# A Primer on Reading Guitar Pickup Specifications

To help with pickup comparisons and as a general aid to understanding test reports, here are some definitions, facts, and points to consider about the various pickup design specifications and how they work together. By its nature some of this information can get a little technical so I have tried to meet in the middle and give a commonsense explanation as well as just a little of the pickup designer geek stuff. Also, remember that comparing pickups on paper can only give a general notion of how they should sound and it is always going to be a poor substitute for comparing by ear if you have the option. Most makers always publish the DC-resistance, often the resonant peak, and sometimes the inductance. In the 70's and 80's, more measurements, tone charts, and specifications were sometimes given, but lately for whatever reason, the trend has been to publish less of this kind of specific information, and more of the subjective and less informative flowery descriptions.

**D-C Resistance -** Though somewhat flawed, this is the most common specification people use to compare pickups. Most all manufacturers provide it and it is easy to measure with an inexpensive meter. Sometimes it is the only specification given so it is all you have to go on. The usual measurement unit is K Ω (1000 ohms) or often just abbreviated K. In general, the higher the D-C resistance, the more output a given pickup will have. This relation is so commonly known that sometimes it can get turned around, leading to an (unfortunately all too common) misconception. The higher output is not coming from more ohms, it is from more turns which create more inductance. The increase in resistance is also from more turns, but it isn't the cause of the higher output. Inductance is a better measure of the ability of the pickup to generate a signal, but just isn't as easy to measure as ohms are. So pickups do not "put-out" so many ohms. DCR is just an easy way to get an idea of how much wire is on there.

The ohms are a measure of how much resistance the circuit has to a direct current trying to get through it. Wire has a certain amount of natural resistivity by bulk, so the longer the wire, the more resistance i.e., more ohms. The wire gauge affects the D-C resistance significantly. The smaller the wire (higher gauge), the less area to carry current - so it has more resistance per foot. The most common wire gauge is 42 AWG, so if both pickups are wound with the same wire gauge and are otherwise similar in design, the D-C resistance does give a comparison of how hot a pickup will be. But other gauges are used at times, particularly 43 and 44 which have higher resistance per foot. Usually the reason to go to the higher gauges is to get more turns in the available space for more output, but the resistance will go up even if the turns are the same. So comparing resistance between pickups made with different wire gauges isn't meaningful. Here is an example: 7000 turns of 42 AWG magnet wire on a strat style bobbin is going to have a DCR of about 5KΩ. The same winding but using smaller 43 gauge wire is going to end up at about 6.3 KΩ. With 44 gauge wire the 7000 turns will give about 7.5 KΩ. That's half again as much resistance as with the 42 gauge. All of these are going to have similar output levels despite the big difference in DCR. Bobbin shape has an influence too, because there can be more or less wire used per turn. For example the same 7000 turns of 42 AWG wire on a P-90 type bobbin would come out about 5.2 KΩ. Of course most P-90s have more turns than 7000, but this is just to illustrate how the DCR varies with bobbin dimensions. Generally speaking, among pickups of the same type, higher DCR also means a loss of trebles and clarity, along with the higher output.

These effects are due mainly to more wire and turns affecting capacitance - but the DCR does go up with them, so it is an indicator.

The temperature affects the resistance measurement as well, roughly about 1% for every 5° F. Other things affect DCR such as the wire stretching as it passes around the ends of the bobbin if wound too tightly. This effectively increases the wire gauge at those places. So use DCR as only a general guide, and remember that more output comes from more turns. You are also going to have to sacrifice some treble response to get more output because of the extra capacitance and inductance that is created with more turns. Many common meters will measure DCR sufficiently. In my test reports, I use the multimeter functions of the Tektronics 2236 oscilloscope to get an accurate DC resistance measurement, and use a calculation built into the test report spreadsheet to correct the value for temperature to 68°F (20°C) based on correction factor tables provided by the wire manufacturers. I use a calibrated digital thermometer traceable to NIST standards to measure the temperature at the bench accurately to within 1°C. Here is a link to a table of temperature correction factors: http://sonnywalton.com/uploads/Copper_Temp_Corrections.pdf

Another thing to note, I have seen some examples of pickups that measured considerably differently from their advertised DCR brand new out of the box. I won't mention makers' names but here is one example from one of the biggest manufacturers: Advertised Specification 6.2k ohms, actual measurement 4.85k. In this particular set, which was for a Stratocaster, both the neck and middle pickups read low on ohms but the pickups were fine, sounded good, and had good output. This kind of thing may not be common, but does happen sometimes. Makers usually wind to certain turns counts, and the DC resistance can vary considerably with the wire used, tension, and other factors, but the inductance is the more important factor. In this case since it was two pickups and they were both fine, I would suspect the magnet wire they were using that day just had a diameter that was on the big side of specs, probably closer to 41 gauge than to 42 which it should have been. That kind of thing can also happen in the middle of a roll of wire on rare occasions.

