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A vibro-acoustical and perceptive Study of the neck-to-body Junction of a solid-body electric Guitar

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The string motion of the solid body electric guitar is captured by an electromagnetic transducer sending an electrical signal to an amplification system, providing the sound to be perceived. Transducer and amplification have been so far well investigated, but the vibrational aspect of the instrument in connection with lutherie has been rarely considered. The aim of the present study is to analyse mechanically and perceptually the own influence of a single construction parameter. Three guitars, whose single difference is the neck-to-body junction, were made specially for this study. The neck can be either screwed or glued to the body, or have a neck-thru construction. The guitars have been played by professionnal guitarists along with semi-directed interviews. The judgments on the guitars are actually very varied and the guitarists have a lot of judging criteria, including criteria in assumed relationship with time-frequency aspect of the sound. We concentrate on the confrontation of time-frequency representation of the notes of the guitars in relation with driving-point conductance. In general when the driving-point neck-conductance measured at the string/guitar coupling point is high at the frequency of the note, an unusual damping of the fundamental frequency is visible on the spectrogram. We nevertheless find a non-neglectible number of exceptions to that.

1 Introduction

The solidbody electric guitar can be roughly described as a string connected to a thick structure with an electromagnetic transducer (called a ”pickup”) capturing the string's motion. The electrical signal is then sent to an amplifier providing the sound. Although the electro-magnetic side of the instrument is obviously important, the body of the guitar is not rigid, coupling phenomena could perturb the vibration of the string and the mechanical side of the electric guitar may be important as well!

A few studies has been done about the mechanical behaviour of the electric guitar. [1] [2] investigated the dynamic behaviour of the guitar and its consequences on the vibration of the string. Conclusions were drawn about — among others — the influence of the asymmetric shape of the head. However the two or three guitars they studied were very different from an organological point of view. In order to investigate the mechanical influence of a single lutherie parameter, [3] studied the wood of the body and could find differences in modal behaviours between three guitars only differing in the wood of the body. A study about another lutherie parameter has been made in [4]: the neck-to-body junction was the only changing parameter, but the instruments studied were rather far from a ”guitar”, in particular they could not be played by guitarists. [5] emphasised the perceptual side and let guitarists play and tell their feelings about the three guitars from [3]. This perceptual methodology and the investigation of a single-lutherie parameter are at the very heart of our acoustical study.

The aim of the present paper is to study the neck-to-body junction and its influence both acoustically and perceptually. The study was carried out on the guitars described in section 2. Section 3 shows the first results of the perceptive study. It is found in particular that timbral aspects are very important for the guitarists. From these results the section 4 investigates time-frequency representations of the notes of our guitars in relationship with vibration measurements.

2 The guitars

We studied three identical guitars, only differing in the neck-to-body junction. There is basically three ways to join the body and the neck of an electric guitar: the neck can be either screwed (”bolt-on”) or glued (”set-in”), or one can have a single piece of wood going through the whole length of the guitar. The latter construction is called a ”neck-thru construction”. Because it is almost impossible to find in the commercial sector identical guitars only differing in one lutherie parameter, the three guitars were made at Itemm [6], one of the main training center in lutherie in Europe. We had thus one specimen for each junction type, and the difference was invisible. The construction was based on the historical *Les Paul Junior* by Gibson. A photograph of the set-in guitar (the organologically closest to the original model) is shown in Figure 1. They were equipped with the same hardware including a Kent Armstrong *P-90 dog-ear* pickup.

Figure 1: One of the guitars of the study, from the *Les Paul Junior* by Gibson

3 Subjective evaluation of the guitars

The main part of the perceptive study is based on the linguistical analysis of guitarists' verbalizations about our three guitars they are led to play. 22 expert guitarists (including 13 professional ones) were invited to freely play on the three guitars and to speak about them. The guitarists' music affinities were multiple: jazz, blues, contemporary music, rock, hard rock, classical music, punk rock...

