8.7 Auditory experiments

The predominant part of this book discusses the function of the electric guitar by way of physical laws, documented via formulae and measurement protocols. This enables us to explain e.g. wave propagation, induction and signal filtering – but not the actual effect on the listener. The verdict of the latter is only made available in auditory experiments. Therefore, the following seeks to give a short summary of methods towards controlled sound appraisal.

8.7.1 Psychometrics

Psychophysics forms an interdisciplinary scientific area bridging **psychology** (= the science of sensory perception, among others), and **physics** (= the science of natural processes); it researches and describes the connection between physical stimuli on the one hand, and the sensations and perceptions caused by these stimuli on the other hand. **Psychoacoustics** narrows the wide area of physics down to sound phenomena, and connects the "science of sound" with the "science of hearing". **Psychometrics** is a sub-area of psychology that has specialized in the (in particular quantitative) measurement of sensations. Electrical voltage is measured with a voltmeter, temperature is measured with a thermometer – but how can we measure the sensation of sound resulting from listening to a guitar? This can work only if the human being is both **measurement object** and **measurement device**, with all connected problems. The human being is the measurement object because his/her sound-perceptions are to be determined; and he/she is the measurement device because he/she needs to describe these perceptions. Since measurement object and measurement device cannot be separated, errors are possible. The statement "I do not hear any tone" can mean that the measurement object (the "subject") indeed does not hear anything and responds truthfully. However, it could also mean that the subject lies and does actually hear something. It could also indicate, though, that the subject thinks that what he/she hears is not a tone but e.g. a noise – in this case the response "not … any <u>tone</u>" would be truthful from his/her perspective. In order to avoid such misunderstandings, and to obtain the subject's assessment in the most unaffected and most reproducible manner, psychometrics has elaborated guidelines for the execution of experiments and their evaluation.

Reproducibility of the sound-presentation constitutes a particularly essential aspect. The reason that a guitar sounds – compared to the studio – different on stage is found more in the (physical) room acoustics, and not primarily in perception psychology, although the assessment *criteria* (measurement device!) can be situation-dependent, as well. In order to guarantee reproducibility in the presentation, many experimenters used specially equalized **headphones**. While this is an improvement over exposing the test person to a totally undefined sound field, it does not warrant an exact sound exposure, either. The position of the headphone (relative to the external ear), and the individual shape of the earlobe and the ear canal do influence the sound level.♣ Another problem is the fact that an entirely unnatural sound field is created that turns with the head. Using precise instructions, mechanical fixation, probe microphones, and figurative presentations, these uncertainties can be reduced to the point that they are seen as "bearable" in daily research routine – this is then simply is as good as it gets. Sound presentation via one or two **loudspeakers** would be the alternative – not small PC-monitors, though, but calibrated premium studio monitors. Indispensable is again documentation: room acoustics, transfer functions, impulse responses, best supplemented by dummy-head recordings. The more is documented, the easier the decision after an experiment series whether an effect is due to the hearing system or due to experimental methodology.

♣ Zollner M.: Interindividuelle und intraindividuelle Unterschiede bei Kopfhörerdarbietungen, Cortex 1994.

It may be that not a stored (or artificially generated) sound is to be assessed, but a **sound source**, i.e. an acoustic guitar or a guitar loudspeaker. In this case the question should be considered whether a recording via microphone or dummy head is made (and the recording then is listened to as mentioned above) or whether live-presentation is preferred (incl. documentation like the one involving loudspeaker presentation). A curtain hung in front of a picture will change the visual perception, and similarly the room between sound source and listener will influence the auditory perception. If the filtering by the room is ignored, the assessment is unusable. Only after the sound presentation is fully optimized and documented, the assessment of the sound may be started.

Auditory experiments may be of simple or complex, of fundamental or special character. **Threshold measurements** are easy to do for the subjects. Psychometrics distinguishes between (absolute) thresholds of stimulation, and just noticeable differences. The **threshold of stimulation** tackles merely the issue of whether something is heard. Not every tone with a sound power different from zero is audible – to be heard, the tone-level needs to be above the threshold-level. The threshold of stimulation that is determined for tones that are presented *in quiet* is called the **threshold in quiet**. If another (interfering) sound is present besides the sound to be assessed, the term used is **masked threshold**, e.g. “threshold masked by pink noise”. When determining **just noticeable differences**, the question is from which degree of signal change a subjective difference is noticeable. For example: which change in frequency is necessary so that a change in pitch is perceived? The subject’s task becomes more difficult if the question is not just whether a change is heard but also how big this change is. This **magnitude estimation** targeting the numerical assessment of perceived difference can lead to significant scatter up to the point that it is actually impossible for some experiments. We can “force” assessments, but it is hardly measurable whether something sounds better by a factor of two or three. Psychoacoustics states that it is measurable whether a sound has double the loudness of another sound. Yeah, kind of – but with a scatter of ±6 dB, gripe the critics. Scatter of measurement results is not at all limited to psychometric experiments – all measurements will include variance. It’s just that in psychometrics, the variances are particularly pronounced and therefore need to be looked into with particular scrutiny.

