5.13 Pickup microphonics

That a pickup is "microphonic" means that it is susceptible to air- and structure-borne sound. Actually, a pickup should only react to string oscillations, but whether it was conscious or subconscious, some designers have included rather efficient microphones into their guitars: as one speaks to one's instrument ("god-awful acoustics" …"dropped that bloody slide AGAIN" … "who the **** came up with these lyrics"), everyone can hear it coming over the speakers. In most cases it was probably an overambitious developer who sought to shield against hum, but in fact added – in the form of a **sheet-metal housing** – a microphone membrane. Which on top of everything is totally a lame duck to keep out magnetic fields at low frequencies.

Maybe we could simply pass over the whole subject with an "I never talk to my guitar"-approach, but all too often the issue develops a life of its own and ends in a high-pitched whine. Like it is the case with (proper) microphones, **feedback** develops as soon as the loop-gain increases over 1. Especially shielding covers made of steel sheets are dreaded. Even Seth Lover, famous developer with Gibson, sought to encase his PAF with a housing made from steel sheet metal. He had very correctly recognized that the relatively bad conductivity of this material leads to low eddy-current losses. Because steel is difficult to solder, German silver was in the end used – the standard in the premium range. It is not known exactly which type of steel Seth Lover originally wanted to use: there are indeed non-magnetic steel variants, but most are ferromagnetic and covers made from them – as they are stimulated by airborne sound – would induce significant voltages in the pickup coil, just as the string does. In the early days, when guitar amps were not operated much in overdrive mode, this would have not grown into too much of a problem. However, amplifier power and loop gain increased rapidly and significantly … and suddenly guitars had pickups whistling catastrophically. *"There was a pickup for sound-hole-mounting designated 'GM100' which had – probably due to blatant ignorance – the whole housing made of steel sheet metal. In terms of microphonics, it broke all records [Lemme]"*. Come to think of that this pickup was supposed to be mounted on a feedback-prone acoustic guitar ….. it's howl-scream-whistle-city ….

Even using 'non-magnetic' brass sheets would have been – cosmetically – rather counter-productive due to the yellow, quickly oxidizing color. Such covers were therefore nickel-plated (yellow-ish color) or chrome-plated (blue-ish color). **Nickel**, however, is ferro-magnetic and a similarly good conductor for magnetics as is electric sheet metal. On the other hand, c**hrome** indeed is paramagnetic i.e. practically non-magnetic, and so is aluminum. Still, it is not sufficient to just use nonmagnetic materials: moving a conductor (the sheet metal) within a magnetic field induces an **eddy current** in this conductor – and this eddy current again generates a magnetic AC-field which generates an AC-voltage in the pickup coil.

In a much-simplified model we can describe the cover mechanically as a spring-mass-system. Below the resonance frequency, the spring is contributing more, while above the resonance, the mass does. Together, sound-pressure and surface area of the cover generate a surface-normal force which below the resonance has (cooperating with the spring) the effect of a frequency-independent pressure-displacement-function. Above the resonance, the system is mass-inhibited and the pressure-displacement-function is proportional to $1/f^2$. Since for a ferromagnetic cover it is not the displacement but the velocity which determines the induction effect, an overall band-pass-shaped transmission results. The maximum voltage happens at the resonance of the cover. If that has low dampening (this seems to be the normal case for sheet metal), tremendous amplification factors (Q-factors) can appear. For non-magnetic metals a velocity-proportional eddy-voltage is generated which is transformed upwards according to the number of turns in the coil.

A simple experiment can help us estimate resonance frequency and Q-factor: given there is enough gain set in the amp, tapping on the pickup cover with a non-magnetic item (such as a pick) will generate a noise from the speaker. A short “tock” or “tuck” advantageously indicates a low resonance frequency and a strong dampening; less desirable is a higher pitched “bing”, because it would stand for low-dampening and a resonance frequency in the 2 – 3 kHz-range: rather fatal since here also the pickup resonance resides.