3.1 Experimental protocol

The three guitars described in section 2 were to be played, there was hence one specimen for each neck-to-body junction type. The guitarists were not aware of the main goal of our study and did not know the specifications of each guitar.

The experimental set-up took the form of a conversation between a guitarist and two of the authors. While he freely played the guitars, the guitarist was asked to express his feelings about the guitars. Our role was to reopen the discussion and to ask the musician for a rewording of his verbalizations, without suggesting any technical term. In this article we only present the data collected at the end of the procedure when the guitarists where asked to fill in several questionnaires (see section 3.2).

The interviews took place in a quiet room without special acoustic qualities (the library of the laboratory). The amplification system was made of a Fender *Blues Junior* amplifier connected to an Ibanez *TubeScreamer*. In order to record calibrated data, hardware configuration and setups were the same for all musicians (who had the choice to use both amplifier and pedal, or not). The recording system included a camera and a set of microphones: one for the sound from the loudspeaker of the amplifier, another for the "purely acoustical" sound, and a last one used for the conversation. The direct output of the pickup of the guitar was recorded too (D.I. box).

3.2 First results

The first questionnaire (Figure 2) asks the guitarist to give a global evaluation of each guitar on mute scale: he has to name the scale (each pole) and give a quantitative evaluation on this scale.

Although the bounds and the notation way were let free, all forms but one could be interpreted as a ranking of the three guitars. In Figure 3 (respectively 4, 5) we see how many times each guitar was ranked at the first (respectively second, third) place. One guitarist did not fill this form and another one did not give a ranking, so that we got 20 rankings. Whenever two guitars were ranked at the same place, we counted the awarded place for both guitars, this explains why the overall numbers of votes of the pie charts are not necessarily the same.

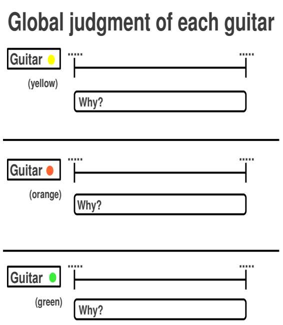

Figure 2: English translation of the form about the global evaluation of the guitars

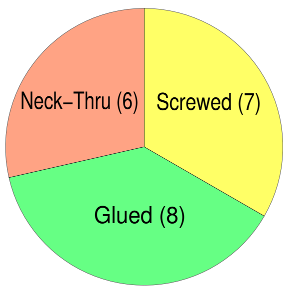

Figure 3: Number of times each guitar was ranked at 1^{st} place

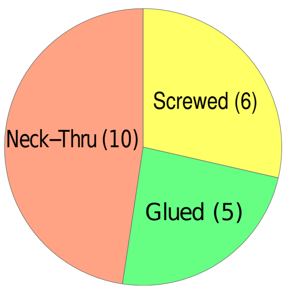

Figure 4: Number of times each guitar was ranked at 2^{nd} place

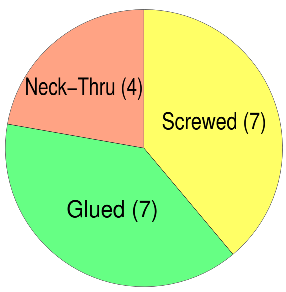

Figure 5: Number of times each guitar was ranked at 3^{rd} place

We see very little agreement between the guitarists. However, the neck-thru guitar seems to have been more often judged as being the "intermediate" guitar. It is somehow a surprise, since among the electric guitarists community the "neck-thru" construction is often thought to be the better solution, even if this construction is not common in the market of the electric guitar: is it just a commonly accepted opinion rather than an actually grounded opinion in comparative perceptual experience.

In the next step we asked the guitarist to choose criteria for a more precise evaluation of the three guitars. The choice and number of criteria to be chosen is let absolutely free, as long as they are relevant for the guitarist. Care has been taken not to influence the guitarist in the choice of these criteria. For each chosen criterion the musician is given 3 forms, which will not be described here: we just focus on the criteria that have been chosen. The list is given in table 1 (the English translation is made by the authors).

