ELECTRONICS

# PICKUP MEASURING TECHNIQUES

**Is it possible to evaluate the quality of a pickup without even hearing it? We propose that it certainly is—no crystal ball or magic tricks required**

BY HELMUTH LEMME

The right pickup can make the difference between a guitar with excellent tone, and one with a forgettable (or even annoying) one. However, when we suggest to measure the pickup electrical characteristics objectively using electronic test instruments, some guitar makers will reply, *“What is this device good for? I do not need that! I rely on my ears, only!”*

Okay, so go make your listening tests. How much time do you need for it? Imagine you have ten or more pickups lying on your table and you want to test them all. You have to open the guitar, remove the old ones, install the new ones, close the guitar again, tune the strings and listen. You can spend hours or days with that. And then your customer is waiting at your door and wants his guitar back because he has a concert tonight.

Meanwhile, there are already probably more than 1000 pickups types on the market. Who can keep an overview? Is there a way to shorten the evaluation a little? Is it possible to predict a pickup's sound properties by electrical measuring without installing it?

Yes, there are a couple of possibilities. Surely they are not perfect but they are certainly helpful with a good ratio of costs to benefits. Pickups are much simpler systems than (for example) guitar bodies, which have innumerable resonances which decisively influence the sound. To analyze these all is nearly impossible.

Engineers often say: " It only exists that which is measurable ". I believe this is not necessarily true—toothache is not measurable, but it really exists. However, the process of measuring allows us to handle things much more efficiently, provided that one uses the right measuring method, which is essential.

Did you know that, in the case of guitar pickups, one can measure a great deal of different properties? Done correctly, preselecting pickups is much simpler and faster than with the conventional listening test. Also, it would be based on objective parameters, instead of a subjective one.

An intelligent man named Alfred Korzybski (a Polish-American philosopher and scientist, 1879-1950) once stated: "The map is not the territory". This is certainly right. Both are often mixed up. But there are good maps which show the way, and bad maps that lead astray. Korzybski added: "A map may have a structure similar or dissimilar to the structure of the territory." So why not use a "map" for pickups - provided it is a good one?

## Debunking myths

A real cult has established itself around pickups. Collector prices of some types have increased to insane heights. It is time to switch back to common sense again. For me, pickups are nothing but electrical devices with certain properties, which ultimately one can like or not. The cult is mostly hot air; it was created and promoted by clever dealers. One does not have to be caught in this manipulative marketing.

Let's start debunking this old myth: old pickups do not automatically sound better than new ones, just because they're old. The truth rather is: Old pickups are subject to much stronger sample fluctuations than new ones. Not only this is valid for the highly-praised Gibson "patent applied for" types of 1957 to 1962 but also for other old ones like Fender, DeArmond, Rickenbacker etc. So what is a "vintage sound"? Nobody can answer this satisfactorily.

Another myth: Musicians stating things like "this and that pickup sounds like so and so". In technical terms, this is nonsense: pickups do not sound—they only transfer the signal originated at the strings. How these vibrate depends very strongly on the qualities of the guitar's body.

To every pickup, the old adage "garbage in, garbage out" applies. For example, install a Gibson 490 humbucker on these instruments: a Les Paul, a Super 400, a pawnshop guitar, and a banjo. You will hear four totally different sounds. So what is "the sound" of a Gibson 490 Humbucker?

Instead of "sound", pickups rather have "transfer characteristics"; in a bigger or a smaller measure a pickup *flavors* the sound material which it gets from the strings. That flavoring is judged positively by most musicians. One also could build neutrally transferring pickups, but these would not be accepted so well. With the coloration caused by the characteristics of different pickups, there are enormous differences in sound. If one replaces the existing pickups in a guitar or a bass with other ones, then the sound can change audibly, as is well known. In some cases it does not change, however, because innumerable pickups may have similar characteristics.

One can very well compare pickups to the tires of a car. A tire has a lot of properties: there are summer and winter tires, tires for the city, tires for competition, etc. Every type behaves differently. But a tire never has a speed of its own. The question "how fast is this tire?" doesn't make sense. It is just as fast as the car on which it is fitted. The same happens with pickups.