Everything has at least two sides to it, though: such a pickup casing resonance may give a guitar a characteristic sound, as long as it does not (yet) lead to unwanted whistling. The guitarist may indeed have bought that specific guitar due to that specific sound. Moreover, since a pickup casing has 6 walls, there is a good probability that not just one but several resonances are in the game. Although designed to be of wondrous shielding quality, a pickup with a complete metal sheet surround may reveal undreamt-of sound qualities … again: only as long as the amp is not turned up too far. A wah-pedal in facts does something quite similar in that it creates a resonance emphasis (which can be altered with the pedal position). We have now arrived in an area where it is the turn of the “vintage guru”: “the original PAF-pickups did not have potted coils so that the resonances and all that were much stronger, much more authentic; the harmonics could unfold much more freely. Everything breathes and sings, and is not as clean as the later high-tech-replicas behave.” All bullshit? Well, there may be a grain of truth in there, or a grain of salt. Either way, about 3000 PAF pickups were installed on the ’58 and ’59 Les Paul’s alone. They will not generally be without housing resonances, and among them there may well have been one with optimal structural resonances. Whether this is audible, remains speculation, plus: what is “optimal”? To be on the safe side, Gibson does today pot the ’57 Classic Humbucker with wax. The BurstBucker, however, comes with “non-potted” coils; just like back-in-the-day without wax. In particular if wax gets between the coil bobbin and the metal cover, it can dampen resonances.

Speculations about the relevance of resonances in the pickup housing can find support or be rebutted to a fair extent by measurements. An experiment carried out in the anechoic chamber should give objective **transfer data**. Several different pickups were mounted 1 m in front of the mouth of a horn loudspeaker and the transfer coefficients were determined with the substitution method. A Brüel&Kjaer-microphone (4190) served as reference for the sound pressure level measurements. It became quickly apparent that the pickups did not only react to airborne sound but also to the electromagnetic fields originating from the speaker and the speaker cable. While this is certainly also a noteworthy characteristic, it was undesirable for the given experiment, and a grounded grid between speaker and pickup ensured that only the airborne sound had any substantial effect on the pickup.

Fig. 5.13.1 shows the free-field transfer factor of a select number of pickups. The smallest sensitivity to airborne sound is found in the G**ibson Toni Iommi**; obviously it was designed for high-gain applications i.e. strong overdrive. The whole pickup housing is potted with a hard material: there are practically no vibrations in the metal sheets. The Gibson ’57 Classic proves to be already more sensitive and yields about 50 nV/Pa at 3,4 kHz; i.e. at 1 Pa sound pressure (= 94 dB_{SPL}) the pickup generates 50 nV. Without cover, that is! Putting a cover in place, we get – depending on the way the cover is fastened – a serious increase of the sensitivity to airborne sound.

The main resonance (1,35 kHz) depends strongly on the individual mounting. It is easy to imagine that over the decades almost every frequency had the honor of being the dominating pickup-housing resonance of a Les Paul – which raises the question about a pickup-housing main-resonance.