Table 1: List of criteria (left column) chosen by the guitarists and the number of times (right column) each was given. The original version in French is in roman letters and the English translation in italic letters

Criterion	**#**
Agressivité de l'aigu *aggressiveness of the high pitches*	5
Son/Sonorité/Rendu sonore *sound*	5
Pureté, clarté/Clarté *clarity*	2
Variété de timbre *timbre variety*	1
Grave de l'instrument *low pitches*	1
Son clair, son saturé *clean, overdriven sound*	1
Brillance *brightness*	1
Profondeur *depth*	1
Vie du son *liveliness of the sound*	1
Spectre, résonance *spectrum, resonance*	1
Homogénéité/Equilibre/Balance *spectral balance*	5
Sustain, résonance *sustain, resonance*	5
Ergonomie/Confort/Jouabilité *ease of play*	6
Réglage/Manche/Lutherie *adjustment, neck*	5
Sensibilité à la dynamique/Attaque/Réponse *dynamics and attacks*	3
Poids *weight*	3
Esthétique/Couleur *beauty*	3
Mécaniques *pegs*	1
Jeu en accords *playing chords*	1
Solo rock *rock-like soloing*	1
Expressivité de l'instrument *expressivity of the instrument*	1
Niveau sonore *output level*	1
Justesse, tempérament *"in-tune-ness"*	1

Many different criteria were mentionned and most of them shared only by few guitarists. Furthermore, without the analysis of the interviews we plan to process, it is not possible to be sure that two guitarists refer to the same concept or feeling when using the same word, or that they use different words to talk about the same thing [7].

For example, "sustain" is a very often discussed feature in the community of electric guitarists and in advertisements for big brands (in this context "sustain" means roughly "long decay time"). In our study the criterion "sustain" has been

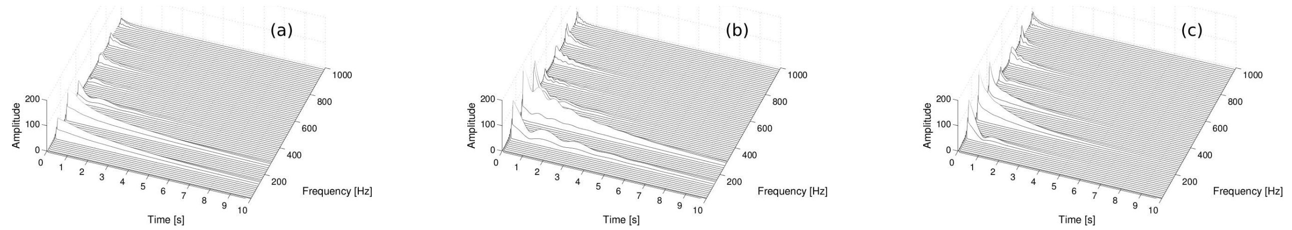

Figure 6: Spectrogram for the C♯3.
Neck-thru guitar (a), glued-neck guitar (b), screwed-neck guitar (c)

chosen by only 5 guitarists. This criterion has here not been the most important one to evaluate our 3 guitars.

Moreover the 10 first criteria of table 1 can be related to the concept of ”timbre” which if perceptually evident and well defined on a semantic ground still remains to be acoustically described [8]. From these verbal answers we have now to connect to physical descriptors : we make the hypothesis that the criterion *spectral balance* may be related to the spectral content of the sound. And the *sustain* criterion might deal with both temporal and spectral aspects of the sound. These hypotheses can be first evaluated from the analysis of the time-frequency aspect of sound and represented on spectrograms.

4 Acoustical study

All notes (23 notes per string) of the 3 guitars were recorded in a quiet room. The output of the pickups was recorded. To minimize the influence of the guitarist, a capo (device acting as a finger of the left hand, but staying fixed during the note) was used. Since it has been shown that the gesture of a trained musician can be considered as quite well repeatable [9], the plucking was done by a skilled electric guitarist. The guitars were tuned with an electronic tuner (reference A4 = 440 Hz) before the recording, however we could notice some frequency deviations during the recording series.