## Worthless: DC resistance

Which electrical parameters can one measure on pickups? A far too commonly used but very bad "map" is the direct current resistance, with measurement unit "Ohm" or "Kilo-Ohm" (1 kOhm = 1000 Ohms). One can very easily check it with an ohmmeter. However, this value totally leads us astray because in a pickup you always have alternating current flowing, never direct current. You can't make a correct statement about the tonal qualities of a pickup based on its electrical resistance to a type of current that's never present during playing. This is similar to measuring the length of a car in order to determine its top speed. But many manufacturers indicate an Ohm figure as if they make a technically relevant statement with that. This is nonsense.

The only use of an ohmmeter is to find out (to a certain probability) whether a pickup's coil is intact or faulty. Most types have values between about 5 and 20 kOhm. If the ohmmeter shows "infinite", then the wire is broken. If the break is on the outside, then one can solder the wire on again. If two or three turns get lost in the process it does not matter. But if the break is deep inside then one must remove the old wire and wind the pickup again.

The other possibility is the ohmmeter showing an unexpected low value. This may happen in the case of some exotic pickups which have fewer wire turns than the normal types, but if this happens with a normal pickup, then one must suspect a short-circuit in the winding, caused by the insulation going faulty between two neighboring wires somewhere. Even if the pickup still works, the signal will be completely different from that of an undamaged pickup. If only a few turns are shorted (something you can hardly see with the ohmmeter) then the treble gets weakened a little; the resulting sounds is very slightly less piercing. Depending on the qualities and the setting of the amplifier, this can indeed sound even quite good. Some people describe this as an "old" sound because such short circuits more frequently happen with old pickups than with new ones. But if some hundred or even some thousand turns are shortened, the treble is totally lost and the sound is muffled. Such a pickup has to be completely rewound. I once had a humbucker which had 7 kOhm on one coil and 3 kOhm on the other one. This difference between the coils was not at all intentional; the pickup was simply faulty.

## Useful: The Inductance

For many a guitarist this parameter means nothing. But it is by far the most important property of a pickup. It is, so to speak, the electrical "size" of the coil. Unlike the DC resistance it really has a relevant meaning.

Inductance is measured in *Henries*, named after the American physicist Joseph Henry (1797- 1878) who did intensive research in this field. Most common pickups have inductance figures between about 2 and 10 Henries. Here are some examples. Sample variations can range in ±10 % or more. The second and third digits after the decimal point of the reading on the LCR meter should be ignored.

- Fender Stratocaster: 2.2 H
- Fender Telecaster Bridge: 3.0 H
- Gibson 490R: 4.2 H
- Gibson 498T: 8.0 H
- Gibson 500T: 8.0 H
- Fender Precision Bass: 6.0 H
- Fender Jazz Bass: 3.6 H
- Big sixties Gibson Bass: approx. 65 H (varying strongly from pickup to pickup).

The smaller the inductance, the more treble will the pickup produce; the higher the inductance value, the more bass and midrange response it will have. So if you measure for instance 6 or 8 Henries you can be sure that this pickup never will produce a "twangy" sound (with high treble) but, instead, will have a warm midrange sound. On the other hand a 2 Henry pickup never will deliver a warm, mellow sound. The old big Gibson Bass pickup type, at 65 H (!) was far apart from all the others, its characteristic was extremely muffled.

It is not very easy to measure inductance exactly. It requires technical expertise; otherwise one can easily measure something wrong. The measuring frequency must be as low as possible. The "PeakTech 2165" shown in **fig. 1** (which is practically identical to the "Voltcraft 4080" by Conrad Electronic) has proved to be good in the practice. It measures inductance at either 120 Hz or at 1000 Hz. The 120 Hz figure is reliable. However, the reading obtained at 1000 Hz is often distorted by the winding capacitance and/or by the eddy currents in the metal parts, so it is not as reliable as the lower frequency.

Is it possible to derive the inductance value from the resistance value? Short answer: No. For example, one can measure the same DC resistance in several copies of the same pickup type but nevertheless they all can have considerably different inductances. This is

**Fig. 1**


*Well-suited LCR measuring instrument "PeakTech 2165 In this example, it is attached to a typical single-coil pickup. As shown by the digital display, the inductance of this pickup is 2.220 H at the selected test frequency.*

caused by the density of the wire winding. If it is wound very tightly ("even wound") then the inductance is greater than in the case of a coil with a lot of cross winding ("scatter wound").
As we said above, a greater inductance produces a warmer tone, a smaller one a brighter tone. This effect is particularly strong in the pickup of the Fender Jazzmaster. Its DC resistance amounts to about 8 kOhms. Nevertheless, the inductance can vary between about 3.0 and 4.5 Henries.

