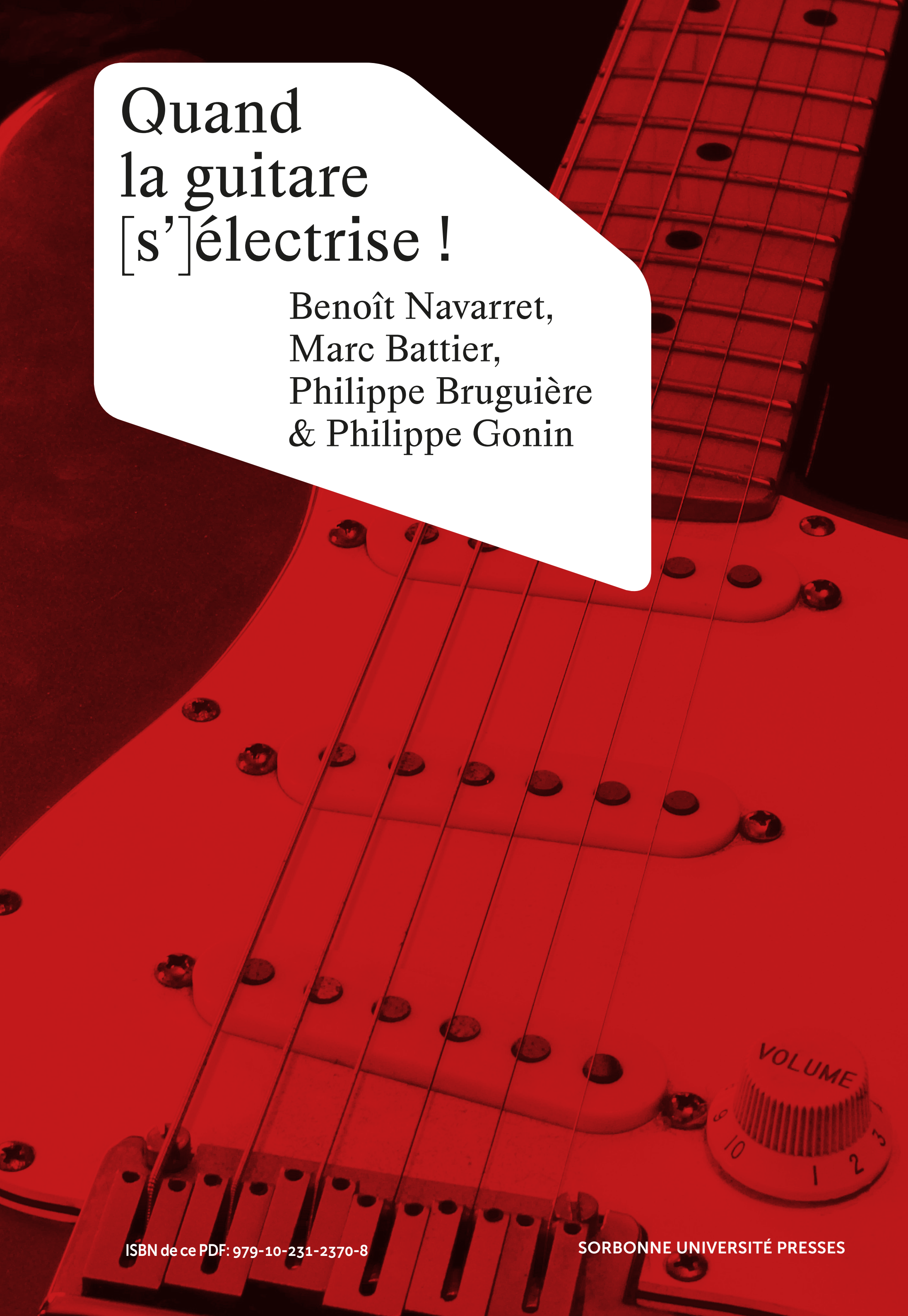
Quand la guitare [s’]électrise !

Benoît Navarret,
Marc Battier,
Philippe Bruguière
& Philippe Gonin



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MusiqueS

La guitare électrique serait-elle l'instrument emblématique du XX[e] siècle ? Son histoire a marqué plusieurs générations de musiciens et d'auditeurs : sa sonorité et sa puissance (qu'elle doit aussi à ses composants externes : pédales d'effets, amplificateurs et haut-parleurs), sa versatilité, son impact visuel et toutes les significations qui lui ont été associées en font un objet incontournable, une véritable icône planétaire.

