



**Acoustics'08  
Paris**  
June 29-July 4, 2008

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**”Acoustics vases in ancient theatres: disposition,  
analysis from the ancient tetracordal musical system”**

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The acoustics of the ancient Greek and Roman theatres has always been rated as excellent by experts, without discussion. Beyond the purely architectural aspects, in this kind of outdoor theatres some mechanisms were used in order to improve the acoustics.

In this paper we have studied the texts about "theatre's vases" of the famous book "On Architecture" by Vitruvius. Different interpretations and illustrations of these vases that several translators carried out in the sixteenth to the eighteenth centuries have been researched.

From the wide bibliography consulted in this regard we have developed a plane with the disposition of the bronze vases in the theatres. In this plane we have specified the frequency of each one of them, and explained their disposition from the tetrachordal musical system acquired from the Greek culture. Finally, an analysis of the disposition of the vases has been made. We have studied and looked for the musical intervals and harmonic relations among adjacent vases.

## 1 Introduction: The Greek and Roman theatres' acoustics

In the last years, great amount of monographs and studies have been published about ancient theatres. We find numerous exhaustive studies of theatres that widely relate the historical circumstances that surrounded its construction, descriptions of its present morphology, reconstruction of past morphologies, similarities and differences with contemporary theatres to the studied one, etc. Lately the science of acoustics has lent to the Greek and Roman theatres a special interest, giving rise to specialized publications and communications in national and international congresses where the acoustics conditions of a particular theatre are studied and virtual simulation are made. Nowadays, virtual reconstruction is the most common research.

Recently coordinated studies like the European Project ERATO (Evaluation and Revival of the Acoustical heritage of Ancient Theatres and Odea), or the project of the Italian Ministry of University and Investigation "ATLAS" (Ancient Theatres Lighting and Acoustics Support) are being developed. These projects fundamentally focus on obtaining acoustics measurements in situ and computer simulations.

Our study shows a different point of view.

The acoustics of the ancient Greek and Roman theatres has always been rated as excellent by experts, without discussion. Nevertheless, there are several different theories that explain the ancient theatres acoustics behavior: the appropriate placements with very low levels of background noise, the well-chosen inclination of the cavea that makes possible the distribution of powerful reflections coming from the stony pavement of the orchestra which reinforce the direct sound [1], etc. Other researchers have studied the important acoustic role carried out by the "scenae frons" in this kind of theatres. Even there are theories that study the role developed by the wind.

Beyond the purely architectural aspects, in this kind of outdoor theatres some mechanisms were used in order to improve the sonorous levels in all the cavea. The most important acoustics artifices are:

- The actors' masks that apparently served to amplify the voice as a megaphone in order to make it audible in all the rows of the cavea (modern experiments put this into doubt, when considering that these masks could difficult the diction and the intelligibility of texts).

- The placement in the cavea of bronze vessels, among the public, in order to reinforce the sound emitted by the actors by means of the natural resonance of the vases.

This paper deals with this latter acoustic mechanism.

## 2 Sounding vessels in the theatre

Since none of those bronze vessels has survived until nowadays, the only information that we have about them is throughout the treatise of M. Vitruvius Polione "Ten Books on Architecture" (written between 27 - 11 b.C. period) [4].

In Book-V we find:

*Chapter III. The theatre: its site, foundations and acoustics*

*Chapter IV.. Harmonics*

*Chapter V. Sounding vessels in the theatre*

*Chapter VI. Plan of the theatre*

Reading the Chapter V "Sounding vessels in the theatre", we find the next paragraph about the form or size of the acoustics vases:

*"In accordance with the foregoing investigations on mathematical principles, let bronze vessels be made, proportionate to the size of the theatre, and let them be so fashioned that, when touched, they may produce with one another the notes of the fourth, the fifth, and so on up to the double octave".*

And about the way to place them in the cavities, Vitruvius says:

*"Then, having constructed niches in between the seats of the theatre, let the vessels be arranged in them, in accordance with musical laws, in such a way that they nowhere touch the wall, but have a clear space all round them and room over their tops. They should be set upside down, and be supported on the side facing the stage by wedges not less than half a foot high. Opposite each niche, apertures should be left in the surface of the seat next below, two feet long and half a foot deep."*

This description is the only reference that we have about the way of placing the bronze vessels in the cavities of the theatres, since none of the illustrations that Vitruvius made has arrived until nowadays. The first translators and researchers of the Vitruvius' treatise drew these vessels (there are different interpretations of the Vitruvius descriptions). But none of them tried to explain the reasons for the

placement of these vessels in the theatre exactly as Vitruvius writes.