## Decisive: The Frequency Response

The way a pickup discolors the sound material (the signal) coming from the strings can best be described by another parameter, the frequency response, represented as a curve.
The tone of a string consists of a fundamental frequency plus a large number of overtones. As a rule, pickups do not transfer all of these evenly, but some are emphasized and some others are weakened. The frequency responses of nearly all most common (passive) pickups have a shape like **fig. 2** (below). The deep and middle frequencies are transferred evenly. At high frequencies (at some thousands of Hertz) there is a "resonance" peak where the emphasis of the overtones has a maximum. Above this frequency, the transmission of higher overtones decreases very steeply. Inferior quality pickups don't have a resonant peak; the curve simply flattens and falls off at high frequencies.
The important fact is: The position and the height of the peak do not depend on the properties of the pickup alone but also on its external electric load. This is primarily the guitar cable, which has a certain capacitance, which should not be overlooked (in general, longer cables add more capacitance to the system, reducing the frequency of the peak, and filtering out some of the desired treble frequencies). So, recapitulating, the resonant frequency (the *frequency* in which the curve peaks) de-

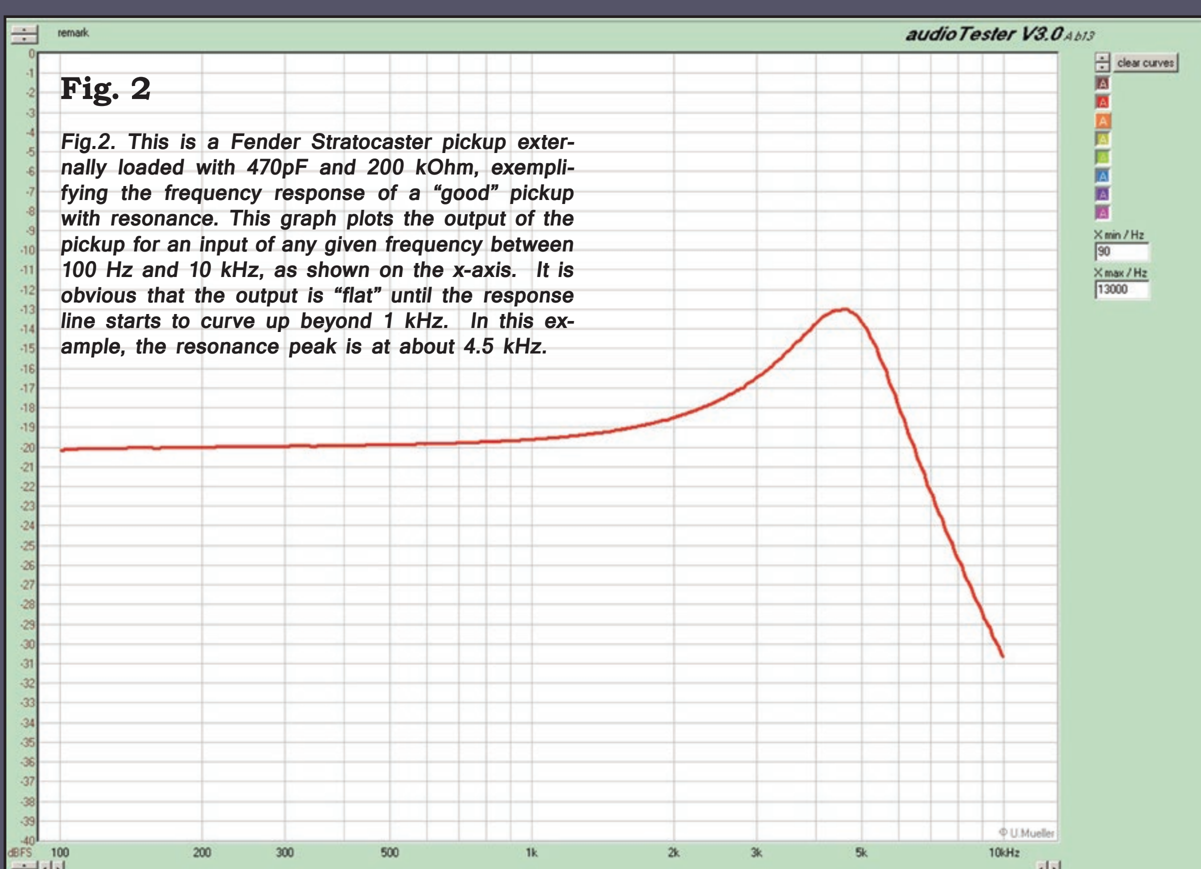



**Fig. 2**

***Fig.2. This is a Fender Stratocaster pickup externally loaded with 470pF and 200 kOhm, exemplifying the frequency response of a "good" pickup with resonance. This graph plots the output of the pickup for an input of any given frequency between 100 Hz and 10 kHz, as shown on the x-axis. It is obvious that the output is "flat" until the response line starts to curve up beyond 1 kHz. In this example, the resonance peak is at about 4.5 kHz.***