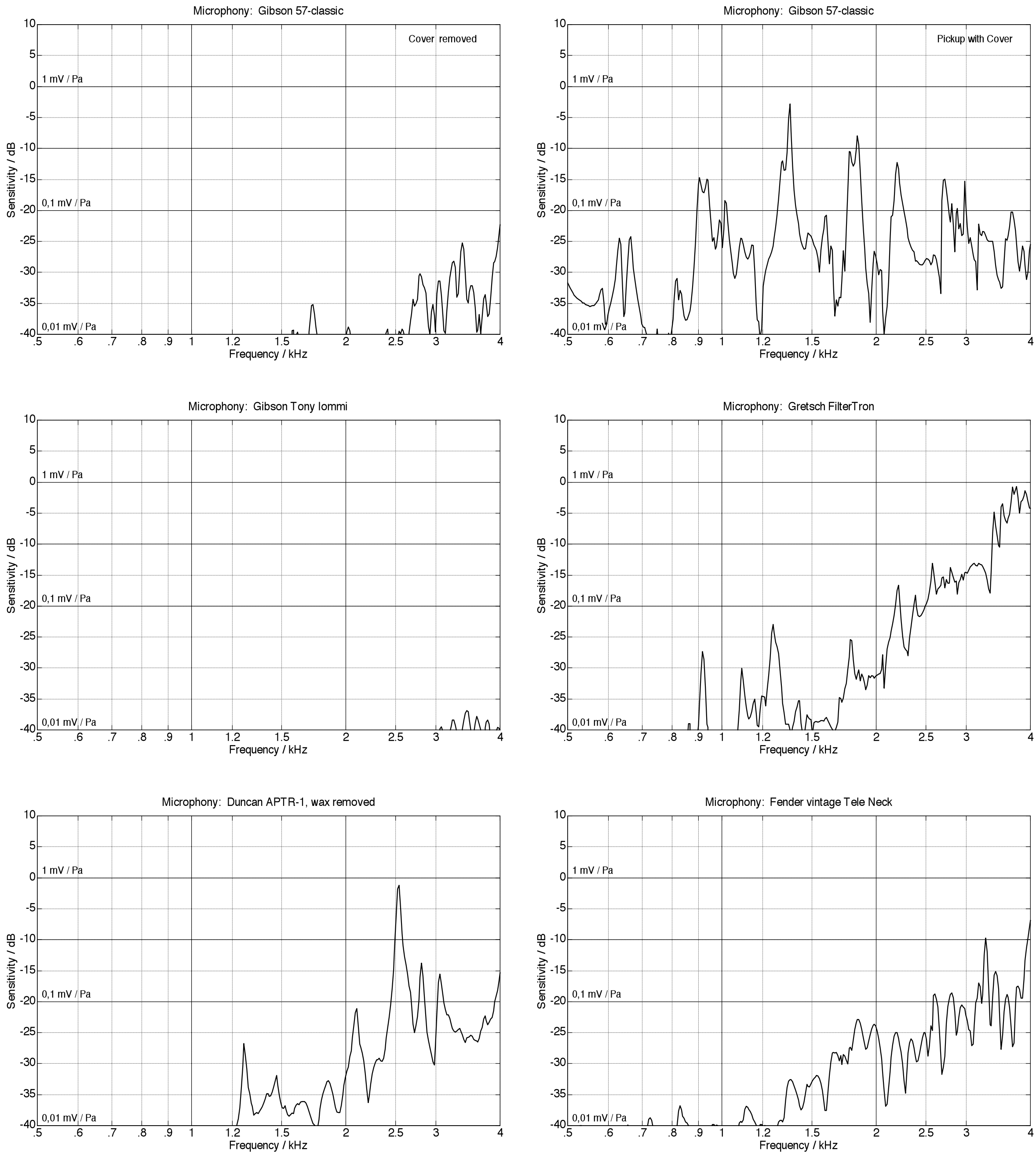
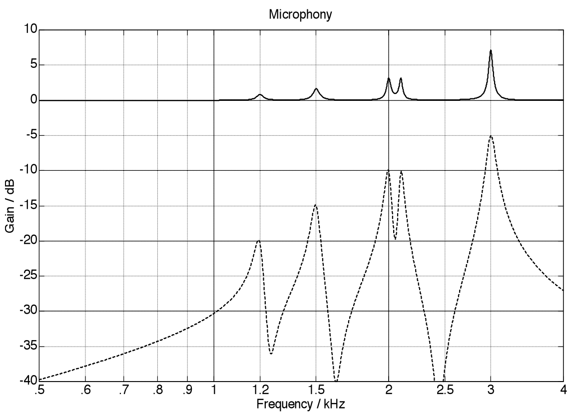


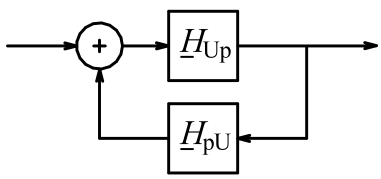
Fig. 5.13.1: Transfer factor for airborne sound (free field). The plots characterize individual pickups, with the inter-individual differences for pickups of the same type being considerable.