### 3 Vitruvius and the Greek musical system. [2]

The terminology used by Vitruvio in its treatise is the one used by Aristoxenus' musical system, a system quite different of the Pythagoras one. The Greek mathematician Pythagoras developed a rationalist system based on the natural consonances. This system is widely studied nowadays in the musical acoustics field.

In the Aristoxenus' Greek system the minimum melodic grouping of musical notes is the *tetrachord*, formed by four musical notes of which:

- two extreme notes are fixed and invariable; they delimit the tetrachord
- two intermediate notes are variable. Based on them we say that the tetrachord belongs to the *diatonic* mode, the *chromatic* one or the *enharmonic* one.

1/2	1	1	Diatonic
1/2	1/2	1 1/2	Chromatic
1/4	1/4	2	Enharmonic

Figure 1. According to Aristoxenus, different modes or types of tetrachords (diatonic, chromatic and enharmonic).

According to what we read in Book-V Chapter-IV of Vitruvius' treatise, there are five possible tetrachords. Each one of them can belong to any of the modes before mentioned. These tetrachords are: *Hypaton*, *Meson*, *Synemmenon*, *Diezeugmenon*, *Hyperboleon*.

The addition of tetrachords generates *systems*. Greek and Roman melodies are developed from the *systems*.

The name of each musical note indicates the tetrachord that it belongs, and the position that the note occupies in that tetrachord (with the exception of three notes: the lowest one *-proslambanomenos-*, and the two central notes *-mese* and *paramese-*).

Figure 2. tetrachords, modes (types) and names of the musical notes [3]

### 4 Disposition of the vessels in the theatre: Analysis and discussion

As starting point of this study, we drew a plane with the musical notes that produced each one of the bronze vases placed in the theatres according to Vitruvius' treatise. Vitruvius explains the differences between theatres "not very great" and the great theatres. We will study these last ones, because the disposition of the vases in a small theatre is the same one as the first row of vases of the great theatres.

The disposition in great theatres according to Vitruvius is as follows:

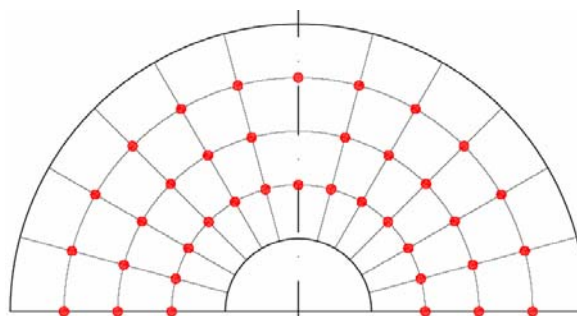


Figure 3. Plan with the vessels placement

The vases are placed in three radial arches. Each arch will have thirteen bronze vessels, placed in a more or less equidistant way to each other, with the exception of the second arch, which has only twelve vessels. They are distributed symmetrically with respect to the central symmetry line of the theatre.

#### 4.1 Modes of vessels. The radial arches

The vases of each one of the arches will reinforce or enhance musical notes of a particular mode according to the distribution of the figure 4.

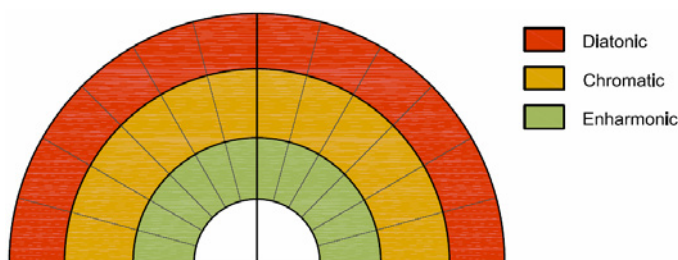


Figure 4. Distribution of vessels in modes

The diatonic mode was the most usual one in Greek and Roman music. In fact, we can easily find in this mode a sequence of melodic intervals similar as that ones of the European music scales of the classical tonal system (s. XVIII and XIX). The enharmonic mode was the most complex and difficult one by having two musical intervals smaller than the half-tone of tonal music (something similar as "quarters of tone"). That's why in the musical development of the Roman culture it will be the mode that firstly disappeared.

