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About the electric guitar: a cross-disciplinary context for an acoustical study

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The electric guitar was born in the 1930s from the will of guitarists to be heard while playing in orchestras including louder instruments. It then became the broadly-spread instrument that we know. Because of its mass-production and of the imitation-like learning methods, it appears that only a few models (shape, woods species, construction parameters) of electric guitar have stood out and have been the master copies of most of the other electric guitars all around the world. These models are few but each of them strongly differs from the others organologically or sociologically speaking. New research topics are emerging at LAM and GRANEM, which are about the study of the electric guitar in connection with lutherie. In this article, this topic is put back in an organological, scientific, musicological, sociological and economic context.

1 Introduction

New research topics about the solidbody electric guitar emerge at LAM [1] and GRANEM [2]. The studies are mainly focused on the organology, the vibro-acoustics and the economy of the instrument. This article gives an overview of the eminently multidisciplinary context within the scope of which those research topics fall.

The history of the electric guitar dates back to the 1920s and 1930s in the USA. In order to make the guitar audible in orchestras including louder instruments like drums or brass, there were many attempts to amplify the acoustic guitar [3]: *Dobro* guitars, bigger sound boards, preference for metallic strings. This finally led to solidbody (i.e. without sound box) guitars fitted with electromagnetic transducers.

The world of solidbody electric guitar has since then been dominated by two famous manufacturers: Fender and Gibson. With this observation as central theme, the section 2 concentrate on the economical aspect of the instrument, and in section 3 the organological and musicological sides are investigated. We then introduce an acoustical study of the electric guitar in section 4, without leaving aside the musician (section 5) and his perception (section 6).

2 The two leaders of the industry

The guitar — covering all types of guitar — is the best selling instrument in France: 49.8% of musical instruments sold in 2009 were guitars. It is the instrument the most played over the last three years: 39% of musicians play the guitar compared to 31% for the piano [4]. The Asiatic or American imports bare witness to this enthusiasm.

The solidbody electric guitar was born in the USA: it is a sixty-year-old instrument that shows no signs of aging. The two leading firms in the market, Gibson and Fender, established the canons for this new instrument at the outset and they have changed little since their creation.

The Gibson Company pioneered the development of the modern guitar. Orville Gibson — the founder of the company that bears his name — electrified his hollowbody (arch-top) guitars, which had a hollowed-out body like that of a violin. The hollow case caused feedback problems and Larsen effects: an unpleasant, very high-pitched whistling.

The electric solidbody guitar represents the best way of overcoming the problems related to high-volume amplification. The guitar then consists of a wooden board, solid or not, to which the pickups and fittings are attached.

This major innovation, which we owe to Leo Fender, is remarkable both as regards sound and for the Taylorian organisation of guitar production [5]. The solidbody symbolizes the era of the industrial guitar.

In 1949, bringing together certain experiments by stringed-



Figure 1: Fender *Stratocaster*



Figure 2: Gibson *Les Paul*

instrument makers on the solidbody guitar, Fender invented what is now considered to be the "mother" of this type of guitar: the *Telecaster* [6], which is still listed in the Fender catalog, remains more or less unchanged since 1950. In 1954, Fender created the "Queen of electric guitars", the Fender *Stratocaster* [7] (Figure 1). This solidbody guitar has outproduced all other guitars worldwide and is also the most copied. Since the 1950s the Fender catalog has added other electric models, completing the range, but these have not caused the stir or had the longevity of the two mythic models presented here.

Fender's main competitor, the Gibson company, only became interested in solidbodies at a later date, first (in 1946) refusing a prototype nicknamed *the Log* or *the Handle* from the person who was to give his name to the brand's future solidbody instrument, the famous guitar player Les Paul. It was only the success experienced by Fender that drove Gibson to sponsor Les Paul again in 1951, in order to perfect the model named after him. Today, the *Les Paul* [8] (Figure 2) is still a canon of the electric guitar. As with Fender, Gibson's solidbody catalog is well provided with mainly top-of-the-line models, because of the more traditional antecedents of the firm's instrument-makers. However, no model has ever achieved the fame of the Les Paul. Thus in the catalogs of the two big American manufacturers, these three flagship models would soon eclipse all the others.