pends on: 1) the inductance of the pickup and 2) the capacitance of the guitar's cable. Both together form an oscillating circuit.

The *height* of the peak, however, depends on other properties of the pickup: the material of the magnets, the type of soft iron used in the pole pieces, the casing, the values of the pots, and the amplifier's input resistance. Pickups with a higher inductance produce a resonant peak at lower frequencies. Pickups with pole pieces made of soft-magnetic steel in the coil(s) have a weaker resonant height than those with magnets directly in the coil(s).

But all these components form an integral system which we must *not* split up into a simple sum of parts. It doesn't have much sense to measure the individual components one by one and draw conclusions about the pickup tone based on those values. Instead, the system needs to be measured as a whole, because it works as a whole.

## A faster way

How can we do this? A device called "Pickup Analyzer" was developed for this purpose. This can be referred to as the king of the pickup measuring instruments (**fig. 3 -** below). Coupled with a computer, it measures the frequency response (including their external load) and displays it on the screen within a minute.

It works like this: the device's transmitting coil produces an alternating magnetic field which is induced into the coil(s) of the pickup being analyzed. The frequency varies over the whole audible range, while the device measures the alternating voltage delivered by the pickup in response. The complete frequency response - resonance frequency and height- is clearly visible in the form of a curve depicted along the analyzed range. The main advantage of the Pickup Analyzer is that it proves ideal for experimentation. The external load conditions are changeable (load capacitances from 47pF


**Fig. 3**

*Fig.3. The Pickup Analyzer measures the frequency response of the pickup. The transmitting coil (ivory colored bobbin) is temporarily attached to the pickup with an elastic band, to ensure that it doesn't shift position during the test.*

to 10nF; load resistances from 111 kOhm to 10 MOhm). So all conditions that occur in real playing conditions are covered, and even more.

The curve shown in **fig. 2** (back in page 30) belongs to a 1972 Fender Stratocaster bridge pickup (2.2 Henries), externally loaded with 470 pF and 200 kOhm (250 kOhm volume pot in the guitar and 1 MOhm amp input in parallel - no tone pot).

The Pickup Analyzer can measure pickups that are installed into an instrument, or loose ones, both in combination with a real guitar cable or an internal load capacitor. Short-circuits can be detected easily, since they diminish or annihilate the resonance and that is reflected in the output curve. Even the effect of metal covers is visible: brass dampens the resonance considerably; German silver (which is actually an alloy of copper, nickel and zinc, and contains no real silver) dampens it somewhat less.

The characteristic of a pickup can be improved by sawing a rectangular opening into the top of a brass cover. In **fig. 4** (on the right - top) this is done with an Epiphone mini humbucker, made in the 90s, with a brass cover. **Fig. 5** shows the resulting curves. The modified pickup (upper curve) “sounds” much more pleasant than the original one (lower curve). This effect also explains why many guitarists prefer the sound of their humbuckers with the covers removed completely.


*Fig.4. Epiphone mini humbucker: A: original with and without brass cover. B: modified (top opened, embedded in epoxy resin)*