Having all this into account, the first thing that surprises us is that the enharmonic mode vases are located in the first radial arch: the most important seats, with the less important mode! Moreover, as Vitruvius says, in the reduced dimensions theatres, Romans put only these kind of vessels. However explaining this is quite simple:

If we represented in three separated pentagrams the musical notes of the vases of each arch distinguishing between the invariable notes of the tetrachords (white notes) and the variable notes (black notes), we will see that all the notes of the first arch -the enharmonic mode arch- are invariable notes (figure 5). They are the common notes that belong to all the modes (diatonic, chromatic and enharmonic). Thus, although Vitruvius calls them “vases of the enharmonic mode”, these vessels are really going to reinforce the more important notes of the Greek musical system, the more stable musical notes, the notes that hold every Greek or Roman melody, independently of the mode to which that melody belongs.



Figure 5. Enharmonic mode vessels: musical notes (half theatre)



Figure 6. Chromatic mode vessels: musical notes (half theatre)



Figure 7. Diatonic mode vessels: musical notes (half theatre)

We shall remember that the notes we have called “invariable” are those ones that delimit the different tetrachords. These notes are: *SI2 - MI3 - LA3 - SI3 - RE4 - MI4 - LA4* (and the coger note, the proslambanomenos: *LA2*). That is why musical intervals that prevail between vessels of this first enharmonic arch are 4<sup>th</sup> interval, 5<sup>th</sup> one and 8<sup>th</sup> one as Vitruvius says in the first paragraph of Chapter-V of Book-V of his treatise.

In agreement with this, we presented the following tables that show the 4<sup>th</sup>, 5<sup>th</sup> and 8<sup>th</sup> intervals existing between musical notes of the bronze vessels of each radial arch in Roman theatres:

Interval	Musical notes				
4 <sup>th</sup>	Si2- Mi3	Mi3- La3	La3- Re4	Si3- Mi4	Mi4- La4
8 <sup>th</sup>	Si2-Si3	Mi3-Mi4	La3-La4		
5 <sup>th</sup>	Mi3-Si3	La3-Mi4	Re4-La4		

Table 1. Enharmonic mode vessels: musical intervals

Interval	Musical notes		
4 <sup>th</sup>	Do#3-Fa#3	Fa#3-Si3	Do4-Fa4
8 <sup>th</sup>			
5 <sup>th</sup>			

Table 2. Chromatic mode vessels: musical intervals

Interval	Musical notes				
4 <sup>th</sup>	La2- Re3	Re3- Sol3	Sol3- Do4	La3- Re4	Re4- Sol4
8 <sup>th</sup>	La2-La3	Re3-Re4	Sol3-Sol4		
5 <sup>th</sup>	Re3-La3	Sol3-Re4	Do4-Sol4		

Table 3. Diatonic mode vessels: musical intervals

On studying the radial arches assigned to the chromatic and diatonic modes, the situation is very different. Here we find only five common notes to the three modes (invariable notes), ten notes of the diatonic mode and ten notes of the chromatic one. The most important musical interval between the vessels of these modes is the 4<sup>th</sup> interval (figure 6, table 2). In this way, we find three 4<sup>th</sup> intervals, none 8<sup>th</sup> one and none 5<sup>th</sup> one between notes generated in the chromatic mode (the second radial arch).

Between musical notes produced by the most distant vases from the *orchestra*, the diatonic mode vessels, we find five 4<sup>th</sup> intervals, three 8<sup>th</sup> ones and three 5<sup>th</sup> ones (figure 7, table 3). Exactly the same number of intervals of each type that we had found in the enharmonic mode! The reason of this apparent coincidence is that musical notes emitted by the diatonic mode vases are the obtained ones when we subtract a tone to each one of the notes emitted by the vases of the enharmonic mode (See figures 5 and 7). Moreover, the order of the vases is not the same.

In spite of the similarity among the vessels of both arcs (diatonic and enharmonic), there is a great qualitative difference between them: all the enharmonic mode vases emit notes that delimit the tetrachords (fixed notes), that is to say, common notes to all the modes or types of tetrachords. That is why these vessels vibrate or resonate with any melody. However only three of the diatonic mode vases are common notes to all the types of tetrachords, while the other ten vases only resonate with own frequencies of the diatonic mode (figure 7).

Now, if we analyzed the figure 8, we note that the vases that resonate to frequencies of invariable notes are placed in the central zone of the theatre and in the zone near the orchestra. Surprising, Vitruvius indicates that in the central cavity of the chromatic arch, any vessel was not placed. We cannot give a trustworthy interpretation of this distribution. It seems that the design wanted “to privilege” the acoustics of the central part of the theatre. Or perhaps they considered that the voice of the actors in the cavea was not homogenous, and the observation and the experience took them to this kind of vases distribution to improve the acoustics.