Around the 60s the market for solidbody guitars was getting under way. Europe had a few manufacturers — notably in Germany (e.g. Höfner), Italy (e.g. Eko), Sweden (e.g. Hagstrom) and France (e.g. Jacobacci [9] [10]) — whose models were modest in design and cost. A few brands stood out in the United States and England (e.g. Burns, Epiphone, Mosrite, and Vox), but if you were a player of modern music there was nothing to challenge the Fenders and Gibsons hardly imported from the United States.

In the 70s, electric guitars were to be copied more or less

faithfully by big Japanese firms. The movement has been called "the copy era". The brand that best represents this mode of development is Ibanez, belonging to the Hoshino Group. Ibanez took its inspiration from models developed by Burns, an English firm, Fender, and later by Gibson, since the design of these guitars lent themselves to an industrial mode of production. Around 1970 the Japanese manufacturers offered increasingly perfect copies of Fender and Gibson electric guitars. Copying of the classic North-American models was the key factor in the success achieved by the Japanese manufacturers, who also used their acquired skills to create original models. The American companies experienced a progressive erosion of their market shares. In 1977 a landmark legal proceeding was launched against Ibanez, which was obliged to stop making copies of Gibsons. Nevertheless, the American inspiration lives on in the Japanese firm's original productions.

Around the middle of the 1980s Japanese production costs increased sharply, forcing the Japanese manufacturers — who were flooding all ranges of the guitar market — to outsource their production to Southeast Asian countries (South Korea, Taiwan, and then, towards the end of the 1990s, China). Facing a flood of low-priced models, the two benchmark American manufacturers adopted diametrically opposing strategies. Gibson favoured the label "Made in USA" and refused to outsource its production. As an American guitar icon, the firm continued to sell high-priced, top-of-the-line models while at the same time attempting to develop a cheaper product based on economy models still assembled in the USA.

Fender's reaction was the opposite. In 1982, Fender began manufacturing a portion of its production in Japan under the Fender name, and then developed a subsidiary brand of cheaper instruments, marketed under the name "Squier by Fender". The search for production savings led the firm to produce as well in South Korea, China, Indonesia, India, Taiwan and Mexico. Although the Fender products are becoming difficult to recognise, the American production still has the aura of the brand's prestige.

The competitive advantage enjoyed by Fender and Gibson is indisputably related to the history of rock music during the 1960s and 1970s. The majority of English and American rock groups made use of both these models because of the complementary nature of their sound... and the Anglo-Saxon model then flooded the media [10]. Although the era of the "guitar heroes" did not outlive the 1960s and 1970s, that music still has an audience and the purchase of a "signature" guitar has become a growth market... and these firms have a strong endorsement and sponsoring strategy. Almost all of the brands employ this strategy, but not with equal success. Some have a real image deficit, because no famous name plays one [11]. Gibson and Fender do not.

The tendency to look to the past is a strong one in music and the attitude that consists of favoring vintage instruments is now a feature of current pop-rock groups. The musician finds reassurance in these historical references, when confronting the extra-large offer available on the guitar market. Fender and Gibson thus have a kind of duopoly in the electric guitar market, stemming from the legend. It all comes down to inimitable prestige that everyone recognizes. It derives from the past, from a sort of musical golden age that has now gone by, but which is still in mind to the competitive benefit of the two American firms [11].

3 Organology

The "electric guitar", as its name indicates, is a guitar and most of electric guitars are made with crafting techniques applied on acoustic guitars.

The Fender and Gibson solidbody guitars became standards and worldwide distributed in few years. Then, the basic specifications of the electric solidbody guitars were established and would not change so much! [12]

3.1 Fender and Gibson guitars specifications

A Fender guitar is usually made of alder or swamp ash for body, with a bolt-on flatsawn or quartersawn maple neck, no neck and peghead angle, asymmetrical headstock shape, maple or rosewood fingerboard and a string length of 648 mm (25-1/2 inch). Most models are equipped with two or three Fender-style single-coil pickups (section 3.2) and 250 k Ω volume/tone pots. A Gibson guitar is often made of mahogany for neck and body (maple can be used for necks and the top of the body as well), with a set-in quartersawn neck (especially with mahogany), angled neck and peghead, rosewood or ebony fingerboard, symmetrical headstock (except for *Explorer* and *Firebird* models) and a shorter string length with only 629 mm (24-3/4 inch). Most models are fitted with two dual-coil pickups called *humbuckers*, or Gibson-style *P-90* single-coil pickups, and 500 k Ω volume/ tone pots. Both Fender and Gibson pickups are linked in parallel; the two coils within the humbucker are connected in series. Bridges are specific for each guitar model but they can be classified into two categories: fixed (non-tremolo) bridges and floating (tremolo) bridges whose musical function is to create vibratos (modulation of pitch) by changing the tension of strings. The guitar player uses a controlling lever, also called tremolo arm or whammy bar, to move the bridge like the Fender *Synchronized Tremolo* or the tailpiece like the Gibson *Maestro Vibrola*. Most of the electric guitars produced today are copies or inspired by the models of the 50s, famous models like the Fender *Telecaster* (1950-1951) and *Stratocaster* (1954), Gibson *Les Paul* (1952) and *SG* (1961).