4.1 Spectrograms

As the timbral aspects in the broad sense seem to be very important for the guitarists to evaluate our guitars, we decided to look at a classical time-frequency representation of sound signals: the spectrogram. The analysis described below has been done for all the notes, but to keep on comparing the 3 guitars we present the spectrograms of the particular note C♯3 produced at the 9^{th} fret on the 6^{th} string. This note has the merit of providing both confirmation and counterexample for the link between string/structure coupling and perturbation of string vibration we try to make clear.

Spectrograms are shown in Figure 6. The one of Figure 6a corresponds roughly to what can be expected from a plucked string signal: a harmonic series of damped sinusoids. In particular, the decay time for the first component is longer than for the higher ones. This is fortunately the case for most of the notes. But the spectrograms of Figures 6b and 6c exhibit more ”abnormal” cases. Figure 6c shows an ”abnormal” damping of the fundamental. It decays much faster than its two first partials. This phenomenon may correspond to a ”dead spot” (as defined in [2]), that is a much shorter overall decay time for this note compared to the decay times of other ones, and potentially an inconvenience for the player [10]. Figure 6b shows both a shorter decay time for the fundamental and strong beatings. These beatings may be caused by coupling between for example the string and the guitar, the string and other strings or two polarizations of the string. The damping of the fundamental frequency could also be explained by a loss of energy from the string due to some couplings as well.

4.2 Driving-point admittance

The driving-point conductance is a relevant indicator to quantize energy transfers between structures. The driving-point conductance is defined as:

$$C = \mathrm{Re}(\frac{V}{F}) \qquad (1)$$

where V is the velocity of a point upon which a force F is applied. Driving-point conductance measurements have been done for the 3 guitars at every point where the strings and the structure can be coupled: at every fret/string crossing and at every connection point between the bridge and the strings. The guitars were laid on a structure simulating free boundary conditions: three sandows attached to a frame forming a structure with much lower resonance frequencies than the studied structure. Force was applied with an impact hammer and measured with a force sensor. An accelerometer was used to access the velocity. Both directions of force and velocity were ”out-of-plane”, i.e. perpendicular to the fretboard.

We show in Figure 7 the driving-point conductances at the two string/guitar coupling points (at the bridge and at the place on the neck where the string is fretted to produce this note) for the note (C♯3) whose spectrograms are in Figure 6. Figure 7 is described below.

- For the neck-thru guitar (Figure 7a) the estimated fundamental frequency of the C♯3 is 138.8 Hz. At this frequency the conductance values (blue triangles) are low. No strong coupling occurs and the vibration of the string remains undisturbed as we see in Figure 6a.
- The neck driving-point conductance plot corresponding to the C♯3 for the screwed-neck guitar (Figure 7c) shows a very high value at the fundamental frequency of the note (139.1 Hz). At the bridge it still takes a low value. Energy is likely to be transferred from the string to the guitar via the neck at this frequency, resulting in an energy loss for the fundamental frequency of the note. The spectrogram of Figure 6c shows that phenomenon quiet well: the fundamental decays very fast. For a majority of the recorded notes, we find this relationship between a high (resp. low) driving-point conductance value at location and fundamental frequency

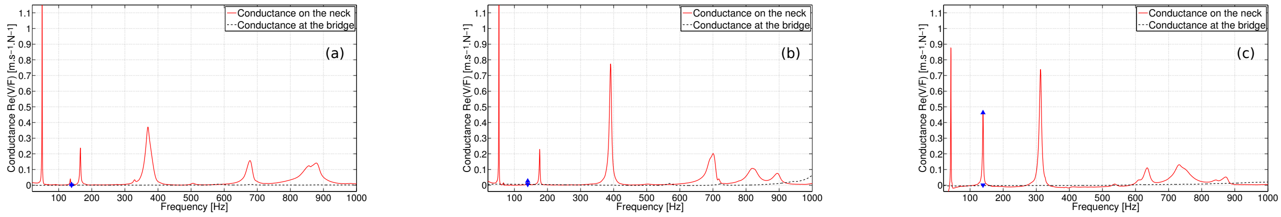

Figure 7: Driving-point conductance at the 2 string/guitar coupling points: bridge (black dotted) and 9th fret/6th string (red solid). The blue triangles mark the conductance values at the fundamental frequency of the note.
Neck-thru guitar (a), glued-neck guitar (b), screwed-neck guitar (c)

of the note and an "abnormal" (resp. "normal") spectrogram.