No subject will increase the level always by exactly 10 dB when asked to adjust to double the loudness. That is why the experimenter will average the intra-individually varying values, deriving a subject-specific mean value. *One* subject would represent an unsuitably small sample, and thus e.g. 24 further subjects need to do this adjustment-experiment, leading to 25 different **mean values** that show inter-individual differences. Again, an average is taken, and finally we get the result that will e.g. express that “on average” the subjects will increase the level by 10 dB to achieve double the loudness. That this mean is not valid for each and every human being – that is often pushed to the back of our minds. So let’s play devil’s advocate: literature reports scatter between 5 – 17 dB, and even 4 – 30 dB is found [Hellbrück 1993]. Even so: *here the center of the distribution was in the class of 8,6 – 9,8 dB*. Well then … that is almost 10 dB. To conclude from the variance that the whole shebang is one giant hokum – that would show some uncalled-for ignorance, after all. Insofar as experimenter and subject are aware of what they evaluate, averaging methods offer the only possibility to reduce clusters of dots to functions. Whether the assessments of fluctuation strength include a scatter of factor 4 or 8 – they still clearly feature a band-pass characteristic with a maximum at a modulation frequency of 4 Hz. We simply have to avoid the mistake to declare such results – with a three-digit precision – as universally valid; average values do have a limited accuracy, too.

Of course, experiment and averaging become questionable if experimenter and subject have different attributes in mind. A strongly exaggerated example would be the following: the experimenter distributes written instructions regarding the scaling of the sonority of drums. Questions are not allowed so as not to influence the subject. And off we go – judging away on a scale from 0 to 10. Not wanting – as a spoor student – to forgo those hourly €15.-, one tags along. Either according to the best of one's knowledge (or rather: perception), or according to the Monte-Carlo-method: everything's coming 'round again, and even this hour will pass. The PC generates some averages, and we have a result. The concept what "sonority" is supposed to be – that should be shared by experimenter and subject … otherwise it all really is one big hokum. And nobody say that a good result proves that this term "sonority" is self-explanatory.

A less construed example from the Süddeutsche Zeitung (an internationally read German newspaper) published on 24.09.2009: positioned within an MRI scanner, a subject is shown various photographs. Depending on the motif, the MRI scanner establishes different brain activities. Exceptional here: the subject is a fish. And even much more exceptional: the fish is dead. In spite of this, the evaluating computer manages to arrive at a significant mean result. In this case, the experimenter is not a charlatan but an honorable scientist seeking to show *how much nonsense is often practiced in modern experimental brain research*. N.B.: having many subjects at hand and using modern ("Russian") averaging algorithms won't guarantee solid data … or, in other words: garbage in – garbage out.

Modern psychology, and in particular psychometrics, increasingly employs statistical evaluation methods; that may be pesky, but it's unavoidable. The most wonderful experiment is no good if the results are erroneously evaluated. Just as nonsensical is to continue to (without experimental experience) process mindless data until a convenient result is obtained. Consider that, in a source-recognition experiment, all guitars are given the numeral 1, all trombones the number 2, and all basses the numeral 3. If the subject has now recognized four times the 1, twice the 2, and four times the 3, then we may not average arithmetically and state that as a mean value a trombone is recognized. These assessments or nominal judgments, after all, and there is no mean value. It would be similarly absurd to calculate a "mean postal area code". That would be possible, yes, but not interpretable.

A **nominal judgment** groups according to names and thus congregates elements of equal attributes into groups. Only with an **ordinal judgment**, a ranking is created – however without any metric. In metrology, class-0 is more precise than class-1, and the latter is again more precise than class-2. Class-0, however, does not necessarily feature double the precision of class-1, and if that were the case, class-1 could well be 3 times as precise as class-2. More mathematically: an ordinal scale is determined via inequations but not via intervals of equal size. The latter comes into play only with **interval scales**, they allow for additivity based on equidistance. What is not required is that the property of the element with the value "0" disappears. 0°C does not imply "no temperature" but rather is an arbitrarily fixed neutral point, and that is also why 20°C is not double as warm as 10°C. At the end of this list we have the relational scale in which the relations of the numbers mirror the relation of the degree of manifestation of the assessed characteristics. The sone-scale is such a relational scale: if two loudnesses have the relation 2:1, the same ratio is also found in the corresponding sone-numbers (8 sone is double the loudness of 4 sone). Conversely, the phon-scale is not a relational scale: 60 phon is not double the loudness of 30 phon.

The following table summarizes scales, properties and operations. Nominal scaling only offers *equal* or *unequal*, ordinal scaling adds in *larger than* and *smaller than*, additivity comes in with the interval scale, and product/division is only there from the relational scale.

The median (numerical value) of a nominally scaled set cannot be determined because for this all elements need to be brought into a ranking – which does not exist in nominal scaling. Only the modus, the maximum rate of occurrence, may be identified. “Most letters were transported for postal code 93057” makes sense, but “the median is postal code 93057” does not. As a rule, to use ratios of levels is pointless – although there may be exceptions here and there, insofar as “0 dB” indeed is mean to imply “nothing”. In terms of the SPL, level ratios are usually without meaning – using an equalizer, however, a boost of 8 dB may be double the boost of 4 dB.

Scale	**Nominal**	**Ordinal**	**Interval**	**Relational**
Synonyms	Topologic scale		Metric scale, cardinal scale	
Allowable statistical measures	Absolute and relative rate of occurrence, modus	Cumulative rate of occurrence, median, percentile	Arithm. mean value, variance, standard deviation	Geometric mean value
Operations	$= \;\neq$	$= \;\neq, <\; >$	$= \;\neq, <\; >, +\; -$	$= \;\neq, <\; >, +\; -, \;\times\; \div$
Features	Nominal feature, categorical or qualitative feature	Ordinal feature, ranking feature, comparative feature	Cardinal feature, quantitative or metric feature	

Table: Scales, features, allowable operations. In addition to the statistical measures in each column, all measures on the left of these are, correspondingly, also allowed.