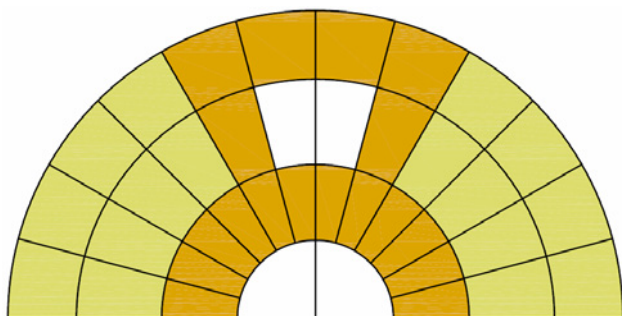


Figure 8. In dark color: vessels that resonate to frequencies of the invariable notes. In clear color: vessels that resonate to frequencies of musical notes assigned to a specific mode (diatonic, chromatic or enharmonic)

### 4.2 The vessels: high and low frequencies

Now we will study the distribution of the vessels from the point of view of the frequency, without considering the Greek and Roman musical system. Thus, we have assigned a color to each musical note in agreement with a progressive scale of color depending on the frequency (figure 9).

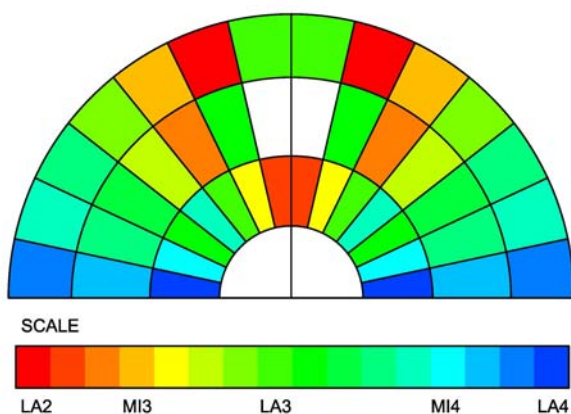


Figure 9. Vessels in the theatre: progressive scale of color depending on the frequency

The drawing clearly shows a colour degradation from the centre towards the wings of the cavea. If we take the colours assigned to the arithmetic mean of the frequency of three notes in every radial section, we obtain a plane clarifies us very much (figure 10).

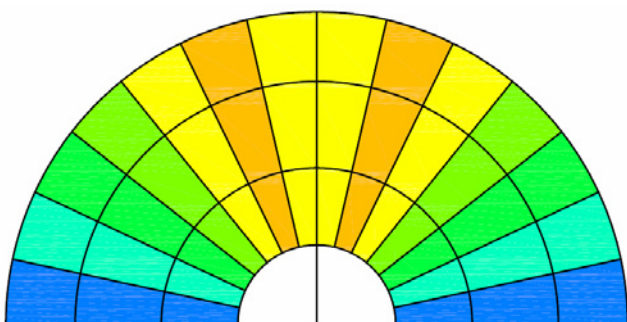


Figure 10. Vessels in the theatre: progressive scale of color depending on the frequency. Simplification

The high frequency vases (600-880 Hz) are placed in the sides of the cavea, while the low frequencies vases (220-400 Hz) are placed in the central part (figure 11).

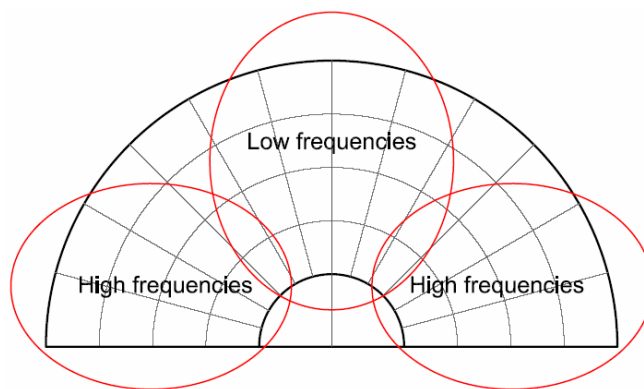


Figure 11. Theatre plan. Scheme with the predominant frequencies of the vessels

We don't know if Vitruvius elaborates all this theory on his own. Probably all what Vitruvius writes in his "Ten Books on Architecture" about theatres is based on experience, practice and custom of the Roman culture and architecture.

