The evolution of the classical guitar & the issue of the longitudinal coupling in the design of the soundboard*

Vladimir Druzhinin Timofey Tkach

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Abstract

This article presents a brief systematic review of the history of guitar development and provides the content, significance, and reasons for changes in its design at different historical stages. While stating the general conclusion about the classical guitar reaching its final evolutionary forms, the authors have discovered the possibility of creating a new variant of the symmetrical classical design relevant to the performance needs of modern players. An analysis of some aspects of sound formation in the guitar as well as a detailed description of the author's new design of the soundboard are provided in the second part of this article.

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Contents

1 Introduction

There is hardly another example of such a fabulously successful career among plucked acoustic instruments as that of the guitar. Over the course of its rather short (speaking of modern classical design) existence, the guitar has not only acquired a vast repertoire of compositions, but has also won the hearts of people from all over the world. From a parlor chamber instrument, it turned into a widely recognized concert instrument. Harmonic, melodic, and polyphonic capabilities; richness, controllability of timbre; and dynamic expressiveness have made the guitar a versatile instrument in high demand in a variety of national cultures. The outstanding potential of the sound[1] was the result of the development of the design in the pursuit of perfect balance, which sometimes requires solving tasks that at first glance contradict each other:

- The sound in the range of three and a half octaves (82–988 Hz, 43 notes!), and under certain conditions[2] up to four octaves, should be efficiently and evenly produced with only six strings. For this purpose, the guitar body's own set of internal resonances should adequately correspond to the range of sounds both in frequencies and dynamic sensitivity. The impossibility, in the case of complex textures, to individually control particular notes, for example, within a chord, is a serious challenge to the evenness of the guitar's sound.

- The low plucking energy should be sufficient to produce a full, timbre-colored and controllable sound with a fast attack in a wide dynamic range from a powerful *forte* to *pianissimo*. Hence the requirement of structural lightness and flexibility of the guitar body, which allow good divisibility within the soundboard (and back also) and at the same time provide sufficient rigidity and coupling.

Solutions to these and other tasks, introduced by outstanding luthiers, became the basis of the classical school. The guitar has undergone several centuries of evolution, during which the structural design, proportions, string number, and tuning have been changing. These changes have entailed new qualities of the sound as well as the expansion of performing possibilities. The evolution of the guitar continued up until recent times. However, there is still no consensus on whether it is finished or not.

[1] A detailed consideration of the issues of evaluation and reproducibility of the sound, as well as the definition of some basic notions, are set out in the previous article [1].

[2] Possible down-tuning of the 6th string; adding a 7th string; increasing the number of frets.

This is the second of a planned series of texts devoted to the interpretation and analysis of some of the most important, in our opinion, subjects concerning the guitar building. In this article, we present our view on the evolution of the modern guitar, discuss the problem of the structural coupling in the instrument design, and suggest a variant of its solution.

Traditionally, luthiery was taught while working in a workshop. Auditory experience and handicraft skills were best exemplified through demonstration. Knowledge was passed by word of mouth directly from the master to the apprentice. This could happen, of course, when the master took learners and the latter were sufficiently gifted. Such practice, especially in view of the objective complexity of documenting many components of training, begot a significant shortage of analytical and methodological texts. The preservation and development of the school is directly conditioned by the resources for education. Therefore, the systematization and documentation of the knowledge that forms the school, the study of its formation and evolution remain highly topical tasks today.

2 Overview of the evolution of the classical design

Successful changes in instrument design that have been accepted and have stood the test of time, are generally associated with the development of music. It is not always possible to ascertain what is ahead — Either the changed requirements for technical virtuosity and the breadth of the range of expressive means have motivated luthiers to strive for new horizons, or the talent of a performer or composer that has appeared by chance has revealed the previously unrealized possibilities of existing instruments. New music requires new capabilities. The relation between the live practice of performance and construction gives birth to instruments relevant to the time and context. One way or another, musicians and luthiers are closely connected in this process and their successes complement each other.

2.1 The guitar before Torres

Summarizing the development of the guitar up to the middle of the 19th century, without going into too many details, we will only mention some points that are important in the context of this article.

The proportions of the body and the internal structural design, from the vihuela and the Renaissance guitar (16th century) to the end of the Baroque

(a) (b) (c) (d) (e)

Figure 1: 17th–19th centuries guitars: (a) A Stradivari, 1679 (b) J. Martínez, 1790s (c) A. Caro, 1803 (d) L. Panormo, 1827 (e) A. de Torres FE21B, 1864

period (circa late 18th century), have practically not undergone any significant changes. The bodies of the instruments of this period have an elongated shape and have small dimensions, relative to the scale length. This is probably due to the fact that the guitar at an early stage of its evolution was a chamber instrument: the musical works performed were addressed to a narrow circle of listeners. There was no need for high sound power. A timbral-colored sound with a fast attack was required, which, for an instrument with free sound decay and low plucking energy, is conditioned by the lightness of the design.

By the end of the 18th century, the process of the sophistication and expansion of the guitar repertoire began thanks to such guitarists and composers as *Ferdinando Carulli* (1770–1841), *Matteo Carcassi* (1792–1853), *Mauro Giuliani* (1781 –1829), *Fernando Sor* (1778–1839), *Dionicio Aguado* (1784–1849), and *Niccolò Paganini* (1782–1840). This led to the transition of the guitar from a Baroque to Romantic design. With the addition of the 6th E string, the range of the bass register was extended by an interval of a perfect fourth. Changes also affected the neck design: if earlier the front surface of the neck was flush with the soundboard and the frets were tied-on, now there is a fretboard with cut-in metal frets. The bridge design also changed. Some luthiers started using a fan pattern for braces in the lower bout of the soundboard. Double string courses, which complicate the performance of sophisticated techniques, give way to single strings of higher tension. We assume that the introduction of fan bracing was due to the need to achieve a more powerful and fully colored sound employing single strings.