Once we now have perfected the sound to be presented, and once the feature-scale to be found is determined, the subjects (test persons) may arrive. From now on it’s: no influencing, and reproducible instructions. With a statement given right at the start of the sort that EC’s “Brownie” is to be assessed, an opinion like “sounds a bit thin” is not likely to be voiced – that guitar will simply sound “killer”. In order to prevent such bias, the desired objective is the **blind test**, although that is not always doable. It would be possible to assess two guitar amps without prejudice if the amps are hidden behind an opaque curtain (a rotary table takes care of positioning problems); however, the immediate difference between a Gibson Les Paul and an ES-335 may only be hidden from the guitarist if rather elaborate precautions are taken. The differences between different scale lengths (e.g. 24" vs. 25,5") are always recognized – blind tests are impossible here. **Written** instructions for all subjects ensure that everyone is told the same, and they also facilitate checking the instructions a year later. If we realize in the course of an investigation that the subject have difficulties doing an assessment, we must not change the instructions until the ”correct” result turns up and average subsequently over all experiments. Out of the question is also something like averaging only over the last five subjects (because only they have heard the difference). Difficult question: should one single out unsuitable subjects? To assess drumsticks, you would not ask harpists to give a verdict; the sound of a guitar amplifier can, however, certainly be judged by a non-musician, as well. Because there are no set rules here, documentation is particularly essential (questionnaires handed out to all subjects). If we want to do a true service to science, we measure the hearing threshold in quiet (audiogram) of the subjects ahead of the start of the experiments. This is because many a musician (and other people spending any length of time in noisy environments) have generated (and have been subject to) so much sound energy in the course of their lives that their auditory system has experienced considerable damage. Corresponding judgments may therefore not be typical for those of normal hearing. Wouldn’t you concur with that, dear Mr. Townshend? Mr. Townshend, sir? Mr. Peter Townshend – HELLO there?? **MR. TOWNSHEND!!!**

Last, we have to consider according to which method the subject is going to deliver the judgment. That is, “last” in the framework of this short overview, because the rules of professional psychometrics♣ are more extensive and go beyond the presently set scope. **Methods of acquiring judgments** differ (among other aspects) according to the degree of involvement of the subject. Is the latter merely supposed to give a verbal assessment (“I don’t hear anything”), or does he/she need to twist a knob such that a tone becomes just audible (or inaudible)? Is a scale of the assessment presented, or can the subject make one him/herself? Is the verdict “no difference” allowed, or is a preference forced (forced choice)? Is the response of the subject considered when new test sounds are selected? May the subject compare test sounds as long as he/she likes, or is a decision called for after two repetitions? For decades, psychologists have never grown tired of preaching that all these details in the experiments are vital to the results, and so we engineers cannot but believe it, and promote it. All the while hoping that – vice versa – the advantages of correct level-measurements find a similarly strong lobby in the psychologist-camp.

Scientific auditory experiments are more than just calling in three pals to in order to verify the hypothesis that the new Fender is another milestone in rock history. The last trap is found in the formulation of the results. The statement “the Makkashitta VR-6 has some mighty sustain” is o.k.; however, declaring “due to its maple neck, the Makkashitta VR-6 has some mighty sustain" is, most probably, rubbish. Unfortunately, it is everyday practice in test reports: the tester hears something (which is his god-given right), and connects without any prove what he has heard to some kind of material characteristic (which is stultification of the reader). Often, e*vid*ent associations (i.e. from visual domain) are dragged into the arena in order to substantiate “ear-sounding” connections (i.e. in the auditory domain). Does a silver trumpet ring more “silvery” than a “warm-sounding golden trumpet? Science says: no, it’s all but imagination, or influencing the player. If the latter has to play under yellow lights and cannot distinguish the metals, he/she plays the same, and then the sound is the same, too – despite different metals (and given equal geometry). Does that big loudspeaker have less treble because its heavy membrane is set in motion more slowly? Mechanics say: no, you are mistaking cutoff-frequency with efficiency. Are the sound pressures arriving at the two ear canals indeed the only excitation quantities for the auditory sense? Well, with the answer “of course not”, the examinee would have most likely failed the psychoacoustics exam in 1979. But since then, much has progressed; we do learn all the time. The visual impressions play an important role in the auditory perceptions, and thus the perceived loudness is dependent on the distance at which we see the sound source. It’s also why the red express train is perceived to be louder than the green one, despite equal SPL [Fastl]; and it is the reason why we may hear “behind us” although the sound source is in front. It’s a wide field, and – for the most part – still an only sketchily examined one.

♣ e.g.: Kompendium Hörversuche in Wissenschaft und industrieller Praxis, www.dega-akustik.de

8.7.2 The sound of the un-amplified guitar

How does the expert test an electric guitar? He first listens to it without amplification (i.e. “dry”). “It is certain that – contrary to common opinion – the desired sound of electric guitars and electric basses is not mainly dependent on the pickups. Rather, the wood forms the basis. If a customer travels to see me in the ‘Guitar Garage’ in Bremen and seeks to discuss pickups, I first listen to the instrument without amplifier.” (Jimmy Koerting, Fachblatt Musikmagazin). Or: “For a first evaluation of the sound quality we do not need amplifier towers nor distortion boxes – a small combo entirely suffices. It would of course be even better to test the sonic behavior in a quiet corner, dry, purely acoustically, regarding response, balance, and sustain.” (G&B 3/97). But why then are two guitars that sound differently dry, not able to feature these differences anymore when played through an amp? “Surprisingly, the differences in sound show up – compared to the dry-test – much less when connected to an amp”. G&B 7/06, comparison: Gibson New Century X-Plorer vs. V-Factor. Or, from a different comparison: "The Platinum Beast sounds dry powerful, warm and balanced, with velvety brilliance and tender harmonics, while the Evil Edge Mockingbird is sonically somehow feeble, poor in the mids, with somewhat more pronounced bass, but also clearly more brilliant and harmonically richer. Connected to an amp, and thanks to the hot humbuckers, everything is different though: hard to believe, but the two instruments now sound almost identical.” G&B 8/06.

