–88, p. 80. This kind of employment of the enharmonic was still in use at the end of the 18th century: Patrizio Barbieri, «G.B. Orazi's Enharmonic Flute and its Music (1797–1815)», in: *The Galpin Society Journal* 52 (1999), pp. 281–304, pp. 290–292.

2. The «modern» one, by setting in consonant counterpoint the enharmonic steps (like G♯-A♭) of the keyboards shown in §§2-3 above.

Concerning their practice, the oldest extant source is an undated *Epistola* by John Hothby (died 1487), the English music theorist who was also in Italy. He tells us that he owned an instrument furnished with enharmonic keys:

> E notate anchora bene che sopra li instrumenti che si fano ogidì il enharmonio non ce, ma cum la voce si fa al mancho uno de li semitonii minimi pur menti di meno. Io [ho] uno instrumento il quale lo ha interamenti, che altrimenti tal generatione sarebbe indarno trovata e anchora il nostro Boetio e li altri harebeno fallito.

He says the extra keys for the B𝄪, E𝄪, and A𝄪 were coloured in red – in addition to the white and black ones – and that such notes gave rise to «melodies» with intervals so narrow that the ear could hardly detect them.[82]

Another reference to an early revival of the chromatic and enharmonic is supplied by Pietro Aron. In 1516 he reports that his teacher – the Bolognese Giovanni Spataro – had written a composition in honour of Pope Leo X, «the tenor [part] of which contained the chromatic and enharmonic genera». This piece – though disapproved of by some well known Italian composers, because of its unusual intervals – was sung with delight by Aron himself and other friends of Spataro.[83] Collating the above information, we can infer that this piece is to be dated 1513–16, but we cannot know whether it was based on Hothby's enharmonic division, or on the consonant treatment of split keys, already present in a few organs of his day, as seen in §2.1 above, although not yet in those of the basilica of San Petronio, where in 1512 Spataro had been appointed *maestro di cappella*.[84]

82 I-Fn Ms. Magl. XIX.36, fols. 74–78, published in Johannis Octobi, *Tres tractatuli contra Bartholomeum Ramum*, ed. Albert Seay, Roma: American Institute of Musicology 1964 (= Corpus Scriptorum de Musica 10), pp. 79–92, pp. 85, 91–92, and 87: «le lor melodie sono tanto strete e serrate che l'orechio apena senti le loro differentie».

83 Pietro Aron, *Libri tres de institutione harmonica* [...], Bologna: in aedibus Benedicti Hectoris 1516, fol. 22v: «[Ioannes Spatarius Bononiensis] modulationem proxime in laudem Leonis decimi pontificis maximi edidit, quam ego et vidi, et libenter cecini. In cuius tenore chromaticum genus complexus est, et enarmonicum, licet a nonnullis non parvi nominis Italis musicis explosa fuerit, quia inconsuetae atque reconditae modulationis rationem minime inveniebant, quam nos tamen amici eius invenimus, atque cecinimus».

84 Only in 1528 Lorenzo da Prato's organ of the basilica seems to have been furnished with these extra keys: Oscar Mischiati, «Documenti sull'organaria padana rinascimentale. I: Giovanni Battista Facchetti», *L'organo* 22 (1984), pp. 23–160, pp. 47 and 75–76.

It should be mentioned that – as late as around 1632–33 – Giovanni Battista Doni set exactly Hothby's three enharmonic notes in the *facies posterior* of his *Lira Barberina*: in fact the second and final tuning of this instrument presented the frets arranged according to a meantone temperament, but with the semitones B-C, E-F, and A-B♭ split into two arithmetically equal quartertones.[85] He also provided a short essay on the Diatonic-Chromatic-Enharmonic genera, daringly superimposing their descending tetrachords in a three-part counterpoint (Ex. 3). As for his *Lira Barberina*, here Doni confirms that – in order to obtain the correct ancient quartertones – the major semitones should be split into two arithmetical parts, and not tuned like those of the multitone keyboards of §2 (i.e., with consonant major 3rds, e.g., C♯-E♯). In such a way, «terze mezzane» should have been obtained, i.e., (very dissonant) «neutral» 3rds midway between the major and the minor ones.[86]