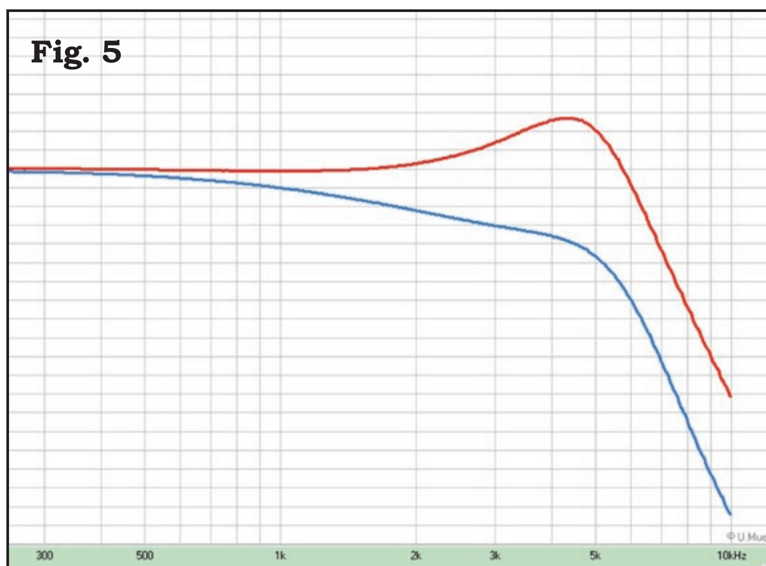
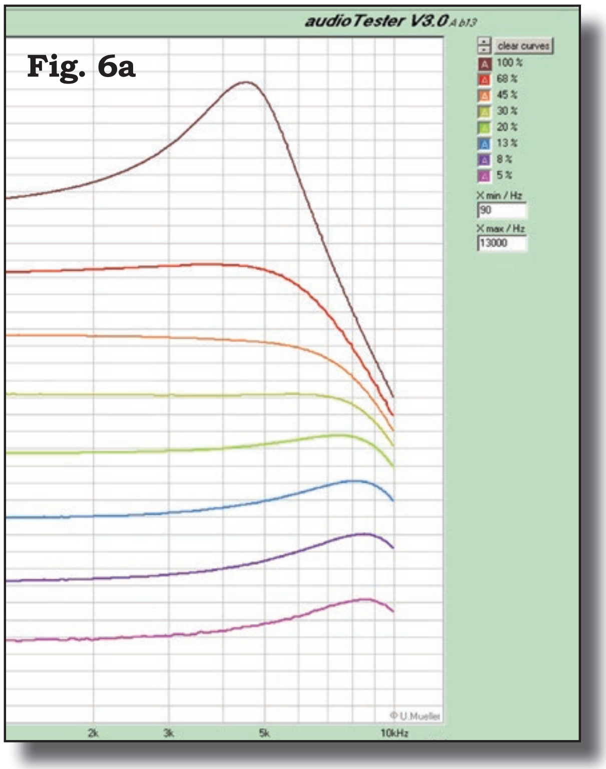


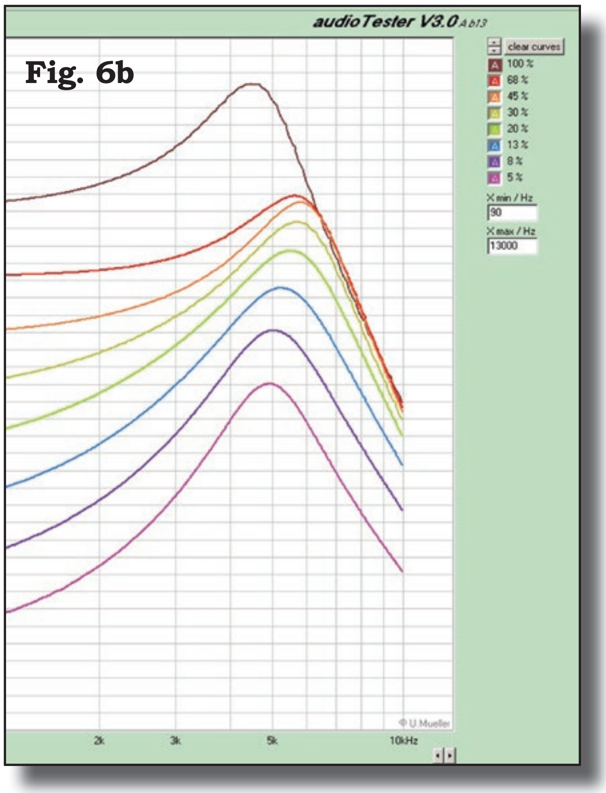

*Fig.5. Frequency responses of Epiphone mini humbucker of fig. 4. Blue curve: original state, sound dull; red curve: cover with rectangular opening cut into pickup cover; the resulting sound is remarkably more expressive.*

The device can also measure the asymmetry in the coils of a humbucker, which is probably is the most important “secret” of some of the Gibson PAF types before 1961. To measure the asymmetric characteristics of the coils, the cover has to be removed and both coils have to be measured separately. Active pickups can be measured, too. The EMG 81 and 85 have totally different curves than all the passive ones: They have a maximum in the midrange and a roll-off on the bass and on the treble side. There is no resonance peak.