Extreme examples will not serve to help in this case. Plywood (or even rubber!) is used as material for the (solid) guitar body in order to justify significance and necessity of high-grade body-woods. That is one extreme: using a totally unsuitable (absorbing) body, a good guitar cannot be built; ergo-1: the wood is more important than the pickups. The other extreme: a brilliant (“under-wound”) Strat-pickup is swapped for a muffled, treble-eating Tele-neck-pickup with a cover made of thick brass, and the result is the statement ergo-2: the pickup is more important than the wood. Both approaches are too lopsided.

From the point of view of system theory, the vibrating string is a generator that on the one hand excites guitar body and neck to vibrate and thus to radiate airborne sound. On the other hand, the relative movement between string and pickup induces a voltage. Airborne sound and voltage are therefore correlated because of the excitation from the same source. If the string-vibration dies down already after a few seconds, the pickup cannot generate a gigantic sustain. Or can it? Within certain limits, indeed, it could – in cooperation with a suitable amplifier (+ loudspeaker). The decay behavior is changed if the signal experiences limiting via the amplifier (overdrive, crunch, distortion). This is the decay behavior audible *via the loudspeaker*, because the decay of the string vibration is not changed. Or is it? Things begin to become unfathomable, and exactly for this reasons we find such contradictory opinions in guitar literature. If guitar and loudspeaker are positioned closely together, feedback may certainly influence the string vibration, as well. Maybe this is where the expert advice comes from: first listen to the guitar without amp. However: hardly any guitar player will buy an electric guitar to play it un-plugged forever. Sooner of later he will plug it in, and then the forecasts from the dry-test are supposed to prove to be true. The likelihood of a fortunate result of that experiment is indeed not entirely zero: electrical sound and acoustical sound are somehow related (correlated) – but in which way exactly is unclear to begin with.

Let's imagine a simple **experiment**: the pickups of a Stratocaster are screwed directly into the wood so that they have a clearly defined position. Will already that change the sound? Anyway, let us assume this special sound to be the reference. Guitar, pickups, and now on to the peculiarity: once with pickguard, and once without. That's a pickguard made purely from plastic so that no metal layer may generate any eddy-current damping. Now, do we hear a difference in sound if that guitar is played with pickguard compared to being played without? In the acoustic sound: definitely yes – in the electric sound: definitely no. Via the body, the pickguard – if present – is made to vibrate. It has weakly damped natural modes (eigenmodes) and is able to radiate audible sound in several frequency ranges. Do these pickguard-vibrations act back to the string? Theoretically: yes, because "all things are connected" (as already reportedly pointed out to the US Government by Chief Seattle as early as 1854/5). Practically no, because between string and pickguard we find the body that weighs in with many times over of the mass of the pickguard. The string vibrations are changed by the pickguard only in such an insignificant degree that the electrical sound does not change audibly. However, the radiated airborne sound does. Or another **example**: singers perform in a concert hall, and listener A listens in that hall while listener B listens from an adjoining room via the open door. Now, the door is closed – what changes? For listener B, a lot – but for listener A, almost nothing. Very theoretically, we can again call in Chief Seattle and demand a correction factor for the wall absorption that the closed door has modified, but in practice not all of such lemmas have been rewarding, as the in the chief's case rather unfortunate history has shown.

What is the connection between the singer and the above electric guitar? In both cases there are two different transmission paths that modify the sound they carry in different ways. Knowing about one transmission path does not allow – in the general case – for any conclusions on the other transmission path. The listener in the concert hall cannot even be certain that the other listener (The Man Outside …) hears anything. This implies for guitars: what use is the great acoustical sound if the pickup winding is broken. Caution, though: we are again entering territory of extreme positions. Thus, not assuming a complete sound insulation for listener B, the latter will be able to make some statements: when singing is going on, when it is paused. Maybe, listener B can even recognize which one of the three sound sources is trying to get to that high C: the little one, the pretty one, or *Fat Lucy* (also called the stage-panzer). Any problems with intonation are perceived through the closed door, as well, as long as the latter in not totally soundproof – and if such problems are present within the expectations of the listener in the first place.

The thing with the expectations can be observed with guitars, also: it is astonishing how some guitar tester become victims of their own convictions. Irrefutable **credo**: "Of course, the original Les-Paul-mix of rosewood fretboard and mahogany body fitted with a thick maple cap – that gives us the unique Les-Paul-sound". That's just how it needs to be written – in this case in a comparison test (G&B 7/02). And then a copy with an alder body (stigmatized with a "!" in the test) dares to sound good. It even commands the tester's respect. "*... it can, in any case – be it alder or mahogany – convince with a first-class clean sound...*" Well, well – let's not exaggerate here! Don't forget, its alder!! And lo and behold: "*... overall somewhat subdued and a bit shy.*" There we are: typical alder. However, oh great Polfuss, what happens only a column further, with the Fame LP-IV also included in the test? *"Those who go for a typical forceful Les-Paul-sound without frills should check out the Fame LP-IV. Indeed, it sounds the most authentic. In all areas, its sound is very similar to that of the original*". **Question**: according to the test, the Fame LP-IV sports a maple neck, an oak fretboard, an alder body, and a mahogany cap – did I get anything wrong here?