In normal operation and depending on string-material, action, and playing style, pickups generate induction voltages up to about **2 V**. Typical guitar loudspeakers are rated by their manufacturer at e.g. 100 dB (1W, 1m) which implies as a rough approximation SPL levels of e.g. 114 dB and a voltage of **10 mV** induced by the corresponding airborne sound. This voltage generated by airborne sound is therefore merely 1/200 of the voltages induced by the string vibrations. Still, it would be premature to conclude that resonances in the pickup housing are generally insignificant. Depending on the specific playing scenario entirely different relationships may arise. An opinion often expressed amongst guitar players is that “pickup-whistling” (i.e. unwanted pickup feedback) would be a problem only for guitar-amplification systems which generate very high SPL values: “In front of two Marshall stack it’s gotta whistle”. This is however not correct as such. The determining factor here is the **loop gain** i.e. the amplification-gain which signal is subjected to after having gone through the loop once: from the guitar through amp and speaker, and through the room (as airborne sound) back to the guitar.

Some numbers shall be given to exemplify: a guitar generates e.g. a voltage of 0,1V (due to the movement of the string) which is amplified to 2V by the amp. For the 8-Ω-speaker, this translates into 0,5W and results in an SPL of 97dB at a distance of 1m in front of the speaker. If this sound now hits the pickup, the latter will generate e.g. 1.4mV due to its sensitivity to airborne sound – in addition to the 0,1V mentioned above. The loop gain is 0,014 and thus substantially smaller than 1. The guitarist may now turn up the amp, either to get more loudness or to obtain more distortion, or he/she may add frequency-selective additional amplification with tone controls or an equalizer. The loop gain will increase and approach 1; in fact it may easily exceed 1. This is when pickup-feedback (i.e. whistling) occurs. Looking at the system very theoretically, an additional special phase condition would also need to be met, but that is always possible because of the manifold sound paths in regular room.

The sensitivity of the pickup to airborne sound will become apparent as sound coloration already at a gain which does not generate feedback. One can look at this as if there was, on top of the desired signal path, a signal decoupling into an additional effects channel. As there is a sufficient level in that effects channel, changes in sound will become audible. A model including a forward signal loop (sound pressure results in a voltage, $\underline{H}_{Up}$) and a feedback path (voltage results in sound pressure, $\underline{H}_{pU}$) is shown in **Fig. 5.13.2**). The feedback path contains 5 places of resonance (dotted line); in the curve on top we see the consequences on the overall frequency response. For a maximum loop gain of 0,1 ($\hat{=}$ –20 dB) there will be no audible effect; however, for a loop attenuation of merely 5 dB (corresponding to a loop gain of -5 dB) pronounced effects will appear. It is not possible to generally determine how clearly the resonance will bear down in the specific case, because sufficient signal energy needs to be present in the respective frequency band – and more room remains again for speculation.





$\underline{SV} = \underline{H}_{Up} \cdot \underline{H}_{pU}$

Fig. 5.13.2: Model of a signal loop and consequences of resonances on the overall transmission. The loop gain $\underline{SV}$ is the product of the forward- and the feedback-amplification.

In order to obtain at least some very rough data under regular operational conditions, a guitar amplifier (**VOX AD-60-VT**) was analyzed in the anechoic chamber. A guitarist had set the control such that, with a Les Paul (Historic Collection), a "slightly distorted, crunchy sound" resulted. All effects incorporated in the amp were switched off. A measurement microphone (B&K 4190) was positioned 1 m in front of the loudspeaker incorporated in the amp and captured the sound resulting from a signal of 1 mV_{eff} fed into the input "High" (**Fig. 5.13.3**). A sound pressure level of just 1 Pa (94 dB) was generated at 2,5 kHz; the voltage gain was about 500 (54 dB). Voltage-to-SPL transfer coefficient was H_{pU} = **1 Pa/mV** at this frequency. In combination with the Duncan APTR-1 described in Fig. 5.13.1 the condition for an oscillation ($H_{Up} \cdot H_{Pu} = 1$) would already be almost met – the 2,5-kHz-spike of this pickup almost reaches H_{Up} = 1 mV/Pa. To be fair, we need to remember again that all the wax with which the potting was done had been removed. With the wax in place the sensitivity to airborne sound would be less.