Undoubtedly, all these innovations increased the potential of the guitar in terms of power, timbre, and convenience for the performer. At the same time, the guitar continued to be a chamber instrument, which probably determined a certain decline in interest in it by the middle of the 19th century. Concert practice was changing, but the magnitude of the repertoire and sound was not yet sufficient to recognize the guitar as a classical[3] instrument.

2.2 The foundation of the classical school

The situation began to change in the middle of the 19th century thanks to contributions made by the luthier *Antonio de Torres Jurado* (1817–1892), influenced by the guitarist *Julián Arcas* (1832–1882), and later by the guitarist and composer *Francisco Tárrega* (1852–1909). Popular demand arose for a more fully and potently sounding instrument. Classical music was also changing. It had ceased to be as elitist, as in the previous era. Instruments were needed that could provide adequate sound to fill a concert hall with a large audience.

We are moving on to the revolution in the guitar made by Torres. The addition of the sixth bass string of the Romantic guitar was not supported by adequate changes in its design. In order for the lower part of the range to sound full, the instrument must have its own appropriate natural resonances. In a small instrument they inevitably turn out to be tuned significantly higher than required. The area of the soundboard and the volume of air inside the body are not enough to achieve sufficient sound power. How can the guitar body significantly be enlarged, keeping the relatively small scale length convenient for playing? Torres conceptualized and solved this problem.

The result of his work was a cardinal change in the proportions and dimensions of the instrument. The body in length became equal to the neck with the head. The bridge has moved to the middle of the lower bout. The body dimensions ratio has changed: the guitar has plumped more than it has added in length. Due to these actions, while maintaining the same scale length, the radiating area and the internal volume of air have radically increased. This made it possible to bring the natural resonance system of the guitar in line with the sound range and thus significantly increased its power. The sound of the lower register has become much more complete. The use of a fan braces system provided smooth rigidity distribution in the

[3] We have in mind the following criteria: well-established design, tuning and sound character; the presence of a recognized, large-scale repertoire, including orchestra, ensemble and solo works; appeal to a vast audiences, practice of performances in concert halls.

lower bout, while on the other hand, enabled better transverse divisibility. This also allowed to achieve quick simultaneous inclusion of the maximum number of harmonics after plucking. Torres' guitar had incomparably greater capabilities than all guitars of previous designs. This determined its further destiny: within a short time, Torres' design was widely recognized and began to be used by luthiers.

Francisco Tárrega, who has played several guitars by Torres throughout his career, created a huge repertoire of both original music as well as Baroque and classical music transcribed for the guitar. An outstanding teacher, he brought up a pleiad of talented followers, the most prominent representatives of which were *Miguel Llobet* (1878–1938) and *Emilio Pujol* (1886–1980). Llobet set the bar for virtuosity, and also contributed to the repertoire (Catalan songs, La Folia variations, etc.). Pujol carried out work on the systematization of technique and created the fundamental school of guitar playing, which remains relevant to this day. This stage determined the popularity of the classical Spanish guitar in the world, but the evolution of its design does not end there.

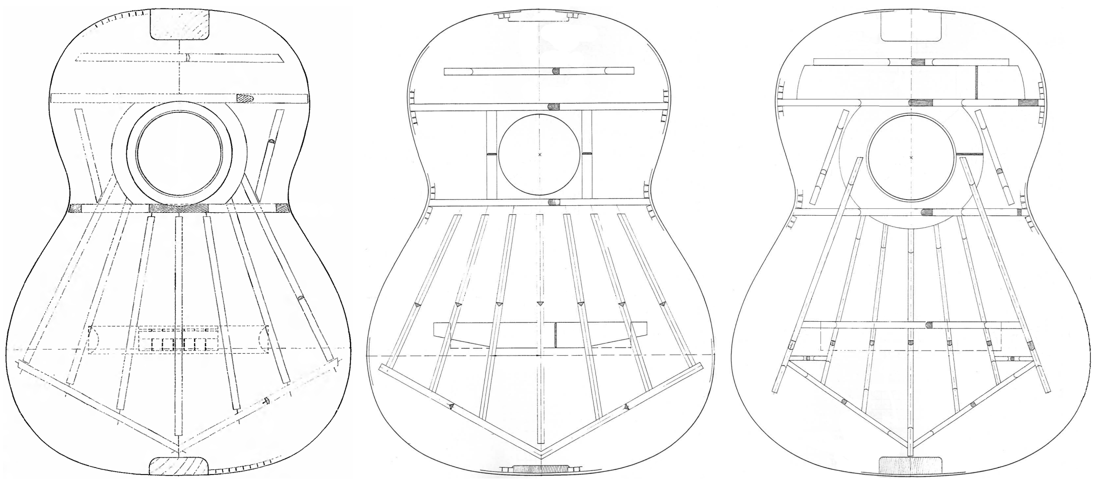
2.3 Sound and design development

The next step was determined by *Andrés Segovia's* (1893–1987) appearance on the stage. Being tremendously gifted, ambitious, but not involved in the traditional environment, he set himself an incredible task. Segovia wanted to transform the guitar from a folk, parlor instrument into an academic one, striving to introduce it into large concert halls. It was Segovia who convinced many composers to create original works for the guitar. In addition, he did an enormous amount of work on transcribing violin, cello and piano music for the guitar. He also performed works by Spanish composers (Isaac Albéniz, Enrique Granados, Manuel de Falla), which sounded natural and organic on the guitar, although they were not written for it.

Such ambitious goals required the unification of the school of performing, broadening the repertoire, and, of course, an instrument that would meet the requirements of academic concert performance.

2.3.1 Symmetrical design

Segovia's first professional guitar was presented to him in 1912 by *Manuel Ramírez* (1864–1916). It was built by *Santos Hernández* (1874–1943), who worked in his workshop at that time. This guitar almost exactly repeated the design of Torres. It was with it that Segovia entered large concert halls. But still, the capabilities of this instrument were not enough for the transcriptions of violin, piano and orchestral music to sound fully. In order to attract the composers of the time and interest them in the potential of the guitar, a fuller sound of the lower and upper registers was still required, as well as an increase in objective power. By this time, the Torres' guitar design had already become a benchmark and a point of reference for further attempts to improve the efficiency of design.