Et pourtant l'étude scientifique de son histoire, de son répertoire ou de sa technologie n'a fait que commencer, tout en allant en s'amplifiant. Peu connue, la recherche menée autour de cet instrument mérite qu'on s'y attarde, tant les approches possibles sont riches et variées : car l'instrument ne peut s'étudier en-dehors de son contexte, ni sans raconter l'histoire de ces pionniers qui se mirent à bricoler des formes hybrides d'instruments, puisant dans l'organologie classique en la mêlant aux techniques de la radio, du microphone et de tout ce que « la fée électricité » a pu apporter en matière d'innovation sonore. L'on ne peut aussi ignorer la construction symbolique de ces figures mythiques, les *guitar heroes*, qui font rêver les foules et alimentent les fantasmes de nombreux amateurs. Sans oublier la multiplicité de ses usages, du club intimiste aux gigantesques stades ou festivals, de son expérimentation dans la musique contemporaine au refus délibéré de la virtuosité dans des genres plus nihilistes, et même dans certaines pratiques religieuses !

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QUAND LA GUITARE [S']ÉLECTRISE !

À la mémoire d'André Duchossoir (1949-2020)

MusiqueS

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*

Le Collegium Musicæ – institut de Sorbonne Université – regroupe des organismes de recherche et de formation spécialisés dans le domaine musical. Il favorise, depuis sa création en 2015, les travaux menés en interdisciplinarité entre sciences exactes, sciences humaines et pratiques musicales. La collection « Instrumentarium », consacrée aux instruments et familles d'instruments, est la première des séries de publications issues des travaux scientifiques du Collegium Musicæ. Suscitant le croisement des regards entre acousticiens, musicologues, musiciens et luthiers, ces travaux permettent la confrontation inédite de données et analyses acoustiques, organologiques et techniques, historiques et culturelles, ainsi que celles relevant de la création et de l'innovation.

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Benoît Navarret, Marc Battier,
Philippe Bruguière & Philippe Gonin (dir.)

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SUP
Maison de la Recherche
Sorbonne Université
28, rue Serpente
75006 Paris
tél. : (33) (0)1 53 10 57 60

sup@sorbonne-universite.fr

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CHAPITRE 4

AN ACOUSTICIAN'S APPROACH OF THE SOLID BODY ELECTRIC GUITAR

*

APPROCHE DE LA GUITARE ÉLECTRIQUE *SOLID BODY* PAR L'ACOUSTIQUE

Arthur Paté
IEMN (UMR 8520 CNRS), département ISEN
Jean-Loïc Le Carrou & Benoît Fabre
Sorbonne Université, CNRS,
Équipe LAM (Lutheries, Acoustique, Musique),
Institut Jean-le-Rond-d'Alembert

ABSTRACT

The perceived sound of a solid body electric guitar mainly results from the electroacoustic system that radiates the signal of vibrating strings. Most of the previous works in acoustics and audio signal processing focused on amplifiers, effect pedals, pickups, etc. However, sound originates from the vibration of strings indeed. This presentation demonstrates that the sound of the electric guitar is determined by its mechanical manufacturing quality, even if it is electroacoustic. By mechanical coupling, the vibration properties of the structure determined by elements of stringed instrument manufacture (wood, geometry, etc.) influence the vibration of strings and, consequently, the resulting sound. An initial body of guitars (relevant regarding organological, economical and musicological viewpoints) was studied by mechanical (vibration analysis) and perceptive approaches (linguistic analysis of conversations during playing situations). This body contains one stringed instrument manufacture element that was intentionally made variant. Results enable to explain certain sonic differences and show that musicians are capable of identifying the variation in this manufacture element. By observing that guitars purposely made identical can present differing characteristics, it is possible to focus on the manufacturing process itself. Thus, two additional bodies were used to study the vibration behavior during construction and the inter-instrument variability at the last stage of industrial production, which indicates the know-how of stringed instrument makers, in order to minimize variability and the importance of the choice of material. Finally, we will discuss how the electric guitar's manufacture elements can contribute to the sound of the instrument: musicians are sensitive to the latter, and some vibration descriptors become aware of it.