In any case, it is Vicentino who – already as early as the end of the 16th century – has been credited with the revival of the chromatic and enharmonic genera. His was the first documented attempt related to the above mentioned «second stage», i.e., to the setting of the enharmonic steps in consonant counterpoint. However, he did not respect strictly the original tetrachordal form of the three Greek genera, mixing them together and hence composing in a style then called «misto». The compositions in strict style were, on the contrary, called «semplici».[87] Apart from the philologist Doni, the first – and also the last – musician to have left a documented attempt in the field of these cromatic and enharmonic «composizioni semplici» was Ascanio Mayone (1618).[88]

5.3. *The «Stylus metabolicus»*. The term «enharmonic» was also used with another meaning. Martino Pesenti – in his above mentioned work (1641) – presents diatonic pieces transposed into keys with three to seven flats (which he calls «cromatico») and with one sharp to two double sharps (which he calls «enarmonico»).[89] Referring to a descending scale such as F-E♭-D♭-C♭-B♭-A♭-G♭-F, in 1638 also Domenico Mazzocchi had pointed out

85 Barbieri, «Gli strumenti poliarmonici», p. 85.

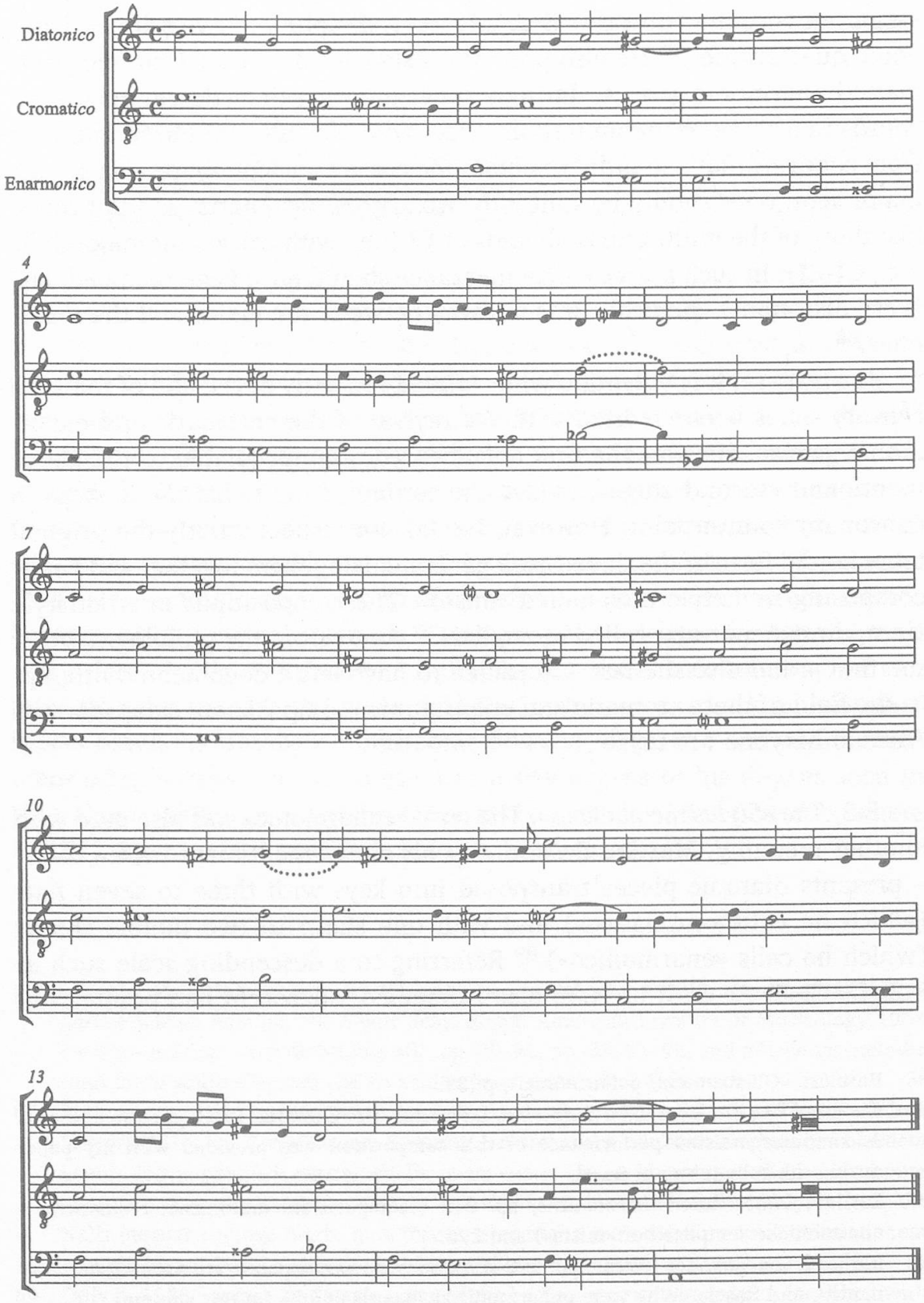
86 Giovanni Battista Doni, *Lyra Barberina*, I, Firenze: Tip. Caesarea 1763, pp. 406 and 410. A computer assisted performance of this composition was provided with my paper during the colloquium in Basel.