Let us postpone the discussion on materials to later, though, and return to the question of how far the conclusion from the "dry" test to the electrical sound is admissible. Apparently there are "**robust**" signal parameters that win through on every transmission path, and "**fragile**" parameters that change on their way through the transmission medium. The pitch is quite robust: whether a guitar is in tune is audible both "dry" and amplified. Not to the last cent, as psychoacousticians know, but with a precision adequate for some first considerations. The sonic balance between treble and bass, however, depends on the tone settings of the connected amp – that much is as uncontested as it is trivial. The "dry" sound can make every effort: it can never hold its own against a fully turned-up bass control. "Anyway, that's not what we mean", the expert will object, "in the dry-test I can hear the fundamentals of the sound, and the soul of the wood." Please, dear scientists and dear psychologists – no malice now … it's o.k. to state something like that here, as a guitar tester who does neither have to understand much about physics nor of psychology. However, the **soul of the wood** does reveal itself to the seeker not a prima vista; it does require many séances in which the spirit penetrates the matter; much knocking on wood needs to happen, and a tuning fork must to be pressed against the solid body of a Stratocaster (in the Fender ads, anyway), and many years of ear training are necessary. At least for this last point we should be able to reach a consensus, shouldn't we? This is not supposed to be about the guitar-o-phobe agnostic with progressive dysacusis, but about the more or less pronounced aficionado of the instrument. Those who – with their more or less extensive listening experience – indeed hear details in the sound not accessible to the layperson.

Problem: how do you describe such sound-details? This is the classic conceptual formulation and task of **psychophysics** and psychometrics that frequently leads to similarly classical misunderstandings. A verbal description (dead, woolly sound) is rejected at the physical docking-port as much too ambiguous and imprecise, just like the exact physical description (8,43% degree of amplitude-modulation at 944 Hz with f_{mod} = 6,33 Hz) is objected to by the artistic/mystical faction as pipe-dream-y and too abstract. Logically, any proposals of compromise trying to bridge the two realms are dismissed by both sides. Well then: rather than the wood's soul, often a dead or a lively sound is mentioned. What distinguishes live from dead matter? The matter that is alive – it moves! And already we have the first objections, because that would define the pen dropping from the table as alive? O.k., so we turn to a fundamental philosophical contemplation of life in particular, and of the universe and everything in general … NOT! No, really not. **What is alive does move**. Period. Conferred to the guitar sound: an artificial tone with its strictly harmonic partials all decaying with the same time constant, sounds dead. However, if the partials decay with different speeds and with different beats, the impression is one of movement and life. In this, the term "movement" may indeed be seen in its original meaning as change in location: when a sound source changes its position in a (sound-reflecting) room, time-variant comb-filters vary the signal spectrum – the movement in space has the effect of a "movement" in the sound. Way back in prehistoric times it was presumably in support of survival if moving sound sources were given a higher priority than static sources; at the same time early researchers in communication discovered that speech sounds will only convey information if they include variations. Without pushing too far into foreign territory: there would be enough reasons why the human auditory system continuously hunts for spectral *changes*. Even though electric guitars are younger that roaring tigers and vandals screaming "arrrghh!", our hearing has its capability to analyze, and it takes advantage of it. A lively tone rich in beats sounds more interesting than a dead sound – at least as long as instrument-typical parameters are maintained.

Similarly to the pitch of the string, the beats between partials can be rather **robust** relative to the transmission parameters, and therefore it is imaginable that the expert may be able to deduce criteria for the electrical sound from the "dry" test. On what does the robustness of the signal parameters depend? Frequency-dependent signal parameters – such as the spectrum – loose their individuality if the corresponding frequency-dependent system parameter (the transfer function) has a similar shape. Three examples follow:

1) Psychoacoustics [12] describes the balance between high and low spectral components as "**sharpness**": treble-emphasizing sounds have a high sharpness; turning down the treble control reduces the sharpness. Spectral details are not as essential for the calculation of sharpness as the basic (smoothed) run of the spectral envelope. To be more precise: the sharpness is taken from the weighted loudness/critical-band-rate diagram which has a mere 20 sampling points in the frequency range important for electric guitars. (Transmission-) frequency-responses of guitar amplifiers can be represented with the same increments (**Fig. 8.45**), and from the kinship of the two data-sets we can conclude that the sharpness of the "dry" guitar sound in general does not correspond to the sharpness of the amplified sound. In other words: changing the tone controls on the amplifier allows for changing the sharpness – from this point of view, sharpness is not a robust signal parameter.

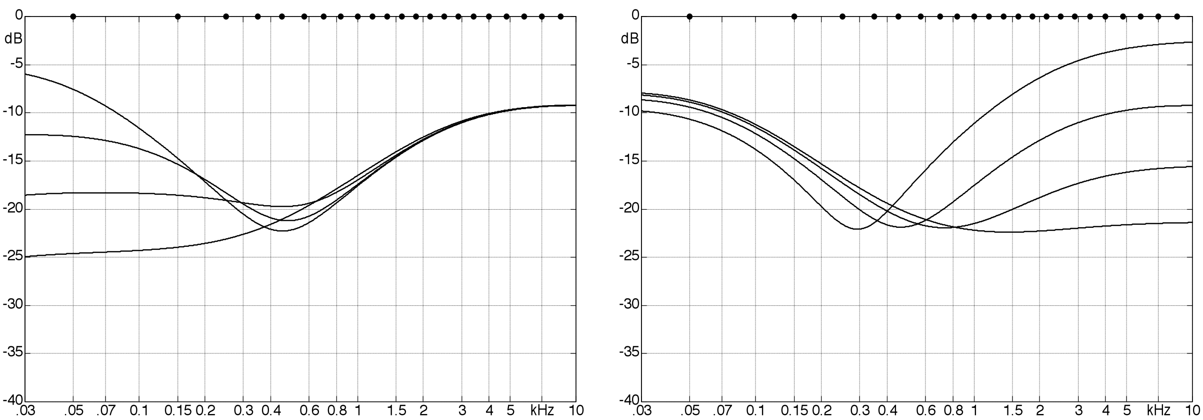

Fig. 8.45: Tone control of a Fender amplifier (transmission factor). The dots on the top mark the critical-band grid (discretization of the abscissa in order to calculate sharpness).