(a) A. de Torres [3] (b) H. Hauser I [4] (c) D. Friederich [4]

Figure 2: Soundboard layout in guitars of symmetrical design

Manuel Ramírez's disciples, Santos Hernández and *Domingo Esteso* (1882–1937), took action in this direction. Each in his own way, they began to look for opportunities to further increase the dimensions of the instrument as well as the volume of air in it. They increased the longitudinal rigidity of the soundboard as well as its transverse divisibility by arranging the fan braces at a lower angle. Both luthiers have remained in history as great masters. Their instruments still amaze us with the beauty and flexibility of timbre, the depth of dynamic range. However, the further course of events was fundamentally influenced by *Hermann Hauser I* (1882–1952).

Being a luthier of the traditional "Viennese" school[4], after his acquaintance with Segovia, Hauser devoted himself to studying the Spanish school. He not only succeeded in this domain, but took some steps to develop the design, which gave his instruments an advantage over others. He slightly increased the soundboard thickness and reduced the height of transverse bars, the ends of which also received bevels of considerable depth. He introduced

[4] The term is arbitrary, as in both Europe and Russia many luthiers had been working in this tradition.

an under-bridge plate, as well as a slight change in the fan geometry. With all the above, a better lengthwise coupling of the entire soundboard was achieved. The instrument sounded fuller in the lower register, had excellent dynamics and timbral flexibility. This gave definitive advantages when performing polyphonic music. The only problem, in our opinion, was a certain lack of warmth of sound, so characteristic of the Spanish classical guitar. Hauser's work was unique, especially considering the fact that he had no direct contact with the representatives of the Spanish school. Moreover, the pinnacle of his work took place between 1934 and 1952, and he worked in Munich. It was a difficult time. Nevertheless, at that moment, Hauser won the competition from the luthiers of the Spanish school, who, to a greater extent, were focused on the domestic consumer and national music.

Unfortunately, the Spanish Civil War, as well as the Second World War, led to the fact that the school of Manuel Ramírez (based on the principles of Torres' work) did not fully realize its development potential. *Marcelo Barbero* (1904–1956) continued the work of Santos Hernández, but, as far as we know, did not introduce anything new to the design of the guitar. Representatives of the famous *Conde* dynasty[5], heirs and followers of Domingo Esteso, elaborated a number of original designs and, of course, continued the development of the school. However, they mainly focused on the needs of the national flamenco musical tradition. From our point of view, their instruments can also sound full within the classical repertoire[6].

But let's take a step back in time. The point is that the Spanish guitar assumed, first of all, a harmonic sound, that is, the sound of a chord which is mainly defined by the middle register. This is a range from 200 to 1000 Hz. Torres, in his time, made an attempt to expand the functionality of the soundboard at low frequencies (below 200 Hz), probably, in the process of building a 10-string guitar. For this purpose, he made arches in the waist transverse bar and through them brought out fan braces into the upper bout (Fig. 2(a)). In this way, he made it possible for the soundboard to work at low frequencies cohesively, vibrating a larger area. This idea was then repeated by Manuel Ramírez, and in the second half of the 20th century *Robert Bouchet* (1898–1986) began to actively use it. The result was remarkable: his guitars were played by Ida Presti, Alexandre Lagoya and Julian Bream. These instruments presented themselves perfectly in terms of sound coloration, lower register sound, timbral mobility, but they did not give a considerable gain in power.

[5]Brothers *Faustino* (1913–1988), *Mariano* (1916–1989), *Julio* (1918–1995) and their descendants, working fruitfully and gloriously till the present day.

[6]A striking example: Joaquín Rodrigo's "Concierto de Aranjuez" and the works of Manuel de Falla performed by Paco de Lucía.

After the world had recovered from the consequences of the Second World War in the 1950s and 1960s, a new rise in the guitar school, both performing and artisanal, began. The luthiers who proved themselves during this period continued to seek ways to achieve a more powerful sound, increase the timbre density at the edges of the spectrum, and expand the polyphonic capabilities of the guitar.

Speaking of the evolution of symmetrical design during this period, we cannot resist mentioning *José Romanillos* (1932–2022). In addition to making beautiful instruments played by outstanding guitarists (Julian Bream, Antigoni Goni, etc.), he had done a great deal of research on the life and creative legacy of Antonio de Torres. In the design of Romanillos' guitars, the work on the problem of the longitudinal coupling in the soundboard is clearly evident.

A special mention should be made for the French luthier *Daniel Friederich* (1932–2020). It might be he who, within the framework of a symmetrical design, managed to achieve an increase in power and a fuller sound of the lower and upper registers. However, he, like *José Ramírez III* (1922–1995) (to whom we will return in the next section), to some extent, neglected the work of the body at low frequencies. Both used rigid duplicated sides, thus increasing the top and back mobility and the role of their interaction with the air.