87 Zarlino, *Dimostrationi harmoniche*, pp. 213 («composizioni diatoniche, cromatiche o enarmoniche semplici», or «miste») and 276.

88 Barbieri, «*La Sambuca lincea*», pp. 190–193. See also van Asperen, «Consonant or dissonant?», and Rasch, «Why were enharmonic keyboards built?» (in this volume).

89 Kirkendale, *Emilio de' Cavalieri*, p. 156. See Rasch, «Why were enharmonic keyboards built?» (in this volume).

Ex. 3: Giovanni Battista Doni (c1632–40): counterpoint with the three ancient Greek genera superimposed, from his *Lyra Barberina* (1763), I, p. 410 (transcription by M. Kirnbauer).



that it could still be called enharmonic, though not respecting the true melodic pattern of that genus.[90] In fact this scale is nothing else than a section of a G major scale transposed down by a minor semitone.

According to Athanasius Kircher, the abrupt introduction of so many accidentals in a composition merely denotes a modulation (or a transposition) and not the use of the enharmonic. Clearly drawing the term from Doni's treatises (who uses the term «note metaboliche», i.e., modulating notes), he adds that such compositions are to be placed in a class whose name should be «Stylus metabolicus».[91] Besides quoting compositions by Doni himself, Pietro Heredia, Pietro Della Valle, Carlo Gesualdo da Venosa, Domenico Mazzocchi, and Benedetto Narducci, he provides an example by Giacomo Carissimi, in which – when in the text the expression of joy turns into tears – the key turns respectively from F major into F minor and from B♭ major into B♭ minor (Ex. 4).

Towards the end of the 17th century split keys disappeared, the new tonal system requiring the unification of the sharps and the enharmonically equivalent flats. In §5.1 we have seen that only in Great Britain, still up to the 1810's, enharmonically doubled notes were sometimes maintained, even on the pianos.[92] In Italy, on the contrary, the last surviving keyboard instruments originally made with split keys are dated 1665 and 1666.[93] Nigetti's last instrument was made in 1670, and this made his fellow-citizen Orazio Ricasoli Rucellai thinking that «maybe in the centuries to come the voice gradation will widen still more» (*c*1665–73).[94] But just the opposite was true: as far as we know, only Giuseppe Sarti – in 1779–84, when he was

90 Domenico Mazzocchi, *Dialoghi e sonetti,* Roma: Zannetti 1638, pp. 175 and 181 («nondimeno adoprandosi alcune parti di esso accomodate al Diatonico, pur tali compositioni si potranno chiamare enarmoniche»).