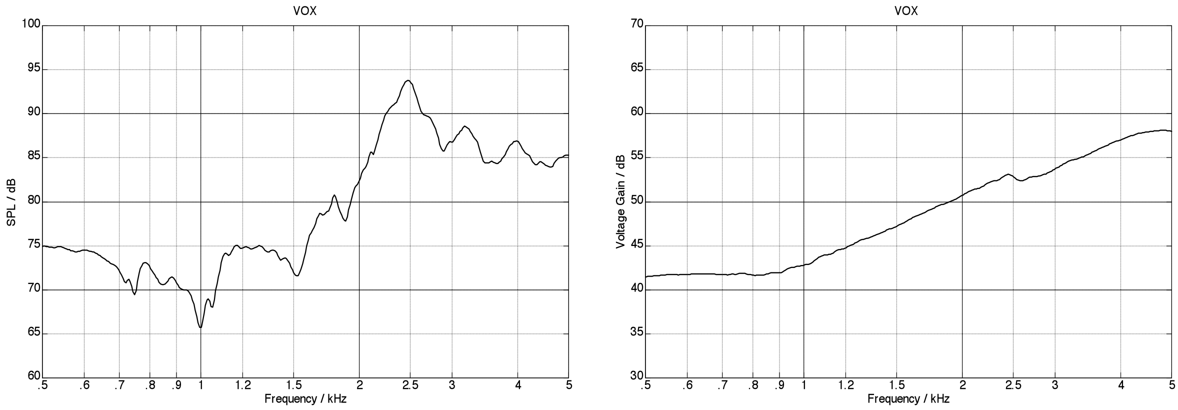


Fig. 5.13.3: SPL generated at 1 m distance for 1 mV input (left); gain factor up to the loudspeaker (right).

The sensitivity to airborne sound of the Les Paul guitar mentioned above was also determined in the anechoic chamber; see **Fig. 5.13.4**. All strings were removed and the guitar was positioned in 1 m distance in front of a horn loudspeaker. The guitar was loaded with 670 pF (cable) and 1 MΩ and all control set to "10". For the somewhat more sensitive bridge-pickup (**Gibson BurstBucker #2**), we found a maximum sensitivity to airborne sound of just short of 0,1 mV/Pa. The neck pickup was loess sensitive by 5 dB. Unwanted feedback will not appear under this condition since the smallest loop attenuation is 27 dB. For the same reasons, any influence on the sound is not to be expected, either! (Compare to Fig. 5.13.2)