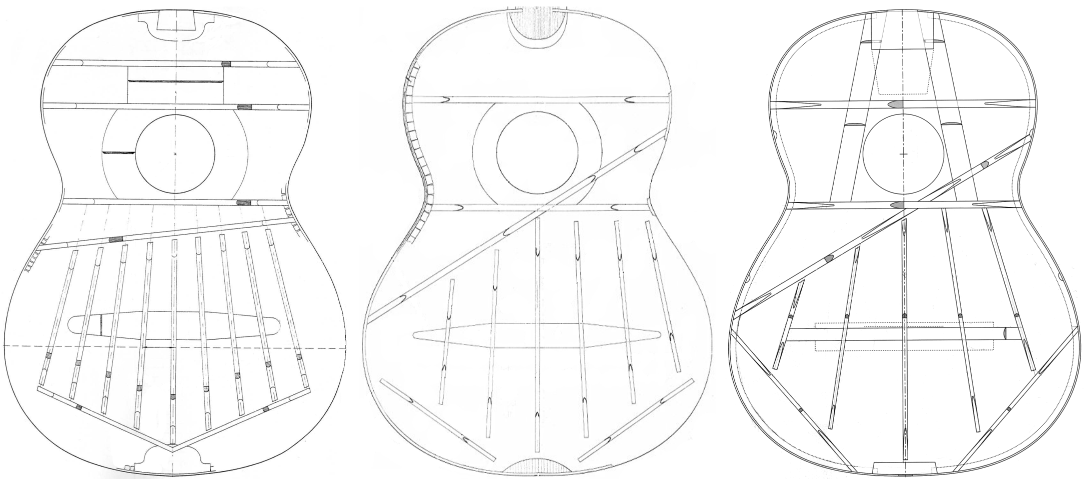
2.3.2 Asymmetrical design

To be fair, it is necessary to say that the diagonal arrangement of the transverse bars in the soundboard could also be found in the guitars of some Italian makers (including Stradivari, of course) since the 17th century. Later this can be found in guitars of the Romantic period and in the Spanish instruments of the first half of the 20th century. For example, the Marcelo Barbero guitar, which belonged to Sabicas, has a tilted bar at the waist[7]. However, this was not of a systematic nature, and likely served mainly the purpose of escaping from the wolf-tones due to displacement of the center of the fundamental mode of the soundboard away from its geometric center. This time, the luthiers of the new era approached the issue more thoroughly and tried to get the most out of asymmetry in different aspects of the sound.

The luthiers who determined the development of the Spanish school of guitar building in the second half of the 20th century are, at first glance, unrelated. *Ignacio Fleta* (1897–1977) was a representative of the Barcelona school, but at the same time, he was a violin maker, which in many ways

[7] The author of the idea was supposedly Santos Hernández.

determined his approach to the guitar. José Ramírez III was the heir and representative of the famous Madrid school, which was founded by his ancestors. *Miguel Rodríguez Serrano* (1921–1998, also known as Rodríguez Jr.) is a representative of the luthier dynasty from Córdoba. They were all united by the idea of making the guitar a concert instrument capable of performing harmonic and polyphonic textures, as well as playing solo. Undoubtedly, Segovia played a decisive role in the work of at least Fleta and Ramírez. As for Rodríguez, he was certainly influenced by the *Romero* family.



(a) I. Fleta [4] (b) J. Ramírez III [5] (c) M. Rodríguez Jr. [6]

Figure 3: Soundboard layout in guitars of asymmetrical design

All of these luthiers, each in his own way, performed the same action. They introduced asymmetry to the design of the soundboard (Fig. 3). Fleta increased the length of the body, put a second inclined transverse bar at the waist, and used a fan of 9 braces. Thus, he increased the volume of air as well as the area of the top and back; provoked smaller divisions of the soundboard; and shifted the center of its fundamental mode, thus reducing its activity. In terms of approach to the functioning of the top and back, the designs of Ramírez and Rodríguez don't differ much. The diagonal bar, passing from the lower bout to the upper one provides the soundboard coupling, and on the other hand, reduces the activity of the fundamental mode and large modes symmetrical relative to the soundboard axis (anti-wolf-tone action). It also favors the fast formation of short waveforms, since a rigid barrier appears in front of the bridge, provoking high-frequency divisions of the soundboard. They differ from each other by the fact that Rodríguez retained the classical approach to the work of the guitar body, in which the sides have significant mobility and actively participate at low frequencies in the vibrations of the body. Ramírez, on the contrary, made a bet on the autonomous work of the top and back synchronized through the neck[8] in active coupling with air.

All three, with good reason, belong to the pantheon of the greatest luthiers in the history of the guitar. They managed to significantly increase the capabilities of the instrument and preserve the character of the Spanish guitar, which so much enchanted the whole world in the 20th century. However, from our point of view, this approach (asymmetry) led to the violation of the timbre balance within the chord vertical to some extent. Yes, the lower register has amplified due to the soundboard coupling, the increase in the role of air, etc. The upper register has become brighter and more powerful. But the balance within the chord has shifted to "edges". In our opinion, at this stage the evolution of the classical guitar as a concert instrument was completed.

2.4 Further steps

Of course, further attempts to change the sound of the guitar have continued. Basically, it was about increasing the power and giving the guitar sound a more piano-like character. Movement in this direction led, unfortunately, to the loss of sound authenticity: the piano did not work out and the guitar was lost. The reason for this was the abandonment of the basic principles of the classical school. Generalizing, let us formulate: we are talking about the approach in which all parts of the instrument are balanced among themselves, have a similar flexibility. Not a single structural element is excluded from vibrations, is not decorative, but, on the contrary, is endowed with the greatest possible functionality. The main advantage of the guitar is a warm, exceptionally volatile sound, possessing countless colors, as well as great dynamic variability. Exactly these qualities fell victim to attempts to further increase its power. However, in our opinion, there is still a small possibility for even fuller realization of the potential of the classical symmetrical design.

3 Some aspects of sound formation

The mobility of the support points of the string as well as their coupling, both among themselves and with other elements of the guitar body, are of decisive importance for the processes of sound formation. The vibrating part of the string is connected to the instrument on the bridge saddle and

[8]The rigid bonding of the neck with the top and back through the fingerboard and heel foot fulfills this function.

the fingerboard fret pressure point (or the nut, in case of an open string). Through these points, the string vibrations are transmitted to the entire structure of the guitar. As they propagate, they reach certain structural elements, excite their vibrations and, finally, radiate into the air: we hear sound. Each harmonic of a sounding string induces vibration of a specific oscillation mode, which combines elements from different parts of the guitar body. The presence of effective mechanical bonds (coupling) between the string and all corresponding structural elements enables them to activate quickly and oscillate in a coordinated manner, as part of a single mode.

The generalized objective of building an instrument can be reduced to:

1. Creation of degrees of freedom in its body to allow the emergence of as many oscillation modes as possible with frequencies evenly distributed in the sound range.

2. Ensuring effective coupling between the structural elements that constitute these modes.

It is worth noting that in a situation where each mode encompasses the elements of the entire structure of the instrument (top and back in their parts, neck, sides), their significant mutual influence on each other is evident. When making changes to any part of the structure, corresponding adjustments must be made to associated parts in a coordinated manner. Otherwise, the shape of the oscillation mode will be disrupted.