BIOGRAPHY

Arthur Paté is a Ph.D. in acoustics. His research aims to bring mechanical and perceptive description of sonic phenomena together. His doctoral thesis entitled "- Lutherie de la guitare électrique "solid body" : aspects mécaniques et perceptifs", which is the key source of this paper, was written

at Acoustique-Musique / Institut Jean le Rond d'Alembert between 2011-2014 and defended at Université Pierre et Marie Curie (now Sorbonne Université) in 2014. He also worked on the perception of sonified seismic signals and airplane noises, as well as the voicing of harpsichord plectra. He is now an associate professor at ISEN in Lille, France.

Contact : arthur.pate@isen.fr

RÉSUMÉ

Le son perçu d'une guitare électrique *solid body* provient principalement du système électroacoustique rayonnant le signal de vibration des cordes. L'essentiel des travaux antérieurs en acoustique et traitement du signal audio s'est ainsi focalisé sur les amplificateurs, pédales d'effet, *pickups*, etc. Cependant, la vibration des cordes reste bel et bien à l'origine du son. L'article s'attache à démontrer que le son de la guitare électrique est conditionné par la qualité de la fabrication mécanique de l'instrument, même si celui-ci est dit électroacoustique. Par couplage mécanique, les propriétés vibratoires de la structure, déterminées par les éléments de lutherie (bois, géométrie, etc.), influencent la vibration des cordes, donc le son résultant. Un premier corpus de guitares (pertinentes des points de vue à la fois organologique, économique et musicologique), dont un seul élément de lutherie a été volontairement rendu variant, a été étudié via des approches mécanique (analyse vibratoire) et perceptive (analyse linguistique des entretiens en situation de jeu). Les onze résultats permettent d'expliquer certaines différences sonores et montrent que les musiciens sont capables d'identifier la variation d'un élément de lutherie. Constatant que des guitares voulues identiques peuvent présenter des caractéristiques contrastées, on peut s'intéresser au processus de fabrication lui-même. Ainsi deux autres corpus ont été utilisés pour étudier l'évolution du comportement vibratoire au cours de la construction et analyser la variabilité inter-instrument en fin de chaîne de production industrielle, montrant le savoir-faire des luthiers pour minimiser la variabilité et l'importance du choix des matériaux. En conclusion, nous montrons que les éléments de lutherie de la guitare électrique peuvent participer au son

de l'instrument : les musiciens y sont sensibles et certains descripteurs vibratoires en rendent compte.

BIOGRAPHIE

Arthur Paté est docteur en acoustique. Ses recherches tentent de mettre en accord la description mécanique et la description perceptive des phénomènes sonores. Sa thèse intitulée *Lutherie de la guitare électrique* solid body *: aspects mécaniques et perceptifs*, principale source de cette intervention, a été préparée au sein de l'équipe LAM (Lutheries, Acoustique, Musique) de l'Institut Jean-le-Rond-d'Alembert et soutenue en 2014 à l'université Pierre-et-Marie-Curie (actuellement Sorbonne Université). Il a également travaillé sur la perception des signaux sismiques sonifiés, la perception des bruits d'avion et l'harmonisation des becs de clavecin. Il est actuellement enseignant-chercheur à l'ISEN Lille.

Contact : arthur.pate@isen.fr

The sound of a solid body electric guitar is often considered to be the result of a complex electro-acoustic chain starting from the output of the pickup, going through effects pedals, pre-amplifier, amplifier(s), and ending with the loudspeaker(s). Previous scientific research has mainly focused on all these elements: see (Horton et Moore, 2009 ; Lotton, Lihoreau et Brasseur, 2014) for the pickups, (Holters et Zölzer, 2011) for the effects, or (Karjalainen et Pakarinen, 2006 ; Macak et Schimmel, 2010) for the amplifiers. The studies of the mechanical vibrations of the instrument have remained very rare (Fleischer et Zwicker, 1998 ; Fleischer et Zwicker, 1999). The mechanical vibrations of the strings are however the actual source of the sound, as the pickup does nothing more than (in a rich, complex and non-linear way, though) transduce these vibrations into electrical oscillations feeding the electro-acoustic chain.