2) Beats between partials can in the time domain be described as amplitude fluctuations, and in the frequency domain as the sum of closely neighboring partials. For example, two partials of equal level but slightly differing frequencies (e.g. 997 Hz, and 1003 Hz) lead to the auditory perception of one single 1000-Hz-tone fluctuating in loudness with 6 Hz [3]. In order to change this beating, a highly frequency selective operation is necessary. Such an operation is untypical for tone controls in amplifiers. From this point of view beats in partials are robust relative to simple tone-control networks.

3) The spectrum of a quickly **decaying** sine-tone (**Fig. 8.46**) is largely limited to a narrow frequency range. Any changes in the decay behavior need to be done using highly frequency-selective methods, too. In other words, a linear, guitar-amp-typical tone control network will practically not change the decay-behavior of individual partials – the decay behavior is robust in this respect.

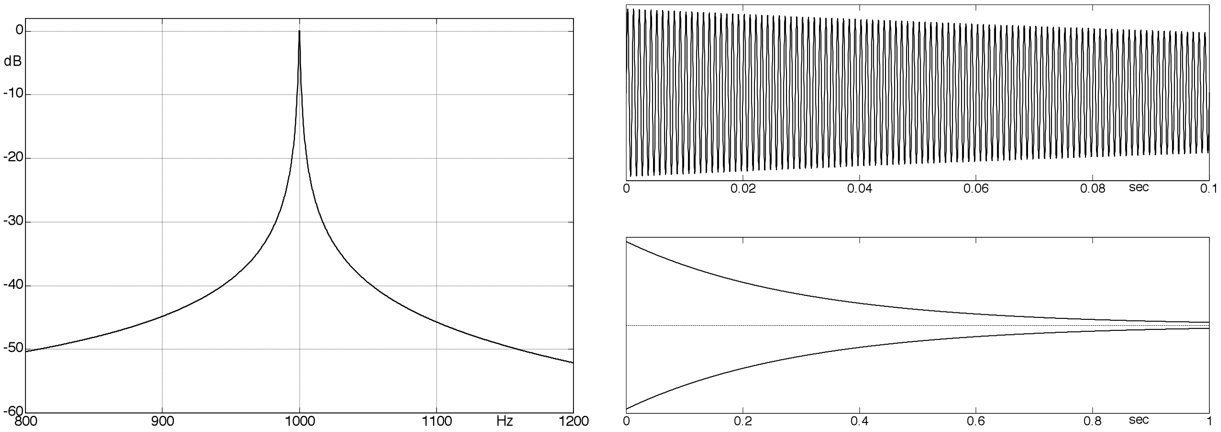

Fig. 8.46: Decaying sine-oscillation, $f = 1000$ Hz, time-constant $\tau = 0{,}3$ s.

These simplified representations do, however, require supplements in some points. It is not only the transfer factor of the guitar amplifier that changes the spectrum of the string oscillation. The loudspeaker (including its enclosure) acts as filter, as well; in the detail, its transmission curve is of stronger frequency dependence than the tone-control network is. Still, a loudspeaker membrane does not reach the high (resonance) Q-factors of decaying guitar partials – it would have to generate clearly audible natural tones for that, and this it does exactly NOT do. The last filter in the transmission path is the room with its reflective borders. Its effect cannot be neglected even in the "dry" test; when playing connected to the amp/speaker, the distance to the speaker needs to be added in as variable, as well. As long as one remains within the near-field of the loudspeaker, the effect of the room can be regarded as equal for both playing situation in a first-order approximation.

Special consideration is required for effects that achieve more than what simple tone control does. Adding artificial reverb can extend decay processes and feign life that is not included in the original in that form. Chorus/phaser/flanger are time-variant filters with high (resonance) Q-factors – their use always aims at changing the fine structure of the partials. Single band, and in particular multi-band, compressors change the decay time constant of individual groups of partials. Overdrive has similar effects but adds in additional partials. It is therefore very well possible to also influence the signal parameters designated as robust above. However, even without deploying radical effects one may – within certain limits – extrapolate from the sound of the unamplified guitar to the sound of the amplified guitar. Which of the many beat- and decay-parameters are crucial to the 'good' sound, though, is at the most implicitly appraisable … and we have not even touched the wide field of frequency- and time-related masking [12]. Therefore, only this principle can hold: **the unamplified sound of an electric guitar should basically not be evaluated**. Only for the expert, and in consideration of his/her special knowledge and listening-experience accumulated over decades the exception, this rule allows the exception that the "dry" test reveals "everything", after all, in the individual case. Experts who may claim this exception for themselves are: testers of all guitar magazines, all guitar sales-personnel, all guitar players who have had of who have wanted to have a guitar for more than a year, and all listeners to CD's who still have the sound of Jeff Beck's signature guitar ringing in their ears (see Chapter 7). And please, dear experts who have now received so much legitimization for your obviously indispensable "dry" tests: that the assessment of tactile vibrations is nonsensical – that should by now be o.k. for a consensus, should it not?