To illustrate the correlation between the mode elements, the third harmonic of a stretched string vibration may be considered as an example. Figure 4 depicts three half-waves between fixed supports, separated by two

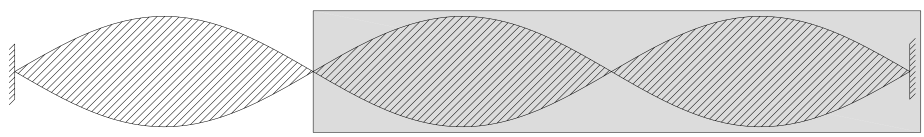


Figure 4: The third harmonic of a vibrating string

nodes. If the elasticity and density in the string are distributed evenly, the lengths and amplitudes of all half-waves will be the same. The immobility of the nodes creates an impression of independent, isolated movement of the parts of the string. If two of the three half-waves are unobserved, we will not be able to distinguish the node from the support, and the oscillation form from the first harmonic. Dampening, for example, the third half-wave will stop the movement of the entire mode. In this case, it will appear to the observer that the oscillation has suddenly ceased without any external influence. This misconception arises from an incorrect assessment of the nodal point's role and, consequently, a flawed understanding of the actual form of the oscillation.

In the case of an uneven distribution of elasticity and/or mass, the three half-waves will no longer be identical. The common frequency of the mode will correspond to different lengths and amplitudes of the half-waves formed, causing the position of the nodes to shift. Variation of the physical properties in one part of the string will change the oscillation form in all its parts.

If we abandon the ideal example and move to the situation with a real instrument, we will find that the "fixed" support points of a vibrating string are not completely still. They connect the string with the complex oscillatory system of the guitar body and allow the energy of vibrations to be transferred both from the string to the body and vice versa. It turns out that every harmonic of the string is coupled with corresponding oscillation form in the guitar body, in fact, combining with it into a single mode.

Additionally, it is important to note that the relatively small mobility of the string's support points allows, in some approximation, to consider its vibrations as damped natural harmonic oscillations with a high quality factor: their damping time is much longer than the characteristic period of the string's vibrations. The energy from plucking is transmitted directly to the string, which is a "generator" that gradually expends the stored energy. The body vibrations, excited and supported by the string, have the nature of forced vibrations, the modes of which are formed "around" the natural modes of the body close in frequency. Natural oscillations of the body have a low quality factor.

4 Justification of the new design

We present the author's original guitar design, built within the framework of the classical Spanish school. The new model continues the tradition of the Manuel Ramírez branch by implementing the development of the symmetrical guitar soundboard design. A number of methods are used to make it possible to achieve an increase in the longitudinal coupling within the top, while simultaneously expanding its divisibility by adding new degrees of freedom for the formation of oscillation modes. By preserving the layout principles of the soundboard elements, its symmetry and flexibility, characteristic of the classical design of the first half of the 20th century, it allows you to expand the potential of the guitar sound without compromising its timbral coloring and controllability. At the same time, we capitalize on the experience of luthiers from a later period as well.

4.1 Soundboard

The position of such important structural elements of a classical guitar soundboard as a sound hole and transverse bars is dictated by the very shape of the instrument. Transverse bars, being an integral part of the soundboard,

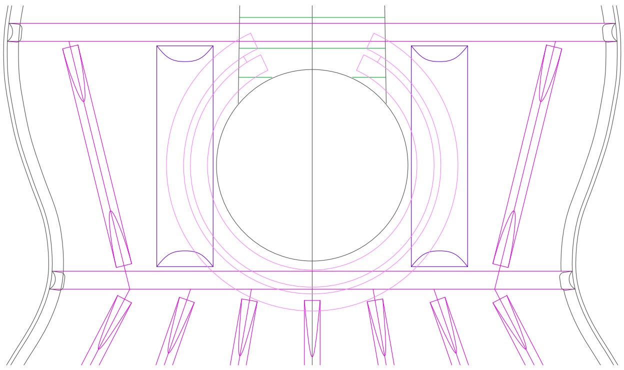


Figure 5: The central area of the Torres' design soundboard

are simultaneously the structural stiffeners of the guitar body that link the vibrations of the body and the soundboard. The sound hole cuts through the fibers of the wood, thus greatly reducing the longitudinal rigidity in the central strip of the soundboard between the fingerboard and the bridge. Such a configuration in a Torres-style design (Fig. 5) creates a rather sharp cutoff from the lower bout. The coupling between the lower and upper bouts of the soundboard, as well as between the waist bar and the soundboard, is provided only by the latter's own longitudinal rigidity. A similar situation is observed in the upper bout. The neck is directly connected to the body through the fingerboard and the transverse bar, while the transmission of vibrations to the lower bout also occurs only due to the rigidity of the soundboard itself on both sides of the sound hole.

Earlier we mentioned some design solutions in which the stiffness elements (braces, bars, plates) unite the soundboard in a longitudinal direction one way or another. Additional links within the soundboard, from the neck through the fingerboard to the bridge and further to the tail block, ensure better coherent vibrations of the instrument parts, and therefore improve the characteristics of the guitar's sound dynamics, controllability, and attack. We set ourselves the task of composing the most successful methods together into a self-consistent and integral system, thereby generalizing the experience of our predecessors. When planning the configuration of the soundboard elements, we set the following goals:

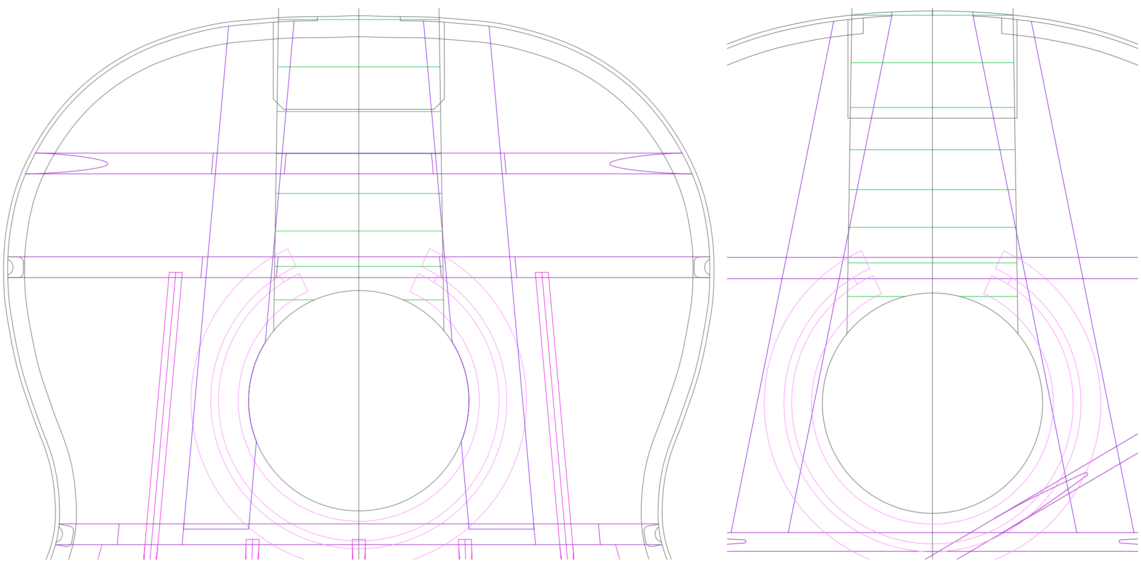
1. Strengthening the longitudinal coupling of the soundboard while maintaining its flexibility and divisibility. Expanding of dynamic capabilities with a characteristic fast attack, controllability and variability of sound.

2. Preservation of the full-fledged sound of the mid-range register (200–1000 Hz), characteristic of symmetrical classical designs.

3. Provocation of large waveforms of the soundboard. Thereby expanding the sound potential of low frequencies (< 200 Hz).

4. Provocation of small divisions of the soundboard and an increase in the density of the high frequency spectrum (> 1000 Hz).

4.1.1 Rosette reinforcement plates, upper bout



(a) in the design of T. Tkach

(b) M. Rodríguez Jr.

Figure 6: Rosette reinforcement plates

The idea of moving the plates that are reinforcing the top under the rosette outside the area between the transverse bars was developed by many luthiers. **Miguel Rodríguez Jr**. applied a very elegant idea in the design[9]

[9]In his both symmetrical and famous slanted bar design.

of his guitars, which allowed him to achieve several goals at once. As can be seen in Figure 6(b), the plates are positioned at an angle to the axis and fibers of the soundboard, pass through the grooves in the upper transverse and diagonal bars and, partially entering under the fingerboard, are glued into the heel block socket. Thus, in addition to its basic function of strengthening the area around the sound hole, the plates link the neck to the central part of the soundboard, and also prevent the soundboard from possible cracks provoked by the edges of the fingerboard and heel block.

We adopted and expanded upon this idea. The plates are turned at a smaller angle. Figure 6(a) shows the inserts of the plates into the waist bar mortises, as well as the arches in the two transverse bars of the upper bout, through which they are passed to the heel block (see also photos in appendix A, p. 22). Thus, we increase the mobility in the central strip of the soundboard, while simultaneously coupling the oscillations of the neck (through the fingerboard) and the upper bout itself with the waist bar.

4.1.2 Fan bracing and transverse bars configuration

The presence of a fan bracing system in the lower bout of the guitar top has become a fundamental characteristic feature of classical school instruments. At the same time, the fan configuration varied significantly, depending on the tasks being performed. A non exhaustive list of optimized parameters includes: the number of braces; the shape of their cross-section profile; the angle of divergence; the orientation of the cut; the ratio of width and height; the ratio of the height of the brace and the thickness of the top; the margins from the perimeter of the lower bout; the layout relative to the bridge; the shape and length of the end bevels.

The same applies to transverse bars. Their position; shape and proportions of the cross section; the cut; and the presence and shape of bevels and arches are determined by the range of tasks to be performed.

Summarizing some previous experiences, we relied on the following ideas:

- **Antonio de Torres** in 1864 FE 19 "La Suprema" guitar used wide arches in the waist bar (Fig. 2(a) on p. 8) to let the 4 extreme fan braces into the central part of the soundboard. This made it possible to enhance the coupling between the vibrations of the body and the soundboard, as well as to unite the waist bar with the lower bout in the low-frequency range (impact on the general dynamics and spectrum density at low frequencies), while maintaining its dividing function in the rest of the sound range.

- **Santos Hernández** experimented extensively with the fan configuration. In the 1930 guitar, the braces are turned almost parallel (Fig. 7). At the same time, a wide under-rosette plate is glued beneath the waist bar groove and brought out into the area of the lower bout. These actions, aimed at increasing the longitudinal rigidity in the lower bout and enhancing its linkage with the waist bar (affecting attack, dynamics, density of the low-frequency spectrum), as well as provoking transverse divisibility and mobility of the small oscillation modes (raising the density of the high-frequency spectrum), certainly found their reflection in the sound.

Figure 7: S. Hernández 1930 guitar soundboard design elements [7]

- In his famous book José Ramírez III [8] presented some interesting photos taken in the workshop of his father and mentor, **José Ramírez II** (1885–1957). One may see a soundboard of a symmetrical design with 9 fan braces diverging at a relatively small angle (Fig. 8). All their ends are glued into a clearly distinguishable groove under the waist bar, in which, apparently, a rabbet is cut. We see another original approach to achieving the same goal, which, as far as we know, for some reason was not in demand by followers.

