In a nutshell, we have the following situation (for further elaborations see Chapter 7.12.3): In electric guitars with heavy strings and a high action, string/fret contacts (other than the actual fretting action) are rather rare, the low partials can develop nicely, and the electric sound is quite full. The string vibration can approximately be modeled in a linear fashion. Given light strings and the correspondingly connected light playing forces (Chapter 7.4.1) each individual note may be accompanied by string/fret contacts (especially for strong plucking), resulting in a more percussive sound with more treble. The low-frequent partials are less distinct because they lack the required amplitude. Of course, the individual plucking process always is essential: with brute force, it is possible to make a heavy string bounce onto the frets, as well, and a light string may be plucked so gently that it does not come into contact with the frets. That's what this statement is based on: **it's all in the fingers, man!**

For short notes, the **guitar body** has next to no influence on the electric sound, and for solid body guitars no influence is felt for longer sustained notes, either. With hollow-body instruments, in particular two effects are found: since especially the low-frequency notes are (acoustically) radiated better, the corresponding decay times are shorter, and for the same reason these instrument tend to feed back more quickly.

In terms of influencing the sound, the way/style of playing comes first, and strings and pickups are next (in high quality guitars). We then get to the mechanical characteristics of the bridge, and then to the frets (even the higher-most, possibly "never used" ones). That the acoustical sound radiated by an electric guitar would give "complete" testimony about the electric sound is a fairytale – albeit one that apparently cannot be silenced. Already Leo Fender and Les Paul fully understood that the vibration-energy needs to remain in the string as long as at all possible – as little as possible should be transferred into the body. Any acoustic sound needs to be channeled through the body (to use layman's terms) – so the material it is made of is relevant, but – alas! – only for the acoustic sound. The guitar body can influence the electric sound, but only in terms of absorption. Since it seems that every guitar player demands a sustain as long as possible, the absorption needs to be as low as possible. In that case, however, the influence of the body wood on the electric sound has to be as small as possible, too. Knowing that, it is not surprising that an electric guitar build from undefined, knotty platform-wood can fill the guitar player with enthusiasm due of its sound (G&B 7/10) … because of its electric sound, that is, of course.

7.12.3 The roots of the electric sound

Of course, the pickup voltage does not yet yield a "sound" – for that, amp and speaker are required, and – diving into philosophy – a listener, as well. Wouldn't it make for a great debate to ask whether airborne vibrations that are not heard by anybody merit the term "sound"? But that would be the realm of those physicists who – good heavens! – seek to become a DPhil rather than a DSc, i.e. move into a world completely foreign to the Doctor of Engineering. In short: without amplification, the electric guitar generates an acoustic sound, amplified it generates the electric sound. Only the latter is addressed in the following, as is the analysis and description of its origin.

Step-excitation and pick-filter

From a systems-theory point-of-view, plucking a string represents an impressed force-step – however not one in the form of an ideal step-function but modified by the pick-filter (Chapter 1.5.2). Due to mode-coupling in the bearings (bridge, frets) and magnetic pull-forces, the string vibration does not remain in one plane but starts a wobbling motion in space (circular polarization, Chapter 7.7.4). Using angle of pick-attack, plucking-strength and -direction, and via further finger/string contacts, the guitarist shapes the electric sound to a significant degree.

String vibration

Starting from the plucking location, transversal waves and dilatational waves run in both directions. They are reflected at the bearings and (approximately) result in standing waves. Dilatational waves that propagate dispersion-free are of lesser significance but they may lead to frequency-selective absorption losses (Chapter 7.7.4.2). Transversal waves (the important wave-type) propagate with dispersion; their propagation velocity increases towards higher frequencies, leading to an inharmonic spreading of the line spectrum (Chapter 1.3). This inharmonicity (dependent on the string diameter) is quite desirable: it livens up the tone, especially in case of non-linear distortion in the amplification chain (difference tones, see Chapter 10.8.5).

String material

The (manufacturer-specific) relation of core- and winding-thread (Chapter 1.2) is – right behind the overall diameter – the other important parameter influencing the inharmonicity of the partials. A further influential factor could be how tightly the outer thread is wound onto the core; but compared to ageing processes (skin oils, corrosion), it takes a backseat.

Plucking (picking) position

The plucking-position separates the string into two sections, the length-ratio of which determines the zeros of the plucking-interference-filter. The closer the plucking happens to the bridge, the further apart the filter-zeros are, and the harder and more trebly the sound gets (Chapter 2.8). The plucking-interference-filter operates with an individual characteristic for each string and cannot be simulated with a simple effects device.

Pickup position

Just like the plucking-interference-filter, the pickup-interference-filter is a comb-filter; its zeros are, however, determined by the pickup position and not by the plucking position (Chapter 2.8). For the single-coil pickup, one comb-filter is active, for a humbucker there are two. If there is a difference between the two humbucker-circuits, further degrees of freedom in the signal filtering result. Again, the pickup-interference-filter acts string-specific, and its effect is dependent on the fretted pitch.

Magnetic aperture, non-linearity

The aperture-filter is a string-specific low-pass (Chapter 5.4.4) that is defined by the width of the magnetic window. Decreasing the distance between magnet and string, and increasing the magnetic strength increases the cutoff frequency. The filter is string-specific. For strong picking attack, the magneto-electric transfer (Chapter 5.8) based on the law of induction shows a non-linearity that should not be neglected. This non-linearity is string-specific and therefore must not be mixed up with amplifier distortion.