Concluding the topic of guitar tests, a few citations in the following:

Yamaha Pacifica-guitars (maple neck, alder body) in a comparison test: "The acoustically quite comparable basic characteristics of the Pacificas differentiate themselves rather clearly according to their pickups, after all. (G&B 6/04)."

Gibson Les Paul Faded Double-Cutaway: "Already with the very first striking of the string it becomes clear that the economy-varnishing curbs the resonance properties of the woods to a lesser degree. The guitar vibrates from the feet (strap-knob) to the tips of the hair (machine heads) so intensely that you can feel this even in your own body; (G&B 6/04)."

Ibanez IC400BK: "The slight underexposure of the E_6-string as it appears in the dry test has suddenly disappeared with the support of the pickups; (G&B 6/04)."

Squier-Stratocaster, comparison: **mahogany**-body vs. **basswood**-body: using the neck- or the middle-pickup, both guitars sound almost identical (G&B 5/06).

"Picking up the **Pensa-Suhr**-guitar and playing it un-amplified, the reasonably learned ear immediately hears where this is at. … both standing up and sitting down, you feel already in your belly the fantastic vibration-behavior of the outstandingly matched woods." (Fachblatt, 6/88).

"Despite using humbuckers, a Strat will never turn into a Les Paul"; G&B 2/00. **Ozzy Osbourne** on Joe Holmes: "In fact, I normally don't like Fender guitars. But Joe gets this fulminant Gibson sound out of them"; (G&B 2/02). "**Jimmy Page** recoded the whole of the first Led-zeppelin album using a **Telecaster**; the guitar sound on this album is exactly that of a Les Paul"; (G&B Fender-special-issue). **Mark Knopfler**: "If I look for a thicker sound, I use my Les Paul; it simply is more dynamic. That doesn't mean that I couldn't do the same thing with a Stratocaster"; (G&B Fender-special-issue). **Gary Moore:** "Some people think that a Fender Stratocaster is heard on 'Ain't nobody'; actually, that is my own Gibson Signature Les Paul"; G&B 7/06 p.91.

Big mass of wood (**3,9 kg**): Due to the big mass of wood, the response seems a bit ponderous and the notes don't get off the starting blocks that fast; (G&B 7/06).
Even heavier (**4,15 kg**): the guitar vibrates intensely, responds directly and dynamically, each chord or note unfolds crisply and lively; (G&B 8/06).
Despite the enormous mass of wood (**3,85 kg**), almost every note responds crisply and dynamically, and unfolds very swiftly; (G&B 7/06).
The lower **mass** can be more easily made to vibrate; (Thomas Kortmann, gitarrist.net).
A slender guitar **body** also creates a slender sound; (G&B 7/02).
Thinner **body** = less bass; (G&B 4/04).

Thick neck = sonic advantages; (G&B 8/02). **Thin neck** = round, fat tone; (G&B 10/05). **Thin neck**: the lower the mass that needs to be moved, the more direct and quickly response and tone-unfolding get off the starting blocks; (G&B 3/05). **Crisp** and direct in the response, every note gets quickly and lively away from the starting blocks, **despite the immense mass of the neck** (that needs to be first set into motion, after all); (G&B 9/05). **A thin neck** has no acceptable vibration behavior whatsoever; (G&B 3/97). Sonically advantageous is that the **neck** weighs in with **a lot of mass**; (G&B Fender-special-issue). The **Ibanez JEM 777** sports an extremely thin neck design: the basic tonal character is powerful and earthy; (Fachblatt, 6/88). Of course, the **shape of the neck** contributes to the tonal character of the guitar, as well; (G&B, 12/06). What is absolutely not true is that **thick necks** will sound better than thin ones. I have already built the same guitar with the thick and a thin neck and could not find any difference; (Luthier Thomas Kortmann, gitarrist.net)

8.7.3 Tactile vibration perception

There is scarcely any guitar test-report that does not praise the exorbitant vibration-happiness of the electric guitar under scrutiny: "The design shows considerable resonance properties, after each picking of a string it vibrates intensively and clearly noticeable.” G&B 9/06. Or: “ From a vibration-engineering point of view, the MTM1 ranks at the highest level because the whole structure resonates intensively into the last wood fiber after each picking of a string; this results in a slowly and continuously decaying sustain.” G&B 8/06. Or: “Combined with the given open freedom of vibration (sic), we achieve a beaming sound color.” G&B 8/06. Or: “Less mass can more easily be made to vibrate.” Luthier Thomas Kortmann, Gitarrist.net. Or: “At Fender they even proceeded to build bodies from several wood-parts … Of course, the ability of the wood to resonate is restricted by such a number of differently sized pieces.” And loc. cit.: “That Ash moreover has almost optimum resonance properties was thankfully acknowledged at the time. It does not bear contemplating that Leo Fender might have opted for mahogany back in the day.” Day et al. Or: “Clearly noticeable right into the outermost wood fibers, both Strat and Tele show very good resonance properties.” G&B 4/06.