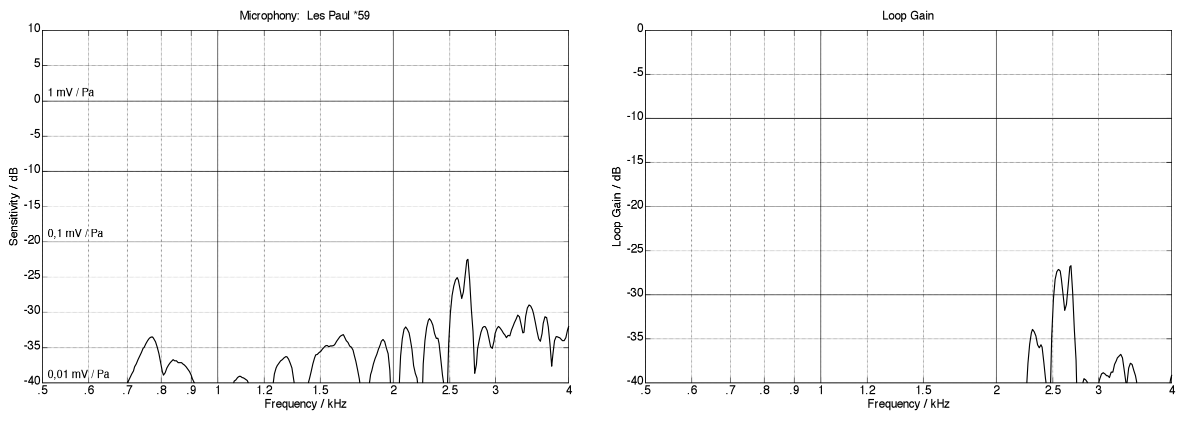


Fig. 5.13.4: Gibson Les Paul '59: Transfer factor for airborne sound (left), loop gain factor (right).

As the gain is increased by 6 dB (relative to Fig. 5.13.3), a much more distorted guitar sound is already generated for normal playing – well usable for *lead-Sounds a la Beano Blues-Breaker*♣. The maximum loop attenuation is 21 dB and thus still well in the green. Not unless all three volume controls (gain, volume, master) of the VOX amp are maxed out (introducing an additional 26 dB of gain), the setup generates nothing but piercing whistling noises. Under this condition it makes moreover no difference where the guitar is positioned in the room relative to the amp – it remains "mission impossible". The guitar would have to be removed from the room, or the pickup selector switched to the neck pickup – the slightly less sensitivity to airborne sound of that pickup♦ enables the guitarist to find a few positions which are not subject to feedback. From the point of view of the conservative musician the resulting messy sound is not actually desirable. Although: only now – so the control engineering approach says – do the resonances of pickup-housing have an effect on the overall frequency response.

From the carried-out experiments the following results can be derived:

1) A metal pickup housing with well-done dampening has little resonances and does not change the pickup transfer characteristic in the case of distortion-free reproduction (clean sound, stage volume) at all. (here we are not considering that a cover may cause eddy-current-dampening → Chapter. 5.9.2.2). Even at "normal distortion" there are no effects on the sound. At extreme gain-settings (ultra-distortion) some effects are conceivable – however: an entirely distorted guitar sound is not really the right condition to be able to discern subtle sound differences.

2) Pickup covers with weakly dampened resonances may have a sound-altering effect, depending on the amplification. However, going on stage with such a caterwauler is a bit of a ride on a cannonball: you never know at which point things will go sideways. If the loop attenuation is high enough, you won't hear any difference, there will be no effect of the housing resonances, but as they become audible, the limit towards uncontrollable pickup feedback is just a hair away, as well. This is of double (or triple) validity for thinline and full-bodied electric guitars: their sensitivity to airborne sound is even larger than that of a badly dampened pickup. Now, there are guitarists who are looking exactly for this borderline situation, and some have even reached true mastery in that battle with the unbridled resonance-power. So if a special guitar is said to have that very special unique sound drawing upon the pickup housing resonances: impossible it is not from the point of view of physics. With the single exception of the Gibson Toni Iommi, all the potted pickups examined in the framework of this book showed – upon opening them up – a interior distribution of the wax of … shall we say (to remain safe from the attorney assault): the wax distribution was following artistic considerations. As such, every guitar again is a unique specimen. But we already knew that, didn't we … even without the whole physics shebang.

What remains is a matter of faith. *Thesis: "The pickup covers, as well, add a material-specific resonance to the sound. If you love that throaty and nasal PAF-sound (a la Allman Brothers or even Peter Green), you should absolutely use covers on the pickups"* [U. Pipper, Gitarre & Bass, 9/2005]. That's one way to look at it. *Anti-thesis: "You may have heard that I remove the covers from my pickups; the improvement in the sound is unbelievable"* [Eric Clapton, in Bacon/Day]. That's the other side of the faith.

♣ Back in the day, the original setup included a Marshall combo amp.
♦ All these statements relate to one specific individual guitar.