Pickup directionality

If a pole-piece of a pickup is positioned exactly underneath the string, the pickup will sample almost exclusively the fretboard-normal string-vibration (Chapter 5.11). This implies that pickups offset to the side will to some extent tap into the fretboard-parallel vibration, as well – this may be of significance for fret-bounce processes (Chapter 7.12.2)

String damping

The string vibration is dampened by several mechanisms (Chapter 7.7); it is in particular the internal damping, and the damping at the bearings, that stand in the way of "endless sustain". The internal damping is generated by micro-friction as the string is deformed; for wound strings, the damping occurring between core-wire and winding may be included here, too. Also, already minor residue from skin or talcum in the winding leads to dramatic reduction of the decay time (Chapter 7.7.6). The damping due to bearings happens at the bridge and at the frets (or at the nut) because a small part of the vibration energy is not reflected but drains into the bearings. This is the only mechanism with which the **guitar body** can have any influence on the electric sound at all♣, but because this damping effect is supposed to be as small as possible in order to support long sustain, the influence of the body is very small. In particular in solid-body guitars, the body inflicts little absorption. The bridge – located between string and guitar body – may exert a comparably larger influence on the string vibration.

Neck, action, frets

Forceful picking and/or low action will have the effect that the string often bounces off the frets (Chapter 7.12.2). The percussive sound caused by this depends largely on the height of the individual fret – and the "never touched" uppermost frets are relevant here, as well. Therefore, if a musician notices the sound of a guitar changing over time, this is not because – as Neil Young opines in G&B 12/05 – every played note somehow stays in the guitar ☹, but very probably because of fret-wear ☺. Which would also explain why that vintage guitar acquired for a 5-number sum does suddenly not sound "vintage" anymore at all after the urgently required re-fretting job has been performed.

Finger- and hand-damping

As soon as the fretting hand touches the guitar neck, it acts as an absorber and potentially reduces sustain, and a similar effect is caused by the finger pressing the string against the fret. We may find pertinent frequency-dependencies with open-played, brand-new strings – however, these dependencies quickly loose their significance after having played for half an hour, and when analyzing not only open strings.

Pickup transmission

The transfer-function of a magnetic pickup is predominantly determined by the inductance of the winding, and the capacitance of the cable (Chapter 5). Together, the two form a low-pass the cutoff frequency of which may lie below 2 kHz, or above 5 kHz – thus, the pickup plays a decisive role for the electric sound. The transmission coefficient that may easily vary by +300% contributes significantly to the sound in case the input stage of the amplifier is overdriven. Consequently, there can be no serious statement along the lines that the pickup would just add a few "nuances" to the "sound of the wood". Apart from the LC-lowpass, the pickup may contain further frequency-determining components, such as metal sheets causing dampening of eddy-currents, or guides for the magnetic field that result in a spatially more spread-out sampling of the string vibration. In humbuckers, inductive and capacitive coupling processes may cause complex filtering. The parameters of pickups of seemingly the same build can have considerable scatter: in particular in old pickups, the number of turns in the winding, the thickness of wire and varnish, the magnet material, and the fittings can vary strongly, and even magnets mounted the wrong way 'round may occur. Moreover, old pickups may have shorts in the winding, and therefore there is not "the" Strat-pickup, nor is there "the" 1958-Strat-pickup.

♣ Regarding body- and neck-resonances, see Chapter 7.7.4.4.

Electrical circuit in the guitar

The electrical components (potentiometers, capacitors, possibly also coils) included in the guitar form an electrical network the filtering effect of which may be described without much effort. The “holy aura” attributed to old components can scientifically not be substantiated, and in particular horrendous markups are not justifiable, even if corresponding myths are eagerly celebrated by some failed HiFi-authors. On the other hand, the coaxial cable connected to the pickup may spring a surprise due to a possible peculiar, humidity-dependent capacitance. Also: amplifier, loudspeaker and room must not be forgotten (Chapter 10 & 11).

The insignificant

Of course, given the right equipment and putting in many hours of effort, even minute changes in the decay behavior can be measured, e.g. when machine heads (tuners) are exchanged. The same may be possible if varnish is stripped off the guitar body, or if it is replaced by another type of varnish. However, all these changes are so tiny compared to the variations effected by the fretting hand that they simply bear no significance whatsoever.

Kaput: the broken, busted, worn out and dead

And then there are of course all those more or less broken, in fact unplayable guitars that “feature” unacceptably uneven frets, loose necks, rattling truss rods, pickups with shorts in the winding, scratching pots, bridges that shift from one rest-position to another at the slightest touch, or a “custom job” done by Mr. Knowitall. May the Eternal Shredder graciously accept their souls ….

You others, though, who in your hands an unbroken guitar you hold:
Do search not for new gimmicks, but to play learn – everything else come to you it will.

7.12.4 There’s nothing there, or is there??

That we tried, in this chapter, to trace the tiniest measurement artifact, and to capture conductances with, if possible, no less than 80 dB dynamic range – that does not imply that all the little peaks we could eventually measure are at all audible. Just as the executive authority needs to be separated from the judiciary authority, we need to distinguish psychoacoustics from instrumentation when doing an analysis of sound. The better the analytics, the safer it is to attribute a measured effect to the object to be measured, rather than running the danger that the measurement device fooled us. Indeed, it is a great result, as well, if a bridge conductance measured with much effort proves to be so small that its irrelevance is now safely established. And even if an audible effect shows up: not every difference in sound points to the source of the purportedly never-again-reproducible vintage-tone (whatever that may be) … not every fart renders the planet inhospitable.