3.2 A real electroacoustic chain

The electric solidbody guitar is equipped with one or more electro-magnetic pickups [13]. These sensors are made of magnets wrapped in a coil of fine enamelled copper wire. The vibration of a metallic string perturbs the magnetic field, feeding a low voltage alternating current through the coil. The induced current can be modified by the electronic components of additional audio processors and is then sent to the amplifier. The amplifier increases the current's amplitude and provides the power needed to drive the loudspeaker cone(s). The perceived sound is essentially radiated by loudspeakers, and less by the "acoustic" instrument itself. So, we might consider that the electric guitar is one element of the tone chain, with an amplifier as sound *provider*, and the guitar player as *conductor* (Figure 3).

3.3 More and more tools for creative applications

As can be seen from the previous section the electric guitar was first conceived as an "expanded acoustic instrument"

with its pickups and amplifier: for instance, the clean "twang" sound of the *Telecaster* could be considered as the "amplified acoustic sound" of the banjo which was the main plucked instrument used for bluegrass and country music [14]. But soon, tremolo and spring reverb effects, high gain level preamps, acoustic feedback, distortions, wah effects, octaver, phaser and so on, revealed that the electric guitar was a real new instrument with unexpected wild sounds that had to be tamed. Thus, the electric guitar reached a second step in its evolution and became a modular augmented instrument. Besides, the electroacoustic chain has evolved more than the guitar itself since the 1960s: a lot of sound treatments became available and powerful technologies were designed especially for guitarist gears like e.g. digital emulations of analog hardware integrated in amplifiers and pedals. Composing and recording methods were renewed as well thanks to a democratized access of computer music tools and home studio equipment. This hardware chain can be relatively easy to understand by a conceptual point of view — the guitar being simply plugged into some boxes, amplifier and/or computer... — but this alchemy reveals a strong creative potential and can produce some impressive complex sounds [15].

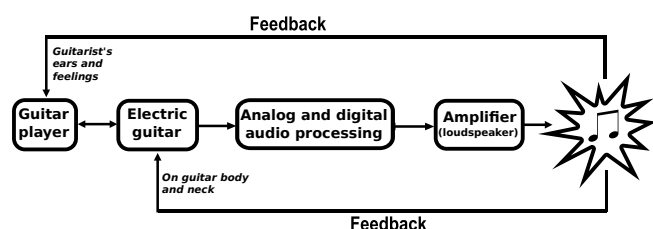


Figure 3: The electroacoustic chain of the electric guitar, including effects, amplifier, and feedbacks between elements

3.4 *Les Paul* and *Stratocaster* as versatile instruments

Gibson archtop electric guitars are usually chosen by musicians for playing classic jazz, Fender *Telecaster* or Gretsch hollowbody guitars for rockabilly and early rock'n'roll, Rick-enbacker for British pop music or Fender *Jazzmaster* for surf music... On the other hand, the *Les Paul* and *Stratocaster* models seem to be more versatile instruments as they are often played for blues, funk, rock, heavy metal, punk music, jazz-fusion, progressive rock or reggae [14]. By changing hardware parts, pickups, fret size, neck shape, body colours... you can customize the original model for the music you want to play. That's why you can find a Fender-style and Gibson-style guitar for playing the same music. For example, most of guitar models are played for blues-rock both by American and English musicians: Gibson hollowbody guitars (BB King, Freddy King, John Lee Hooker, T-Bone Walker, Freddy Green, Alvin Lee), Gibson solidbody *Les Paul* with single coil or humbuckers (Jimmy Page, Gary Moore, Joe Bonamassa), Gibson *Firebird* with neck-thru body construction and non-conventional shape (Johnny Winter) or a symmetrical shape *Flying V* for the left-handed guitarist Albert King. In Fender family, lots of guitarists have chosen the *Stratocaster* (Buddy Guy, Jimi Hendrix, Stevie Ray Vaughan, Jimmie Vaughan, Robert Cray, Eric Clapton, John Mayer) and some the *Telecaster* (Muddy Waters, Albert Collins, Roy Buchanan, Jeff Beck). Furthermore, famous gui-