- The driving-point conductance (Figure 7b) for the C♯3 (fundamental frequency 140.3 Hz) of the glued-neck guitar can be seen as a counterexample to the relationship explained above: the conductance values at the bridge and on the neck are low, but the fundamental (Figure 6b) lasts little shorter than its first harmonic, and lots of beatings are to be seen. This is the case for a non-neglectible number of notes.

In conclusion the relationship between a high driving-point conductance value at the string/guitar coupling point for the frequency of the fundamental of the note and a spectrogram where the fundamental decays faster than the other frequency components has been observed. But some notes showed the opposite behaviour: a high conductance value could lead to no high damping of the fundamental frequency at all. And notes were also found to have "abnormal" spectrograms even if the neck conductance at the point where the note was played did not show any peak. These results slightly differ from those of [2].

4.3 T30

As suggested by [2] we can examine the "T30" as decay time indicator. Inspired by the room acoustics, the "T30" we compute is the time taken by the smoothed envelope of the signal to reach a reference level diminished by 30 dB. The smoothed envelope is computed with the backward integration method from [11]. The reference level we chose is 10 dB below the maximum level: the transitory effects are thus removed. Because sometimes the dynamic range of our signals was not large enough, we used a linear interpolation of the smoothed envelope. According to [2] problems occur when the T30 value of a note is much lower than the ones of its neighbours (notes produces nearby on the same string): a "dead spot" is reached and the overall decay is driven by the harmonics (i.e. the fundamental decays faster than the other components). The T30 was naturally computed for every recorded note. The values for the example note are given in Figure 8 which we describe below.

- Figures 8b and 8c exhibit clearly a gap for the C♯3: the T30 value of the C♯3 is much lower than those of its neighbours. It is a "dead-spot" in the sense of [2]. But we saw that the spectrograms of the corresponding guitars (Figures 6b and 6c) are not similar.

- Figure 8a shows a less marked gap for the C♯3. If there is a decay time "problem", it might be not related to a flow of energy toward the structure, but perhaps also to other damping mechanisms: viscous friction and internal friction for example [10] [12]. Those mechanisms are frequency-dependent, so that without interaction between the string and the guitar it is "normal" to have a decreasing T30 value with increasing fret number (increasing frequency).

When looking at every note the T30 was sometimes found to be a too global indicator. There are some notes for which the T30 values were high enough (in comparison with the neighbours), but either with fast decay of the fundamental, or with high conductance value at the frequency of the fundamental. Two problems should be mentionned: if higher frequency components have enough energy, the T30 value may be not affected. We also notice a problem in the case of a strong string/guitar coupling: double-slope decays appear, so that the definition of a unique decay time is not a light task and the computed linear interpolation reaches its limits.

5 Conclusion and perspectives

According to our forms, the guitarists did not reach an agreement about judging which is the best guitar. The judgments are actually very varied and the guitarists have a lot of criteria. The ongoing transcription of the recordings of the interviews and the upcoming linguistical analysis will complete these first results.

We concentrated on the confrontation of time-frequency representation of the notes of the guitars in relation with driving-point conductance. In general we find quiet similar results as [2]: when the driving-point neck-conductance measured at the string/guitar coupling point is high at the frequency of the note, an unusual damping of the fundamental frequency is visible on the spectrogram. We nevertheless found a non-neglectible number of exceptions to that: they will be the motivation of further work.