After some time working with the pickup analyzer, one understands how the measured curve and the tonal impression are related. One can carry out the selection of pickups much faster now.
In addition, one can distinguish much better which part of the sound of a guitar or bass are created by the strings and the body and which part is added by the transfer characteristic of the pickup. Both are normally mixed up, of course, causing the sound properties that belong to the strings and the guitar's body, to be erroneously attributed to the pickups. For instance, I have read abook about pickups. which comes with an enclosed CD with sound examples, that incurrs in  this mistake. What one hears are not transfer characteristics of different pickups but sounds of the different guitars that are fitted with the mentioned pickups - plus the influence of the cable. For a correct comparison all the pickups should have been installed on the same reference guitar, otherwise the comparison doesn't make any sense. This is like comparing two car tires, one set used on a Volkswagen Beetle and the other one on a Porsche (remember the example given at the beginning about fitting a Gibson 490 on four different instruments?)
With the Pickup Analyzer we can also examine how the transfer characteristic is changed when the volume pot in the guitar is turned down. As is well known, the lower the volume pot is set, the more the treble frequencies are lost. The measured curves points this out: The resonance peak gets weaker and eventually disappears totally (**fig. 6a**).

A common remedy is a bypass capacitor between the right end and the wiper of the pot. With this trick the peak is conserved at lower volume settings (**fig. 6b**); but the tone gets even more piercing. This can be corrected by connecting a resistor in parallel to the capacitor, with about the same




***Treble loss effect with the volume pot (Fender Stratocaster with 470 pF):***

***Fig. 6a: No bypass capacitor: resonance vanishes at lower volume settings.***

***Fig. 6b: With bypass capacitor 470 pF: resonant height increases at lower volume settings, but resonant frequency shifts upwards***

value as the pot (**fig. 6c -** on the right). The resonant frequency is shifted upwards (towards higher frequencies) because the cable capacitance does not act alone anymore, but in serial connection with the bypass capacitor. If the capacitor has the same value as the cable capacitance, the resonance frequency will be higher by a factor of about 1.4.

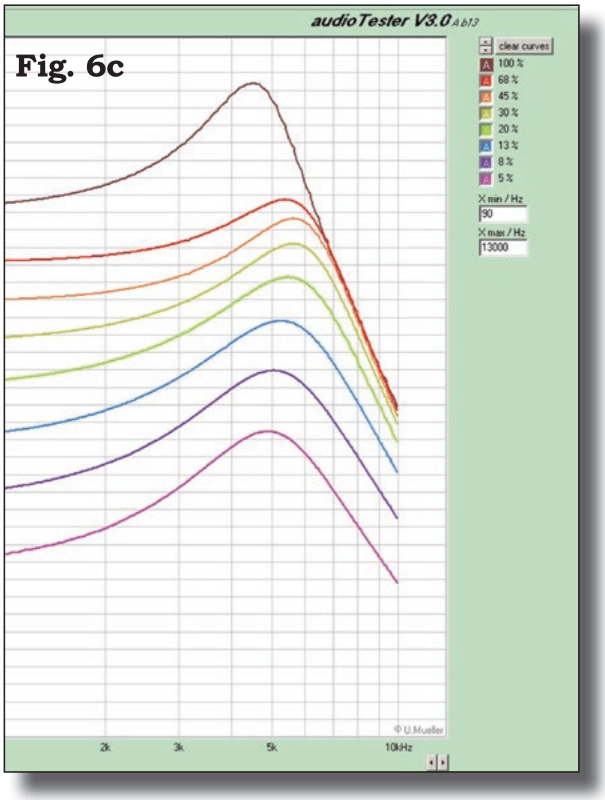
For comparison, **fig. 6d** shows the frequency response when the volume pot is connected reversed (pickup to the wiper, right end as output) as done e. g. in the Fender Jazz Bass and in Rickenbacker guitars. Here the treble vanishes much faster, and a bypass capacitor has nearly no effect; so, many musicians do not like this pot connection.

So, everything can be measured with the pickup Analyzer very exactly; and as consequence one learns that in principle there is no way to obtain a neutral volume adjustment in a passive wiring.