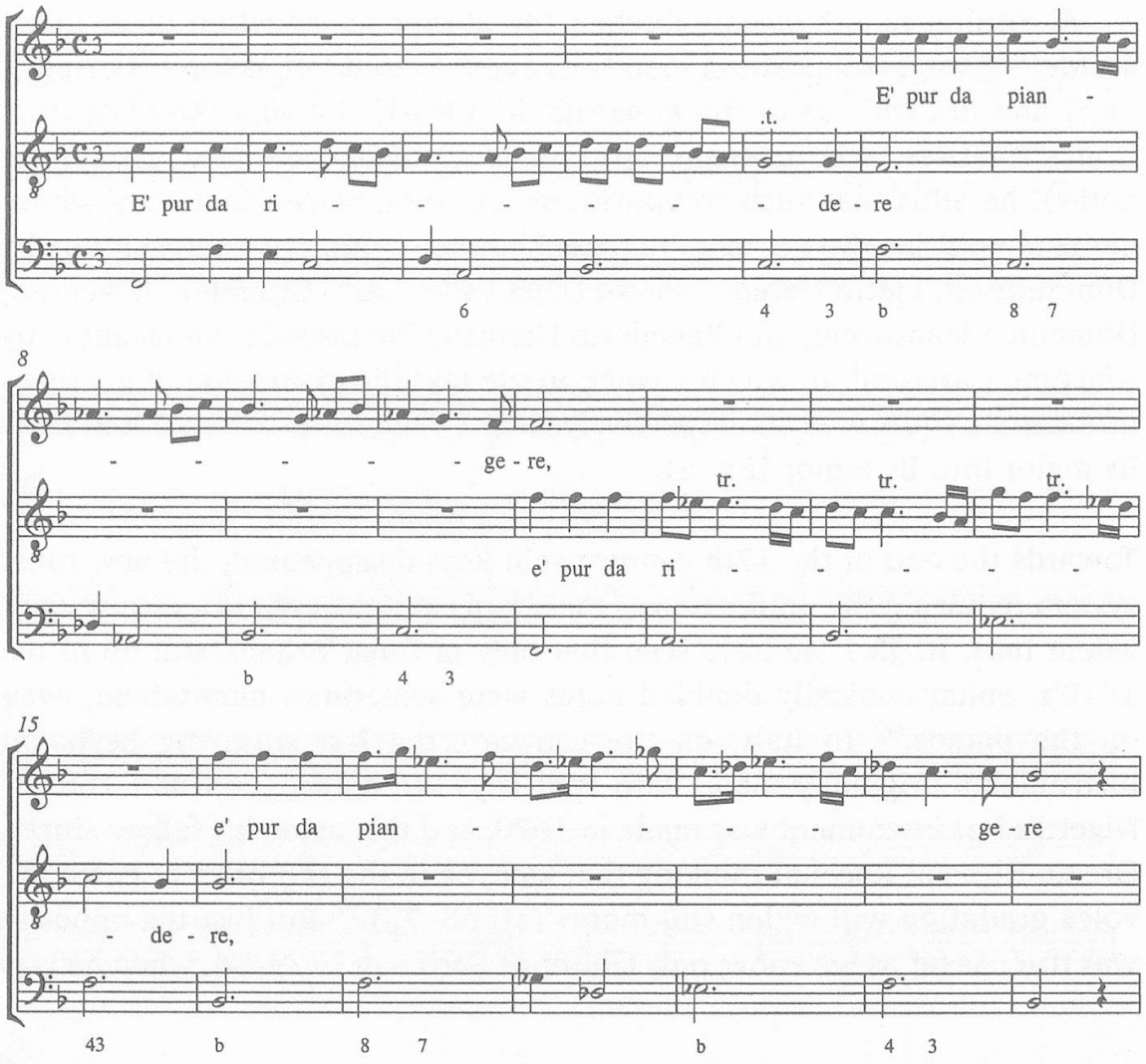
91 Doni, *Compendio*, p. 62; Athanasius Kircher, *Musurgia universalis*, I, Roma: Corbelletti 1650, pp. 672–675 («De mutatione modi, sive toni, sive stylo metabolico»).

92 Of such a kind, still in 1799 were even «the Temple [church] organ and one at Lord Uxbridges»: John Wall Callcott, *A critical examination of the musical theory of Kirnberger*, [London] Feb. 8, 1799 (GB-Lbl Ms. Add. 27648, p. 97).