Figure 9 shows a plan of Timofey Tkach's guitar design. We are implementing the idea of a counter linkage in the central part of the soundboard. Both fan braces from the lower bout as well as the plates from the neck block are brought there. Thus, without violating the symmetry and characteristic flexibility, we achieve an effective, block-to-block system of internal links, distributed over the entire soundboard area. The ends of the five central fan braces are glued into the transverse bars mortises: the two extreme are in the

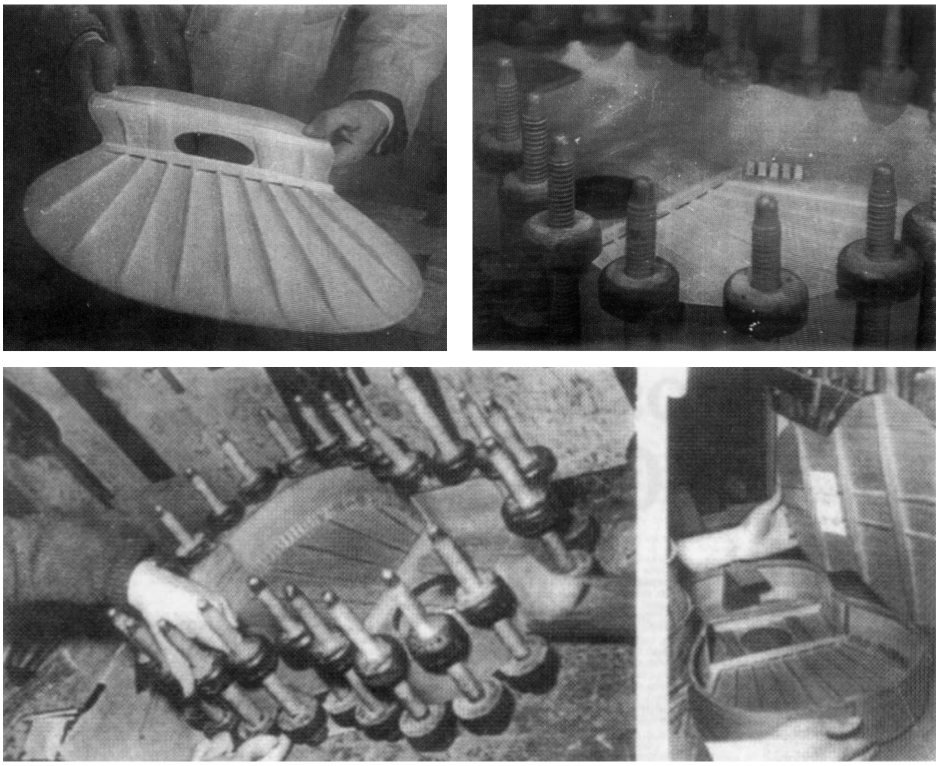


Figure 8: Interior elements of the guitar by J. Ramírez II

upper bar, while the remaining three are in the waist. The through passage under the transverse bars is implemented using arches. In the wide middle part of the waist bar, the arches create an additional degree of freedom, extending large forms of low-frequency vibrations beyond the lower bout.

In the bridge-wide central strip of the soundboard, the fan braces are turned at a slight angle. The smoothing of the transverse rigidity distribution and transverse coupling in the lower bout are achieved through the bridge; the use of an under-bridge plate; diagonal braces at the bottom; as well as through the waist bar supporting the fan. In this design, we do not use bevels at the ends of the transverse bars and join it to the sides through special props. The increased rigidity of these joints makes it possible to achieve greater consistency between the soundboard and body vibrations. We use separate cedar peons and traditional binding to join the top and the sides.