## Other parameters: Loudness Measurement

There still are some important properties of pickups which the Pickup Analyzer cannot measure; primarily the loudness. It is generally known that pickups do not only produce different tone colors but also very different output voltages, driving an amp into distortion in different ways. For example, consider the Gibson humbuckers 498T and 500T: Their frequency responses are roughly the same. But they have very different magnets. The 500T delivers more than twice the output voltage of the 498T. So the sound is considerably different in the "crunch" range of an amplifier.

Loudness is not a simple thing to measure. It does not work if one simply plucks a string and measures the output voltage of the pickup with a voltmeter. Firstly, the



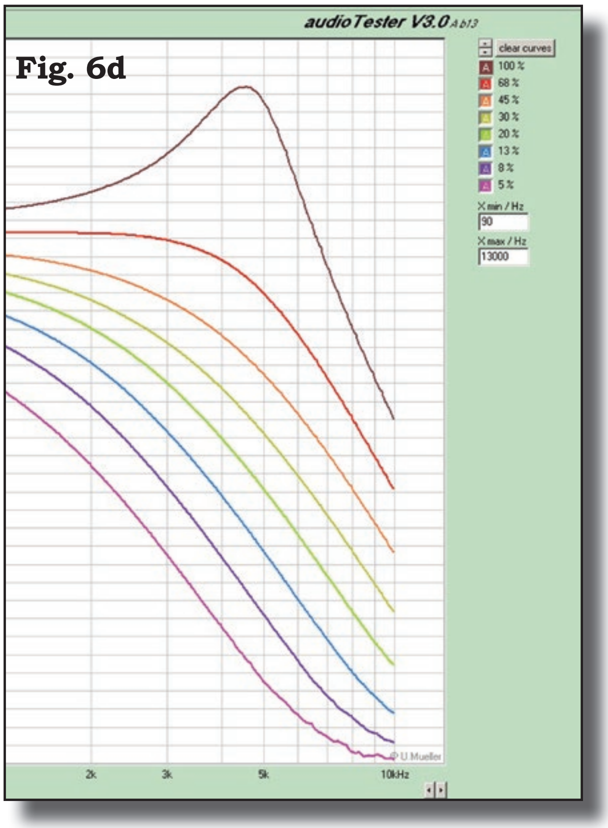




*Fig. 6c: With bypass capacitor 470 pF and bypass resistor 220 kOhm in parallel: resonant height stays about the same, but resonant frequency still is shifted*

*Fig. 6d: Volume pot connected reverse, no bypass capacitor and resistor; sound dull at lower settings.*

pluck is not exactly reproducible by hand. So one would need a mechanical device which always produces even plucks for consistency. But this still is not enough. The curve form produced by a vibrating string is anything but a sine wave. One can see this well on an oscilloscope. And the high peaks at attack disappear quite fast. Which value shall one take here?
Another method works much better. One uses a steel wire rotating eccentrically about the axis of a brass tube (**fig. 7,** on the right), driven by an electric motor with electronically stabilized speed. The turning speed must be much lower than the resonant frequency of the pickup. Over the axis a little table is mounted on which the pickup is placed, so that it always has a reproducible distance. The result: The loudness of a pickup does not have fixed value but a variable one (**fig. 8,** below). So one must always indicate a range "from *x* mV to *y* mV". The strongest pickups (e.g. the Schaller "Hot Stuff") produce a signal with voltage more than ten times higher than the weakest ones (e.g. Fender Stratocaster).