Details of the different elements presented in this short paper can be found in a Ph.D. thesis recently defended (Paté, 2014). The aim is to show how the sound quality of a solid body electric guitar depends on the craft quality (material selection, assembly of parts). Indeed, mechanical coupling with the guitar as a vibrating composite structure made of many parts alters the vibration of the strings, hence the resulting sound.

This article starts with setting a theoretical model describing the string – structure coupling. Using this framework, mechanical measurements are undertaken to characterize two versions of a specific lutherie parameter: the fingerboard wood. In parallel, a perceptual study investigates how these two versions of the lutherie parameter are perceived. The study is then extended to the evolution of the instrument's vibratory behavior during the making process, and at the end of an industrial production chain.

MECHANICAL MODEL OF STRING-STRUCTURE COUPLING

The string vibration – and hence, again, the baseline signal for the pickup output – can be described in terms of "modal frequencies" and "modal dampings". Modal frequencies can be seen as "harmonics", or "partials". The modal dampings describe how each harmonic decays in time: the higher the damping, the faster the decay and the shorter the resonance.

Calculus and measurements (Paté, Le Carrou et Fabre, 2014) show that the electric guitar can be seen, from the mechanical point of view, as a string connected at one end (at the bridge) to an immobile body[1], and at the other end (at the nut, or at a fret) to a vibrating body. Using the following characteristics of the string *c*: the celerity of transverse waves in the string and *Zc* the string's impedance (both depending on the string's material and tension), and L its length, and the quantity *Y (f)* being the "mobility" of the neck at the string-neck connection point, describing how likely the neck is to move when the string provides it with vibratory force (the higher the mobility, the higher vibration level for a given input force from the string), and defined for any frequency *f* as:

$$Y(f) = \frac{V(f)}{F(f)}$$

where *V* is the velocity of the structure under applied force *F*.
One can show that the string's modal frequencies *fn* and dampings *Σn* in the coupled case (coupling with a structure described by the quantity *Y*) are perturbations of the uncoupled (*i.e.* connected to rigid, immobile bodies at its both ends) string's frequencies *fn,o* and dampings *Σn,o* (Paté, Le Carrou et Fabre, 2014):

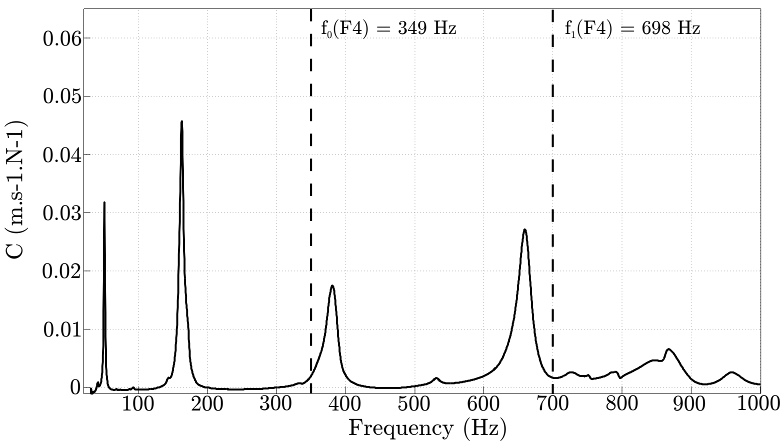
$$f_n = f_{n,0} + \frac{cZ_c}{L\pi} Im\left(Y(f_n)\right)$$

$$\xi_n = \xi_{n,0} + \frac{cZ_c}{L\pi} Re\left(Y(f_n)\right) = \xi_{n,0} + \frac{cZ_c}{L\pi} C(f_n)$$