A last point to mention is the bridge conductance. We could observe in line with [2] and [3] that the driving-point conductance at the bridge is in general small compared to the ones on the neck. This fact is to be put into perspective: it should depend on the bridge type. The bridge of our guitars is not as rigid as other bridges, at certain frequencies the conductance at the bridge can be found to be bigger than on the neck. So in further works the bridge conductance will still be taken into account.

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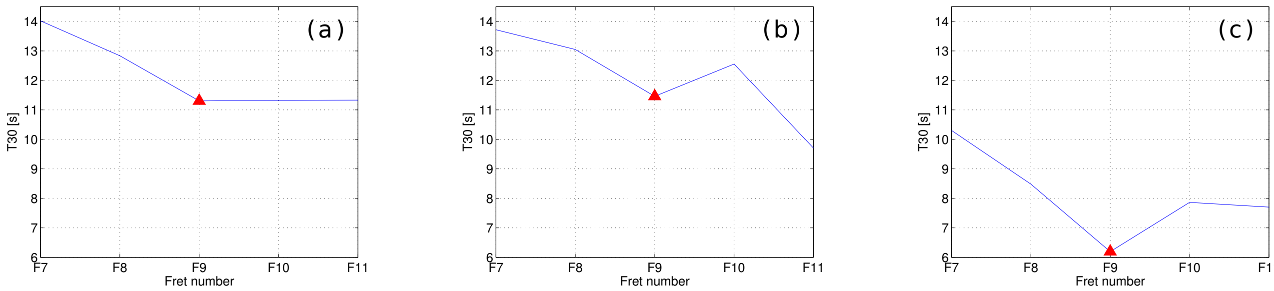

Figure 8: T30 values for the C♯3 (red triangle) and its neighbours.
Neck-thru guitar (a), glued-neck guitar (b), screwed-neck guitar (c)

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References

[1] H. Fleischer, T. Zwicker, ”Mechanical Vibrations of Electric Guitars”, *Acta Acustica united with Acustica* **84**, 758–765 (1998)

[2] H. Fleischer, T. Zwicker, ”Investigating Dead Spots of Electric Guitars”, *Acta Acustica united with Acustica* **85**, 128–135 (1999)

[3] J.-L. Le Carrou, J. Frelat, A. Mancel, B. Navarret, ”Guitare électrique : quel rôle pour les éléments de lutherie ?” *Congrès Français d’Acoustique* (2010)

[4] R.M. Mottola ”Sustain and electric guitar neck joint type”, *American Lutherie* **91**, 52–55 (2007)

[5] B. Navarret, ”Etude de la qualité sonore de la guitare électrique solid body”, *Musique & Technique* **4**, 43–59 (2010)

[6] Institut technologique européen des métiers de la musique, website : ”http://www.itemm.fr”

[7] P. Cheminée, ”Est-ce bien «clair »? Stabilité, instabilité et polysémie d’une forme lexicale en contexte” in *Le Sentir et le Dire, Concepts et méthodes en psychologie et linguistique cognitives*, Danièle Dubois (editor), L’Harmattan Ed., 311–340 (2009)

[8] M. Castellengo, D. Dubois, ”Timbre ou timbres ? Propriété du signal, de l’instrument, ou construction cognitive ?”, *Cahiers de la Société Québécoise de Recherche en Musique* **9**, 25–38 (2007).

[9] D. Chadefaux, J.-L. Le Carrou, B. Fabre, L. Daudet ”Experimentally-based description of harp plucking”, *Journal of the Acoustical Society of America* **131** (1), 844–855 (2012)

[10] H. Fleischer, ”Vibration of an Electric Bass Guitar”, *Acta Acustica united with Acustica* **91**, 247–260 (2005)

[11] M.R. Schroeder, ”New Method of Measuring Reverberation Time”, *J. Acoust. Soc. Am.* **35**, 409–412 (1967)

[12] C. Valette, C. Cuesta, *Mécanique de la Corde vibrante*, Hermès Ed. (1993)