tar and amplifier combinations like Gibson guitar / Marshall amplifier or Fender guitar / Fender amplifier are not the only rule to work and the "science" of sound depends on these fundamental artistic choices too [16].

4 Acoustics

In the previous sections it has been shown that Fender and Gibson produced with respectively the *Stratocaster* and the *Les Paul* the two leading models of solidbody electric guitar. Why are they — from an acoustical point of view — so particular? We saw (section 3.1) that these two models are very different: wood, shape of the body, head, junction type between the neck and the body, pickup, bridge, fret, finger-board... All of these lutherie parameters may have an influence on the dynamic behaviour of the instrument. And since the string is connected to the guitar, its motion must be perturbed by the dynamic behaviour of the instrument.

Only a few studies have been done about the dynamics of the electric guitar. A reference study [17] investigated precisely a *Stratocaster* and a *Les Paul*. From this study conclusions are drawn about — among others — the influence of the symmetry of the head on the dynamic behaviour of the guitar. This influence is very likely to be real, but so many other parts are different between the two guitars that it is hard to conclude about the influence of a single parameter.

The method we chose is to wonder about the influence of each lutherie parameter on the dynamics of the guitar. For that purpose, we study guitars only differing in a single parameter. Since it is very difficult (actually almost impossible) to find such guitars in the commercial sector, we are working together with Itemm [18], one of the main training center in lutherie in Europe, from whom we can obtain sets of similar guitars (possibly following the specifications of well-known models) differing one from another by a single lutherie parameter.

Preliminary studies have dealt with the wood of the body [19] and with the neck-to-body junction (bolt-on necks, set-in necks, neck-thru constructions) [20].

Further studies will concentrate on other guitar parts (without neglecting pickups or strings) and quantify their influence on the dynamics of the guitars, and eventually on the sound produced (by direct radiation or through capture and amplification by the pickup and amplifier). We will carry out experimental measurements on the guitars, as well as analytical modelling and numerical studies as a prediction tool.

5 The electric guitarist

But the electric guitar would not be anything without the guitarist. We focus here on the teaching and learning opportunities of the electric guitarist, on his habits and techniques which are proper to the electric guitarist and his instrument.

5.1 The electric guitarist and his training

The teaching of the electric guitar has been since the creation of the instrument different from the one of the classical instruments. Even nowadays, almost 80 years after its "invention", the electric guitar is rarely taught in French conservatories [21] [22]. Although there also exists private schools

(yet again speaking of what happens in France), the teaching of electric guitar seems to be rather oral and informal for most of the learners. A common way of learning is to imitate the famous guitarists. At earlier times one had to attend the performance to know how the guitarist was playing. As time went by the learners have had access to audio and video recordings (tapes, discs and now the Internet). Students could dissect and analyse the playing of the stars, try to repeat the gestures and sonic results they hear. Another way of passing on the knowledge of electric guitar playing is to use the mediation of magazines. The Press publishes explained scores from famous groups (for example, *Guitar Part 105* included transcriptions of songs by Blink 182, Queen of the Stone Age, Prince, Iron Maiden, Zebda and Moby [23]).

Although it does not come from the popular music (it was used a long time ago for the lute) we notice that the scores for electric guitar are often written down in a tablature form (a very instrument-dependant notation which gives the technical means to produce sound) and not necessarily in a western classical form such as the staff notation (an instrument-independant notation which gives pitches, duration, interpretation keys). The tablature notation could appear as being poorer than the staff notation (in Figure 4 we show the same phrase in both notations), but we could take a new look on this apparent poverty through the prism of another conception of music. In opposition to western classical music, which is first thought to be written down, most of the music for electric guitar is "popular" and not thought to be transcribed. This music highlights improvisation within mostly very simple structures (basically alternation of verses and choruses): the tablature notation allows a quick access to fingering, letting the interpretation suggested by listening to records and of course by the own feelings of the player.