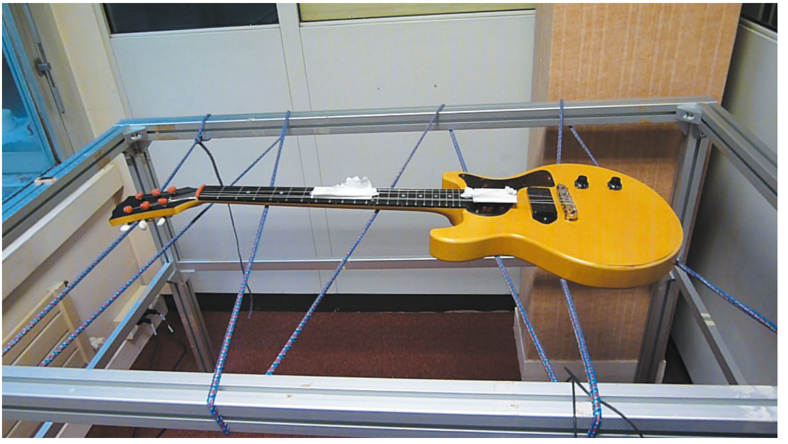
Note that *Y(f)* derives from Fourier spectra, and is therefore complex-valued. Re(.) and Im(.) represent the real and imaginary parts respectively.

1 As it concerns mechanical coupling between structure and string, the electric guitar has an opposite behavior to the acoustic guitar. As the thick and solid body of the electric guitar vibrates much less than the neck (this is indeed its original purpose), one can consider to a first approximation that only the neck moves under solicitation (or energy supply) from the string, not the body.

The two equations above just show that the characteristics of the coupled string can be derived by the knowledge of the uncoupled string's parameters and of the vibratory behavior of the structure at the coupling point. One can show that the coupling does not alter much the string's frequencies, so we will not discuss them further in the following of the paper. On the contrary, the dampings are very dependent on changes in the real part of *Y*, which is called the "conductance" and will be denoted *C*. As *C* can be seen as a summary of the structure's vibratory behavior, each lutherie parameter (wood species, shapes, assembly method, *etc.*) can potentially change *C*, hence potentially the sound. Indeed a high value of *C* at the frequency of a string partial can dramatically increase the damping of this partial while not altering the other partials: this results in a change of sound. **Figure 1** shows an example of a conductance measurement, as a function of frequency: if a string partial has a frequency corresponding to a peak in *C*, it will be highly absorbed by the structure coupling, and it will last much shorter.



1. Example of a conductance measurement, measured at fret 6 along the 2nd string on a copy of *Gibson Les Paul Junior.* Dashed lines indicate the frequency of fundamental and first partial of the corresponding note © Arthur Paté



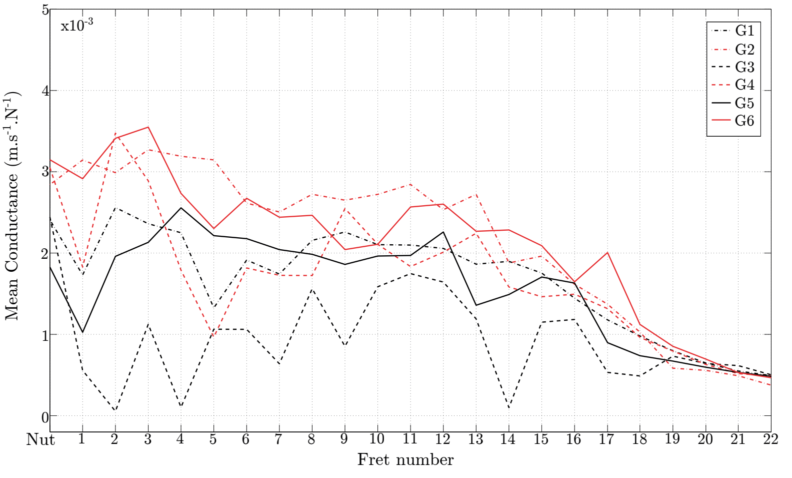
2. A guitar in free boundary conditions. Vibrations of the strings and pegs are avoided using paper and modeling clay in order to measure the vibration of the structure only © Arthur Paté

A LUTHERIE PARAMETER: THE FINGERBOARD WOOD

This section gives an example of a lutherie parameter that changes the mechanical mobility Y (or the mechanical conductance C) of the neck, and known by the guitar players to play a leading role in the sound of the instrument: the fingerboard wood.

We have had the great privilege to establish an enduring partnership with the professors and students in the guitar-making department of ITEMM[2]. Through this collaboration, we were able to have access to a set of guitars that were made at the same time, with woods from the same trees, with identical specifications, and crafted with the same tools and machines. These guitars are copies of *Les Paul Junior* model by *Gibson*: three of them have an ebony fingerboard (G1, G3, G5), three others have a rosewood fingerboard (G2, G4, G6).