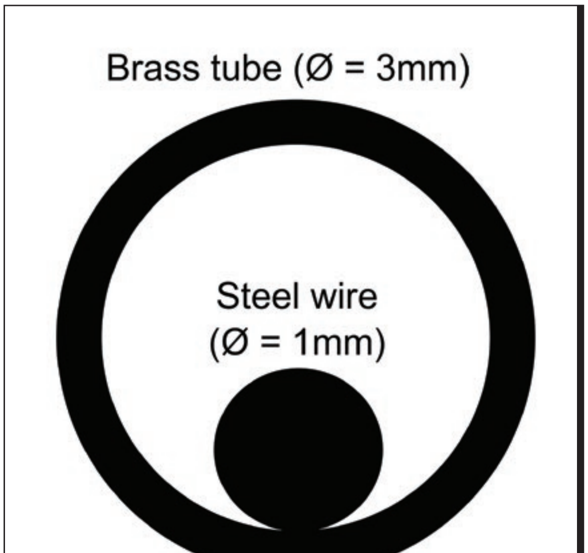



**Fig. 7**

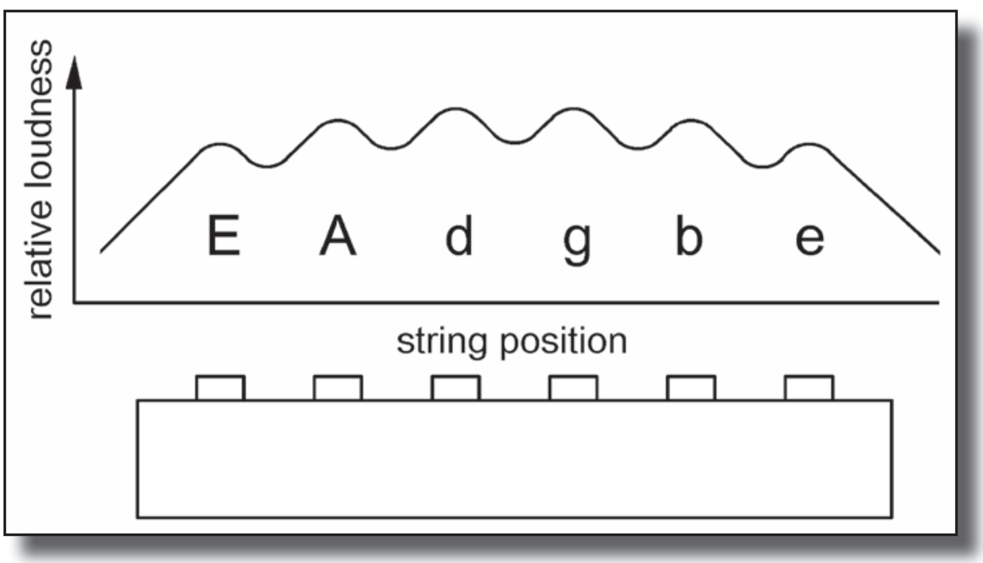
*For loudness measurement: a 1 mm steel wire in a 3 mm of brass pipe in ball bearings As the brass tube is rotated by a motor, the 1 mm steel wire acts as an oscillating guitar string, with a constant sinusoidal motion due to its eccentric orbit within the tube.*

## Magnet Strength

To measure the strength of a pickup magnet you need a so-called Hall sensor. As experience shows, magnets exhibit strong variability. Very old pickups have an especially variable loudness between any two seemingly identical pickups. Gibson PAF's received a fixed number of turns (5000 per coil) since 1961, but the variation of magnet strength remained for many years. By the way, "Alnico 2", Alnico 5 " etc. are very rough classifications; they de-

**Fig. 8**

*Relative loudness on the string positions*



scribe only the material composition of the magnets, but not the manufacturing method which is different with every manufacturer. Ceramic magnets (ferrite) seem to have less variability of field strength than Alnico magnets. It is not possible to assign specific transfer characteristics to specific magnet materials. There is neither an „Alnico 2 sound“, nor an „Alnico 5 sound“, nor a „ceramic sound“. The magnet is only one part of a complex system.

### Nonlinear distortions

They exist and discolor the tone, too, by adding additional overtones which are not contained in the original sound. But it is extremely difficult to measure their strength quantitatively. No usable method is known to me. Maybe somebody has an idea; please share it if you do.

### Summary

Pickup measuring is an extremely useful technique for those who are in the technical side of electric guitars. Unknown types of pickup can be evaluated very quickly. Pickup measuring techniques are not intended to replace listening tests, but they can make such tests much more efficient by sorting out types and qualities of pickups from the very start.

Many pickup manufacturers are afraid of these measuring techniques just like a vampire fears holy water. Their products suddenly would get comparable. Plus, with a pickup analyzer, objective, technical arguments can replace flowery advertising clichés. The halo created by marketing would fall down.
Some people will object to my stance here, saying that if I cut a symphony down to pieces, then it is not a symphony anymore. But of course, I am only analyzing the microphone that records the symphony (so to speak), not the symphony (the guitar sound) itself. In my experience, these methods have proved to be extremely useful. Measuring is not an end in itself but rather a useful tool which accelerates and simplifies the work, one that certainly can open our eyes to the things that truly determine the qualities of a pickup, transcending the mere advertising.

***Addtional information:***
*www.buildyourguitar.com/resources/lemme.index.htm*
*Author's book "Electric Guitar Sound Secrets and Technology": http://bit.ly/1kRejoz*
*Author's website (in German):*
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