93 Wraight & Stembridge, «Italian Split-Keyed Instruments», pp. 168 and 156, respectively. A Willem Hermans organ in Sant'Agnese in Agone (Rome, piazza Navona), in 1667–68 was made with «tasti spezzati», although it is not clear if they were the D/F♯, E/G♯ in the short octave or the usual enharmonic splittings: I-Rdp Mandati di pagamento 1671-V, no. 897 (September 1671): «E più per filo di ferro grosso e filo di otone per la redutione delli tasti spezzati, scudi 1.50».

94 Orazio Ricasoli Rucellai, *Segue il Timeo. Delle musiche proporzioni,* [Florence] no year; I-Fn Ms. Cl. II.III.269, fol. 157r: «e oggi si vede, che da musici di più alto sapere ogni dì si spezzano, e suddividono i tasti delli strumenti, e degli organi, e forse co' secoli avvenire s'andrà più ampliando la graduazione delle voci».

Ex. 4: Giacomo Carissimi's example of «stylus metabolicus», according to Athanasius Kircher, *Musurgia universalis* (1650), p. 673 (transcription by M. Kirnbauer).



maestro di cappella in Milan's cathedral – directed the construction of both a harpsichord (by the Elli brothers) and of an organ (by the «celebrated Fontana») with split keys.[95]

5.4. *Transposing keyboards*. Regarding the Equal Tempered Systems, it should be recalled that enharmonic divisions had also been employed merely for transposing a normal keyboard in microtonal steps, in order to match the pitch of other instruments, e.g., Carl Luython's *Clavecymbalum universale* and Iacopo Ramerino's transposing harpsichord. Together with the possibility of «circulating», in the second half of the 17th century this was even

95 Patrizio Barbieri, «Giuseppe Sarti fisico acustico e teorico musicale», in: *Giuseppe Sarti musicista faentino*, ed. Mario Baroni & Maria Gioia Tavoni, Modena: Mucchi 1986, pp. 221–240, p. 232.

the only practical use of Vicentino's ETS 31, as shown by Francesco Nigetti's *Cembalo onnicordo* (Florence, 1640–70) and Cristiaan Huygens' transposing keyboard (Paris, *c*1669).[96]

6. *Conclusions*

6.1. Owing to practical performance problems, the just tuning system had to be tempered. The first quantitative exposition of such operations can be ascribed to Zarlino (1558–71), but it was Salinas (1577) who established that in each of the regular temperaments (later called «meantone») all tones had the same size.

6.2. Diatonic-chromatic, meantone-tuned keyboards normally provided only major and minor semitones. Their extension into the enharmonic – a genus used above all in Italy – can be divided into four progressive steps: (1) division of a few major semitones only (giving rise to widespread split keys like G♯/A♭ and E♭/D♯, at either end of the chain of 5ths, thus giving to all diatonic notes both the major and minor 3rd), (2) division of all the major semitones (*cimbalo cromatico*), (3) further divisions, beginning to penetrate into the minor semitones' domain (an enterprise started by Zarlino), (4) division of all the minor semitones (Vicentino's *Archicembalo*).

6.3. Just intonation enharmonic keyboards, on the other hand, were built almost exclusively for demonstration purposes. See Salinas' double harpsichord, providing his just intonation «perfect» system in the upper keyboard (24 keys per octave) and the very same system, but tempered, in the lower one (19 keys per octave in three rows, which happens to be a *cimbalo cromatico*). From Salinas' just intonation «perfect» system stem the proposals by Mersenne, Descartes and their Flemish and Dutch followers (among them Joan Albert Ban is the only one to have put just intonation into practice, even compositionally).

6.4. The employment of meantone tuning to fretted instruments required the introduction of the awkward system of the so-called *tastini* and for this reason equal temperament was generally preferred. To this end different, yet correct methods were suggested by Vincenzo Galilei and Zarlino, but on the contrary, Salinas' ingenious construction – based on the golden section – has proved useless for this purpose.

96 Barbieri, «I temperamenti ciclici», pp. 153–155, 178, 184 and 203.

6.5. The introduction of the above mentioned enharmonic keys was due to three factors: (1) the transposition of church modes, for the convenience of singers, (2) the revival of the ancient Greek enharmonic genus, put into practice in two stages, (3) the increasing spread of transpositions and modulations in a single composition, a style that – even in 1650 – Kircher classed as *Stylus metabolicus*.