Mind you: we are discussing electric solid-body guitars here, and not acoustic guitars. The clearly noticeable **vibrating of the guitar** is taken as a criterion for quality. Why don’t we let one of the fathers of the solid guitar, Lester William Polfuss, speak: *"I figured out that when you've got the top vibrating and a string vibrating, you've got a conflict. One of them has got to stop and it can't be the string, because that's making the sound."* Mr. Polfuss sought to let only the string vibrate, and not the guitar top. O.k., one could object that the man was a musician, not an engineer. Still, he was a musician that replied to the question of who had designed the Gibson Les Paul with *"I designed it all by myself"*. The string is intended to vibrate, and the body should just shut up and be quiet. Only the very nit-picking ones will throw in at this point that only the relative movement counts, i.e. if the strings remain at rest, and instead the body would … no, enough with the theories of relativity, it does work better the other way ‘round. However: what does that mean – better? What characterizes a better sounding guitar? In his dissertation [16], Ulrich May cites D. Brosnac with the insight that a guitar made of **rubber** would absorb the vibration energy of the string within a short time and therefore would not sound right. That is understandable but does not prove that ash (or maple, etc.) is better suited. Evidently, there are unsuitable body-materials that will withdraw an unbecomingly big amount of vibration energy from the strings. Rubber is among these materials – but who would want to build a guitar out of rubber? Presumably, damp towels♣ also rank among the unsuitable materials. Or, fresh from the sleep-lab: since a bed of a length of 1,45 m (about 5 feet) is uncomfortable for most grown-ups, a 2,12-m-long bed has to be more comfortable than a bed of 2,05 m length. Or, more guitar-specifically: what the luthiers have learned for the acoustic guitar cannot be wrong for the electric guitar. A guitar has to resonate. Right into the outermost wood-fibers. Intensively and clearly noticeable.

So, what can we feel – as human being in general, and as a guitar-tester in particular? That depends, of course, on the stimulus and on the receptor. However, in terms of vibrations, the subcutaneous Pacini-corpuscles react most sensitively to stimulus frequencies of 200 – 300 Hz; they sense vibration amplitudes as low as 0,1 µm. That also implies that the sense of vibration becomes increasingly less sensitive above frequencies of about 250 Hz. Sound-shaping harmonics remain largely hidden from the tactile sense.

♣ because of the high „damp“-ing ...

Fig. 8.47 shows the frequency dependence of the **vibration threshold**, i.e. the vibration amplitude that needs to be reached in order to generate any vibration perception in the first place. Besides the dependency on frequency and amplitude, the exact shape of the curve depends also on the area of the vibrating surface, and on the location that is stimulated. The given graph can be seen as typical for the thenar. Thus, if a guitarist feels a vibration in the neck or the body of the guitar upon striking the strings, it will be a case of low-frequency vibrations. To **check via a calculation**: if we take 10 N as force at the bridge, a mass of 4 kg, and 250 Hz as stimulation frequency, we get a displacement of 1 μm. It is therefore no wonder that vibrations result that are felt, even without any resonance-amplification.

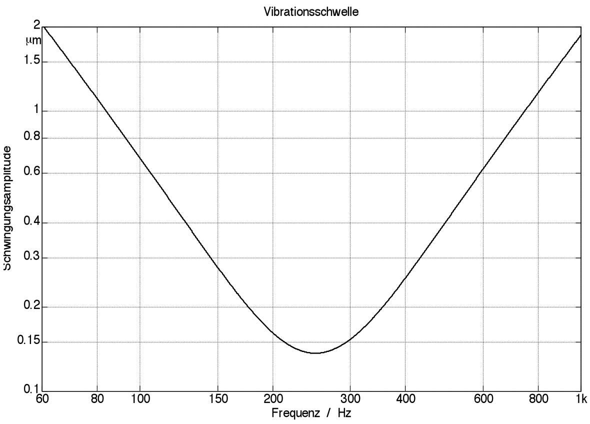

Fig. 8.47: Vibration threshold. Only values above the threshold lead to a perception of vibration. According to this graph, a vibration of an amplitude of 0,4 μm can be felt at 300 Hz; at 800 Hz it would not be felt anymore.
"Schwingungsamplitude" = vibration amplitude;
"Vibrationsschwelle" = vibration threshold

Therefore it is less a question of whether noticeable vibrations can emerge, but more how these should be assessed. If we take up again Les Paul's idea, any body-vibration to speak of would be counterproductive. With a lot of mass (ten-pounder Paula), this ideal can be approached at the cost of wearing comfort, and disregarding natural modes (eigenmodes) that amplify the vibration. The guitar neck in particular must not be too heavy; it will resonate to a noticeable degree in any guitar. What would in fact happen if guitar body and guitar neck could be manufactured to be vibration-free? On every guitar of this kind, comparable strings would vibrate in an identical manner given comparable picking! **Individuality is imperfection**, and it would fall by the wayside. In the acoustic guitar, the luthier seeks to form the transfer function frequency-dependently, and thus let some frequency ranges be radiated better, but conversely let other frequency ranges be radiated worse. An individual sound does result that way. The same principle could be applied for electric guitars, as well, and neck and body could be made to vibrate more at certain frequencies, i.e. the vibration energy would be more strongly dissipated. Whether this is indeed desired can only be judged in an overall consideration of all sound-shaping elements. Still, it would be a remarkable coincidence if exactly those frequency ranges for which the tactile sense is particularly sensitive would require the strongest damping. For one thing is certain beyond all doubt: the vibration energy that is felt, it is sourced from the string. The more intensive "the whole structure resonates", the less the string vibrates. One may agree or disagree with Les Paul's ideas – the law of conservation of energy should rather not be objected to.

Whether we would like to contradict Day et al., however, is again left up to us: "the vibrato-system itself was given a knife-edge-type shape at the six holes foreseen for the screws retaining it. The whole system was therefore mounted optimally in a very low-friction manner but still could transfer the vibrations of the strings optimally to the body." Indeed, this path is known: "**because the tawdry goes down to the corpus unsung**" … Schiller, Nänie. Or something like that.