2 ITEMM stands for Institut technologique européen des Métiers de la Musique (European Technological Institution For The Music Professions) and is located at Le Mans, France.



3. Mean conductance, for each fret (i.e. for each measurement) and each guitar. Black lines denote ebony-fingerboard guitars, red lines denote rosewood-fingerboard guitars © Arthur Paté

A VIBRATORY DESCRIPTION

The mobility, as a velocity/force ratio, can be measured by classical means of experimental mechanics. The velocity is measured with an accelerometer located at the string-neck connection point, and the force is provided by an impact hammer, while the guitar is hung on straps supported by a frame in order to ensure free boundary conditions[3] (see **fig. 2**).

We measured the mobility at each string-fret crossing point, at the nut and at the bridge, on each of the six guitars. As the conductance C (real part of the mobility) is frequency-dependent, we can compute the mean of C over the frequency range, for each measurement. **Figure 3** shows the mean conductance along the neck, for each of the six guitars.

3 "Free boundary conditions" means that nothing constrains (free) the displacement and velocity of the outer parts of the structure (boundary). This is as though the guitar was floating in the air, like isolated from the outside world. This (over-) idealization of the instrument's actual behavior is used because it makes analysis and reproducibility of measurements easier.

As it can be seen in **figure 3**, ebony-fingerboard guitars (black lines) tend to have a lower mean conductance than rosewood-fingerboard guitars (red lines). If we get back to equation 3, we find that high values of C at the frequency of a given partial will decrease the decay time of this partial. Now taking the mean value of the conductance is like giving an estimate of how the conductance will alter *all* partials: a high mean conductance means that the string partials will be more perturbed by the coupling with the structure, in average. In our case, a rosewood fingerboard will probably couple more with the strings, *i.e.* take more energy from them, and as a result the decay times of the string partials will be more altered. More irregular spectrum shapes are expected with tones produced by rosewood-fingerboard guitars. Note that there is absolutely no value judgement here, we just tentatively state that a rosewood fingerboard might "add more color" to the sound of the string.

A PERCEPTUAL DESCRIPTION

We designed and conducted a perceptual test (Paté, Le Carrou, Navarret, Dubois et Fabre, 2015) in order to estimate how guitar players are able to perceive a difference between two different fingerboard wood species. We conducted a free verbalization task with ten professional electric guitar players. Each musician was given the guitars and asked to freely play them (no time limit, no suggested ordering of the guitars, amplifier and effect pedal available but not mandatory). The guitars were not labelled and the light was softened to mask the color differences between the fingerboards. As a single instruction, the player had to talk about her/his perception and feelings, engaging in an interview with the experimenters. A psycholinguistic analysis was conducted on the transcriptions of the interviews.

Results showed that guitar players were able to hear and feel differences between the two wood species, even if they did not explicitely attribute the differences to a change of fingerboard wood. Ebony-fingerboard guitars were described as having and providing to the tones "more clarity" (the notes don't blend together when playing complex chords, or when playing with distortion), "more balanced" (balance between the frequencies), and having "more attack".

A tentative link with the mechanical measurements can be done. Low mean conductances (ebony fingerboards) tend to leave the string vibration unperturbed, *i.e.* tend to preserve the homogeneity of the notes' spectra. Higher mean conductances (rosewood fingerboards) tend to alter the notes' spectra (hence to produce differences in the "balance") and to produce spectrum irregularities (chords made of notes with different spectral shapes might be more difficult to understand, hence with less "clarity").

One of the striking results of this section is the following one: even if guitars were designed to be the same (three ebony or three rosewood models), they still exhibit differences. In order to know where these differences come from, one can shift the angle of study from the guitars to their making process.