### 5 Did vessels exist? Were they useful?

We do not have a clear evidence of the existence of the vessels that Vitruvius describes. The Roman Empire included an enormous geographic extension. It is evident that geographic distances between cities produced great morphologic differences between buildings of the same architectonic typology. Many peculiar characteristics personalized each Roman theatre in agreement with their space-temporary situation. In addition, with the uninterrupted use of the theatres during several centuries, successive architectonic interventions were carried out in order to adapt the theatre to the requirements of every society.

Much more damaging has been the remove of constructive elements (ashlars, columns, sculptures,...) from multitude of excellent Roman buildings in order to use them in new buildings along the history. Taking all this into account perhaps it is normal that none of bronze vessels of Roman theatres has arrived until us. Perhaps it is normal that we do not see in the ruins of any Roman theatre a clear order of hollows that we can associate without any kind of doubts with the cavities where the metallic vases were placed... or may be not.

In Book-V Chapter-V of Vitruvius' treatise, we find:

*"Somebody will perhaps say that many theatres are built every year in Rome, and that in them no attention at all is paid to these principles; but he will be in error, from the fact that all our public theatres made of wood contain a great deal of boarding, which must be resonant. This may be observed from the behaviour of those who sing to the lyre, who, when they wish to sing in a higher key, turn towards the folding doors on the stage, and thus by their aid are reinforced with a sound in harmony with the voice. But when theatres are built of solid materials like masonry, stone, or marble, which cannot be resonant, then the principles of the "echea" must be applied.*

*If, however, it is asked in what theatre these vessels have been employed, we cannot point to any in Rome itself, but only to those in the districts of Italy and in a good many Greek states."*

Did Vitruvius see anytime one of these vessels in a Roman theatre? We can't know it.

And another question: if there were bronze vessels in Roman theatre, was this acoustical mechanism useful? The only thing that Vitruvius says about this, is:

*“Besides, many skilful architects, in constructing theatres in small towns, have, for lack of means, taken large jars made of clay, but similarly resonant, and have produced very advantageous results by arranging them on the principles described”*

The Spanish translator of 18<sup>th</sup> century *Ortiz y Sanz*, doubts of the effectiveness of these bronze vases [4]. He thinks this acoustics mechanism don't help at all to improve the acoustics of the Roman theatres.

The researcher G. Izenour [5] considers that the effect of these vases was very poor. In his book, Izenour notices us about cavities found in Beth Shean theatre (Israel) that may be were made to house acoustics vessels.

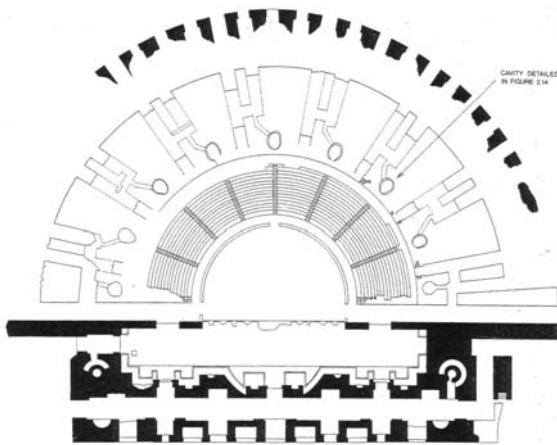


Figure 12. Izenour: distribution of the cavities found in Beth Shean [3]

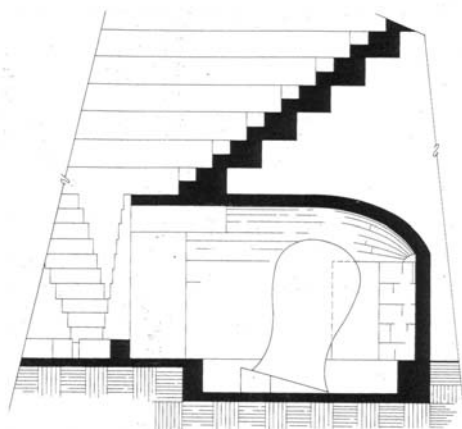


Figure 13. Izenour: reconstruction of a cavity with a bronze vessel (Beth Shean) [3]

Similar examples we can found in Gerasa theatre (Jordan), Scythopolis theatre (Syria), etc, but we never have the certainty that these cavities are the ones that Vitruvius refers in his treatise.

## 5 Conclusions

We have analyzed the bronze vessels in Roman theatres and their possible contribution to improve the acoustics of these buildings. We have research it from the Greek and Roman musical system, and we have elaborated easy schemes that help us to understand the distribution of the vases in the cavea (always as Vitruvius says).

Finally, we have consulted a wide bibliography about ancient theatres, and we have establish the bases to carry out later researches.

## References

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