Despite this imitation-like training, the electric guitarist



Figure 4: Score in staff notation (top) and its corresponding tablature notation (bottom)

remains a manifold being. Among the electric guitar community one can find plenty of musician types. To be more accurate, every professional guitarist seems to endeavour to distance himself from the others, by developing his own style and techniques.

5.2 An introduction to the playing techniques

Most of the electric guitarists pluck the strings with a small piece of plastic (or more rarely wood) called a "plectrum" (or "pick"). But several famous guitarists have built a very personal finger picking style like Mark Knopfler (Dire Straits), Jeff Beck or Wes Montgomery who played only with his thumb. The "hybrid-picking" technique [24] is the use of both plectrum (basically held by the thumb and the forefinger) and fingers (middle, ring and sometimes the little finger). The plectrum could also be held by the forefinger and the middle finger in order to let the thumb (with or without nail) pick.

Some other techniques have been developed, becoming

the features making us recognize a particular guitarist at the first few notes we hear :

- **bending:** a very common technique, in which one finger of the left hand not only presses the string against a fret, but at the same time pushes the string in a direction parallel to the frets (making thus the string "bend") [25] [26]. The result of the continuous increase in string's tension is a continuous increase in pitch. This technique is used by many guitarists, for example by David Gilmour (Pink Floyd). This technique might have appeared thanks to the use of metal strings instead of nylon strings: to reach the chosen note one needs to bend the string less than it would be necessary with nylon strings. There is also less friction between metallic strings and metallic frets.
- **tapping:** one finger of the plucking hand strikes the string at an interfret interval on the neck where usually only the left-hand fingers play [27]. It produces a kind of "struck string" initial condition. The technique was popularized by Eddie Van Halen. This effect can be regarded as a consequence of amplification, because on a guitar with nylon strings it is very difficult to provide a sufficient amount of energy to the string only by tapping.
- **legato:** a series of notes is played in which only the first note is picked with the right hand, and the following one are all played by the left hand [27]. It produces smoother transition between notes and a more fluid phrasing. The technique has been taken to the extreme by Allan Holdsworth. Once again, the technique was made very easier to develop with the "electrification" of the guitar, because of the lower damping of metal strings connected to a thick body (leading to a longer "sustain") compared with nylon strings connected to a moving body, and because of the smaller amount of energy required to make the strings vibrate.
- **feedback:** we all have in mind Jimi Hendrix facing his amplifier, making music from the "Larsen effect". This has been so far broadly used and is not only a typical feature of electric guitar playing but also of the on-stage behaviour of the rocker and of his attitude toward his equipment.

The list remains open and extendable by all electric guitar players! Although sometimes transposable to the acoustic guitar, the important thing is that those techniques are typical features of the electric guitar, which have mostly been made possible by the electrification of the guitar.

6 Perception

The section 5 reminded us that the musician is the most important element in the chain of the electric guitar. Parallel to the mechanical studies on the guitars made at Itemm, perceptive studies has been and will be done on the same guitars. These studies involve skilled guitarists (mostly professional ones) who play our guitars. Preliminary studies [28] [29] seem to indicate that skilled guitarists can distinguish the contributions of the guitar from those of the rest of the chain, even if the amplification system (including effects) is

responsible to a large extent for the sound produced. Furthermore they were able to hear and feel differences between several very similar guitars, the rest of the chain staying identical.

The study of the perception by the players provides us very useful information. What modification in lutherie the guitarists can hear? What can not they hear? What do they listen to? The knowledge of the listening strategies gives heuristics for the vibro-acoustical study. Starting from classical method in vibration measurements [19] [20], we ought to improve them with the clues of the perceptive study to become able to measure vibrational features relevant for the acoustician and for the musician.

7 Conclusions

In this paper we introduced the context for vibro-acoustical, organological and economical studies of the solidbody electric guitar.

We saw that this instrument seems to be multifarious but its multiple forms can nonetheless be viewed as following two historical standards : Fender and Gibson. We also saw how the electric guitar is different from other instruments, and how much the guitar player is important.

It is important to remain aware of this multidisciplinary context including economical and sociological aspects before undertaking an acoustical study of the solidbody electric guitar: which guitar should we choose to study? According to which criteria? What about the musician?

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