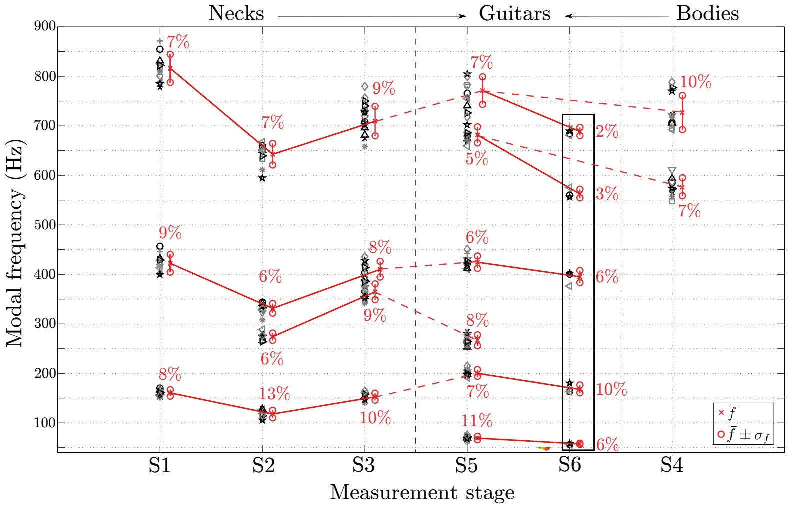
THE MAKING PROCESS

EVOLUTION DURING THE MAKING PROCESS

We studied another set of guitars made at ITEMM, which consisted in eleven guitars, still following the specifications of the *Gibson Les Paul Junior* model and made of the same materials and crafted with the same tools (Paté, Le Carrou, Teissier et Fabre, 2015). Mobility measurements have been done at six steps of the making process:

S1 – raw necks;
S2 – shaped necks;
S3 – necks fitted with fingerboard and frets;
S4 – bodies;
S5 – bodies and necks assembled;
S6 – guitars fully equipped.

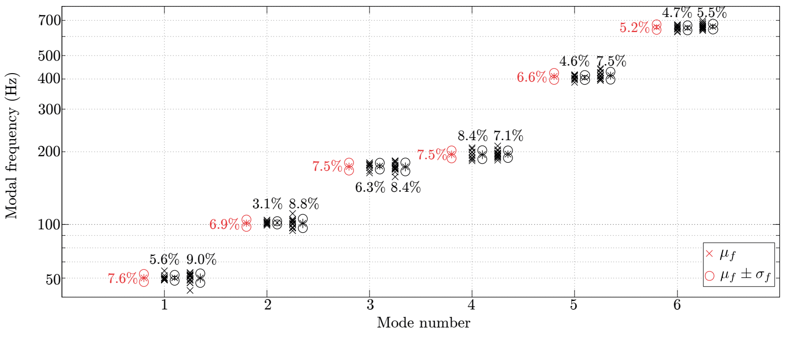
For each measurement, the peaks (see **fig. 1**, p. 105) in the conductance curves (*i.e.* the frequencies at which a high string-structure coupling occurs, which are also the "modal frequencies" of the guitars, corresponding to the "normal modes" of the guitars) are picked and averaged over modes and guitars. The results are shown in **figure 4.**



4. Evolution of the guitar's modal frequencies during the making process. Red crosses (resp. circles) indicate the mean (resp. mean plus or minus one standard deviation) of 11 guitars. Various gray and black markers indicate the individual guitars © Arthur Paté

The successive steps of the making process exhibit different inter-guitar variability (the height of each vertical red line bounded by red circles in figure 4). With respect to S1 (resp. S5), S2 (resp. S6) reduces the variability. At S1, the neck is not shaped by the luthiers: the variability in frequencies is explained by the (well-known) wood's intrinsic variability. At S2, the luthiers shape the necks in order to give an homogeneous set of necks, resulting in a decrease in the variability in frequencies. Similarly, S6 is the final adjustment stage, where the luthiers can work on homogenizing the guitars.

The inter-guitar variability can therefore be explained by two factors: the guitar makers' gesture and the wood intrinsic variability. Simple physical reasoning explains the tendencies of the modal frequencies between measurement stages. Modal frequency decreases can be due to changes in shape (*e.g.* carving the necks between S1 and S2) or addition of matter/mass (*e.g.* from S5 to S6). Modal frequency increases can be due to the stiffening of the structure (*e.g.* lacing the fingerboard at stage S4).



5. Identified modal frequencies on the set of similar industrial guitars: mean (crosses) and mean +/- 1 standard deviation (circles). For each mode, red color denotes the whole set of guitars, black and left is for the subset with rosewood fingerboard, black and right is for the subset with maple fingerboard © Arthur Paté

END-OF-CHAIN VARIABILITY

Previous sections reported studies made on handcrafted guitars. The electric guitar, however, has mainly been an industrial, mass-produced instrument. Thousands and thousands of guitars are produced each year by the industry. Many guitars are sold as being replicas of the same model, but the variability in materials and machine tolerances can make "identical" guitars turn quite different.