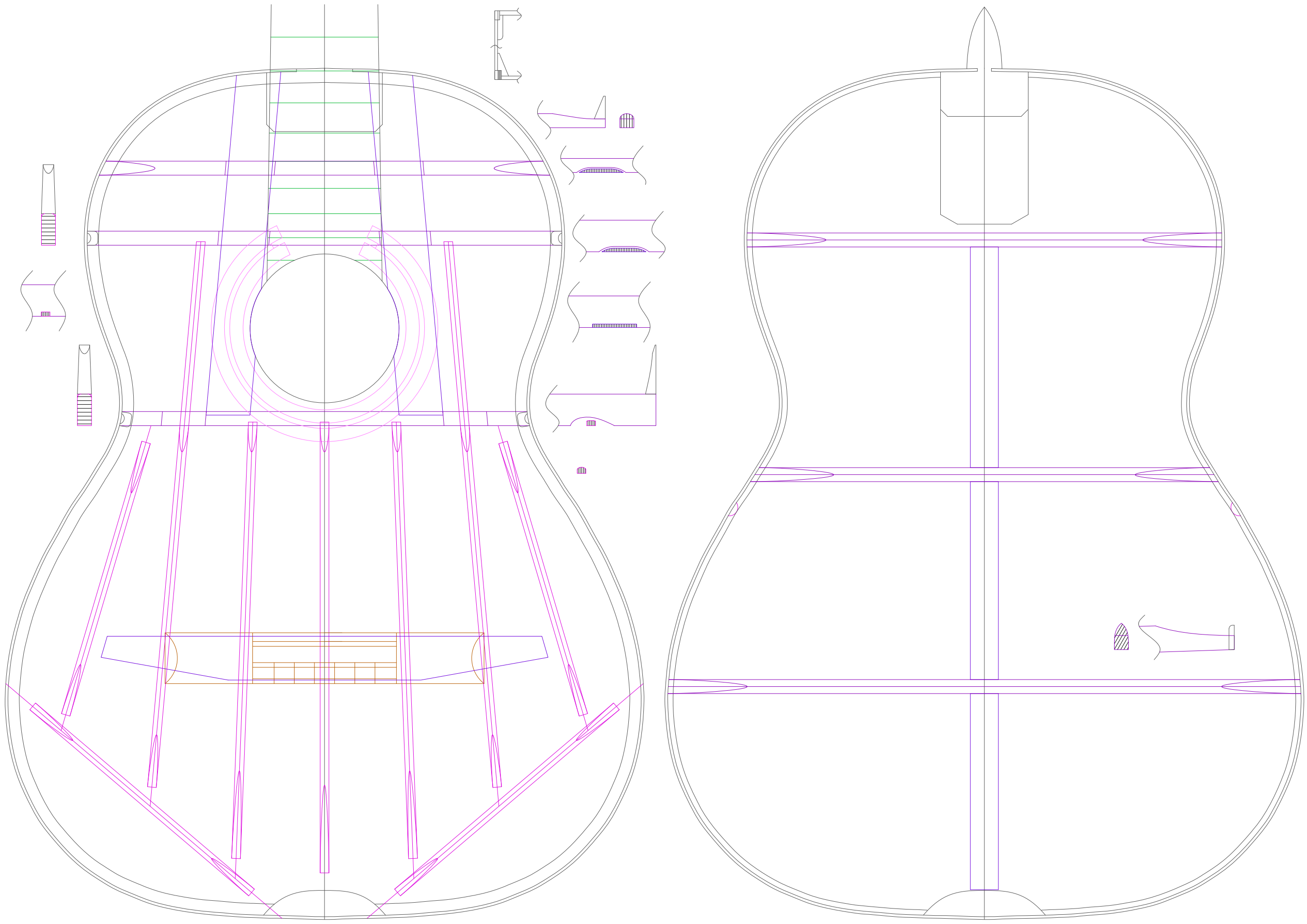


Figure 9: Plan of a T. Tkach's design top and back

4.2 Other structural elements

The changes in the design of the top described above do not go beyond the principles of the first half of the 20th century classical school. Accordingly, we follow the same principles in the planning and tuning of the back, sides and neck. It is worth mentioning that in the design of the back we use cedar bars with fairly long, moderately deep bevels at the ends, which are glued into mortises in the rigid continuous beech linings. Thus, we achieve a balance of longitudinal (through the middle block-to-block strip of the back) and transverse (side-bar) coupling between the body and back.

5 Conclusion

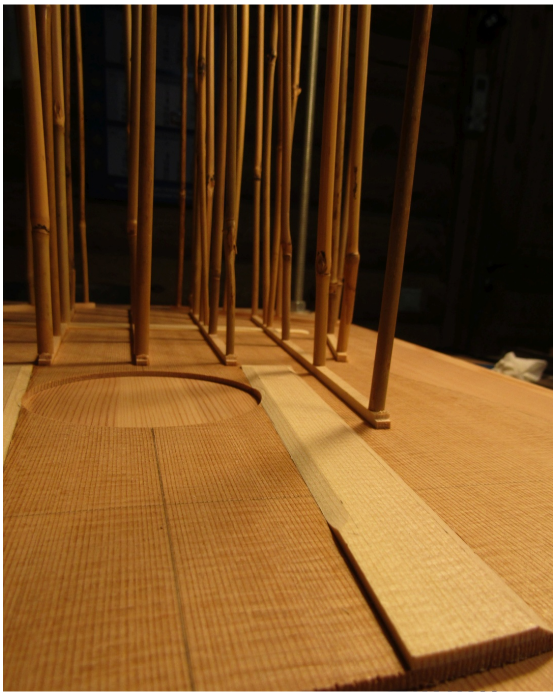
The analysis of the guitar building school's history of development enables us to draw a conclusion about the completeness of the classical design evolution. In our opinion, in the second half of the twentieth century, the possibilities for its fundamental revision within the framework of the classical school approach were fully utilized. However, this does not mean that the creative interpretation of classical designs and further work on them should cease or be deemed futile. Flexibility and variety of solutions to achieve a particular view of the perfect sound balance, the inevitability of a permanent quest for the optimal compromise in solving the tasks characteristic of instrument designing leave ample room for energy application and embodiment of the author's individuality. The task of formalizing the school, and creating a textual foundation for the preservation and transfer of knowledge remains vital and relevant.

The new symmetrical design of the soundboard aforementioned in this paper realizes the classical approach to building an instrument. It represents a variation of the classical design that aligns with the demands of modern guitar performance. Continuous application has demonstrated that the new design, created by Timofey Tkach and implemented by us in several modifications[10], has formed an integral, balanced, and efficient system. Therefore, for the purpose of expanding the dynamic and timbral potential of the classical guitar in the low- and high-frequency sound registers, previously addressed and achieved within the scope of asymmetrical designs, we propose a solution that maintains symmetry and does not compromise the timbre density of the middle register. The new design proved to be particularly effective for guitars with a cutaway and seven-string guitars[11].

[10]Timofey Tkach since 2018, Vladimir Druzhinin since 2022 have built 6-string instruments, modifications with a 7th bass string, and a cutaway model. Materials used: spruce, cedar for the top; Indian and Madagascar rosewood for back and sides.

[11]The cutaway in a classical design creates significant problems: the violation of symmetry and unbalanced increase of rigidity in the upper bout of the top and back inevitably leads to certain loss in sound. Longitudinal coupling of the soundboard and measures to balance the flexibility of the body allows to almost completely neutralize this negative impact. Efficiency of the new design in the low-frequencies range enables a full, controlled bass sound in an extended range with the tuning of the seventh string as low as the A of contra-octave (55 Hz).

A Photo gallery, T. Tkach design





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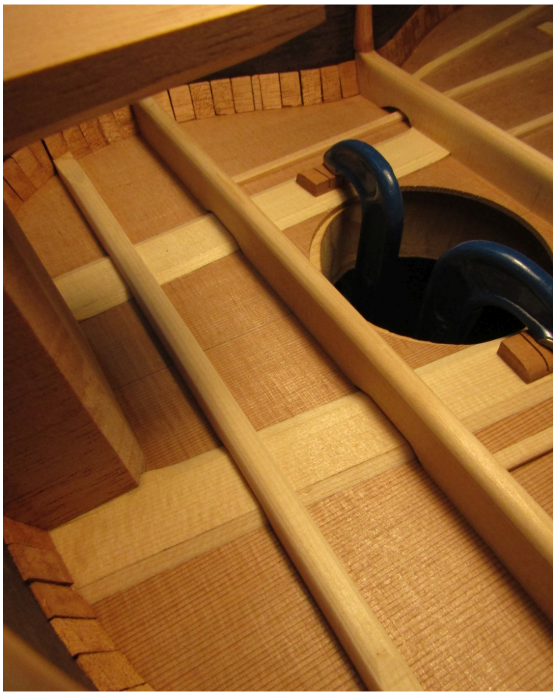

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