A measurement campaign took place at the end of the production chain of a big North-American guitar manufacturer: a mobility measurement was done on sets of similar guitars (Paté, Le Carrou et Fabre, 2015). The variability in modal frequencies was assessed. Figure 5 shows, for the first six modes, the mean and variation around the mean of modal frequencies (peaks in the conductance measurements).

As can be seen in **figure 5**, the variability in modal frequencies (*i.e.* in the position of the conductance peaks likely to alter the string vibration signal) in industrial making and in a handcrafted process are of the same order of magnitude. Furthermore, each of the two subsets (identical guitars, only difference is the fingerboard wood: rosewood or maple) exhibit such a modal frequency variability that they do not stand out from one another.

GENERAL CONCLUSION

This Ph. D. thesis (Paté, 2014), as summarized in this paper, has shown that the choices of the guitar maker (wood selection, adjustment, precise crafting gesture) and therefore the electric guitar as a mechanical body, play a role in the instrument's sound, even if it is often considered to be an electro-acoustic instrument whose sound is controlled by the electric processing chain (only). Mechanical and perceptual measurements can lead to a characterization of the lutherie parameters: guitars with similar specifications share similarities. But "identical" guitars also differ in some ways, making each instrument unique!

REFERENCES

FLEISCHER, Helmut & Zwicker, Tilmann, "Mechnical vibrations of Electric Guitars", *Acta Acustica united with Acustica*, vol. 84, 1998, p. 758-765.

—, "Investigating Dead Spots of Electric Guitars", *Acta Acustica United With Acustica*, vol. 85, 1999, p. 128-135.

HOLTERS, Martin & ZÖLZER, Udo, "Physical modeling of a wah-wah effect pedal as a case study for application of the nodal DK method to circuits with variable parts", *Digital Audio effects* (DAFx11), 2011, p. 31-36.

HORTON, Nicholas G. & MOORE, Thomas R., "Modeling the magnetic pickup of an electric guitar", *American Journal of Physics*, vol. 77, n° 2, 2009, p. 144-150.

KARJALAINEN, M. & PAKARINEN, J., "Wave Digital Simulation of a Vacuum-Tube Amplifier", International Conference on Acoustics, Speech, and Signal Processing (ICASSP), 2006, p. 59-62.

LOTTON, Pierrick, LIHOREAU, Bertrand & BRASSEUR, Emmanuel, "Experimental Study of a Guitar Pickup", International Symposium on Musical Acoustics, Le Mans, France, 2014.

MACAK, Jaromir & SCHIMMEL, Jiri, "Real-Time Guitar Tube Amplifier Simulation Using an Approximation of Differential Equations", Digital Audio effects (DAFx10), 2010, p. 1-8.

PATÉ, Arthur, *Lutherie de la guitare électrique* solid body *: aspects mécaniques et perceptifs*, thèse de doctorat de l'université Pierre-et-Marie-Curie, Paris, 2014.

—, Le Carrou, Jean-Loïc & Fabre, Benoît, “Predicting the decay time of solid body electric guitar tones”, *Journal of the Acoustical Society of America*, vol. 135, nº 5, 2014, p. 3045-3055.

—, Le Carrou, Jean-Loïc, Navarret, Benoît, Dubois, Danièle & Fabre, Benoît, “Influence of the Electric Guitar’s Fingerboard Wood on Guitarists’ Perception”, *Acta Acustica United With Acustica*, vol. 101, nº 2, 2015, p. 347-359.

—, Le Carrou, Jean-Loïc, Teissier, Franck & Fabre, Benoît, “Evolution of the Modal Behaviour of Nominally Identical Electric Guitars During the Making Process”, *Acta Acustica United With Acustica*, vol. 101, nº 3, 2015, p. 567-580.

—, Le Carrou, Jean-Loïc & Fabre, Benoît, “Modal Parameter Variability in Industrial Electric Guitar Making: Manufacturing Process, Wood Variability, and Lutherie Decisions”, *Applied Acoustics*, vol. 96, 2015, p. 118-131.

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