**Inductance –** This is one of the most useful measurements of pickup performance and character because it is measuring the principle on which the pickup works. A simple way to describe inductance is that it is a measure of the behavior of the coil of wire to oppose any changes in the current flowing through it. The permanent magnets in a pickup are one but not the only source of magnetism in the coil. Anytime a current flows through a wire magnetism is created. That adds or subtracts to any magnetism already there (the field). And anytime a wire (the same wire in the pickup's coil) is located in a changing magnetic field (same total magnetic field) a voltage is created by the effect of electromagnetic induction. So the current flowing through the coil (your signal) creates an electromagnet. It is a known principle of electromagnetic induction that if the current in the wire changes, a voltage always opposing the change is created (induced) by the magnetic field of the coil. This is kind of like an electrical sort of inertia. But it also goes hand in hand with the ability of the coil to generate the signal you need which is induced in the coil by the vibrating strings interacting with the magnetic field. The vibrating magnetized strings cause fluctuations in the total magnetic field seen in the coil. Those fluctuations are at the same frequencies the strings are vibrating. So the voltage that is induced (your signal) is alternating at the frequencies of the strings vibrations. A better inductor is going to allow a stronger signal voltage to be induced. The number of turns (more wires in the field) and amount and kind of magnetic metal in or near the coil (different magnetism seen by the coil), winding density and coil geometry all affect inductance. More turns and or more of the nearby metal, or stronger magnets increase inductance. But the kind of metal makes a difference, which is one way magnet alloys, polepieces, and baseplates affect electrical properties and tone. The frequency or rate of change of the current makes a large difference in measurements. Inductance is measured in henrys (H) but you may also sometimes see the symbol for inductance, which is (L). The biggest contributing factor for inductance is the number of turns, but many other factors affect it. We are only scratching the surface here, inductance is quite complicated and not so easy to measure usefully. It is a very good guide for comparisons but only if the measurements are made correctly and in a consistent way. In a pickup, generally more inductance means more output, and a lower resonant peak (darker sounding, less or muddy highs).

A very simplistic way to visualize inductance effects is to think of the weight of a bell. A heavy large bell is going to have more inertia and sound louder and darker with a lower resonant frequency than a smaller lighter brighter one. In the same way, a pickup with a larger inductance is going to sound louder and darker. Of course theorists will find much to criticize about this comparison but it is a convenient and useful way of thinking about it. Not all pickup makers publish inductance readings, but some do. Beware they may not all measure it the same way.

It is especially important when comparing inductances to have an idea of how the measurements were taken. Measurement frequency and other factors have a drastic effect on the reading. I measure inductance using an Extech 380193 LCR meter in serial mode at 1 kHz. The inductance reading is automatically recorded during the test. This is one of the very few handheld meters that will measure low Q inductors like pickups accurately and it is what many pickup makers use. I have other meters that measure inductance but for this application they are off by as much as a factor of 2.

**Resonant Peak** – this is the audio frequency at which the pickup is most responsive and gives the most output. Output will also be stronger at any harmonics of the resonant frequency. Basically, the higher the frequency of the resonant peak, the brighter the pickup will be. The broader the resonant peak, the more full the sound will be. This is good information, but comparisons between different makers can be misleading because there is no standard way among pickup makers of measuring it. This makes comparisons only really valid when comparing measurements made by the same builder. Often the makers who test for the resonant frequency have made their own gear to excite the pickup by sending an audio signal from a signal generator through an amp and driver coil, and sweep through the frequencies to find the highest output, while others excite the coil directly with a signal generator. Some use pure tones and some use white or pink noise and so on. I have tried many such methods and find most of them to be quite subjective, and very much dependent on the test gear setup. Measurements taken of the same pickup by trying to simulate what is known of the sketchy details of different versions of manufacturer's test setups often don't agree, and it is sometimes hard to reproduce the manufacturer's results. The biggest problem is that the signal generator frequency dominates the result so heavily it is difficult to find an exact top or maximum so the results can be almost arbitrary. And all resonant circuits display ringing, showing multiple peaks which are caused by harmonics. This is good to look at because up to a point, the stronger the harmonics, the more rich the tone will be, but if they are too strong it will sound thin. Sometimes with these setups it is hard to distinguish the peaks of fundamentals from the peaks of harmonics.

The method I use is called the zero- phase difference method and it is the most precise and repeatable test I have found, thanks to my pickup maker friends online. This method uses a signal generator to excite the pickup through a simple test circuit that simulates the volume and tone controls and helps to match impedance to the signal generator so the peak can be seen at resonance. The x-y function of the oscilloscope is used with two probes to display an oval shaped trace (lissajous pattern) as the signal generator's frequency is varied when the pickup is being excited. The real advantage of this method is that the pattern shown on the scope will collapse to a straight line only at the exact resonant frequency. The resonant frequency can then be read directly off of a digital frequency counter. This makes the test very precise – and fast. I can repeat this test reliably where I have not been able to do so with other methods. For the electronic engineer guitarists out there, what we are measuring is the exact frequency at which the inductive reactance and the capacitive reactance are equal, which is the textbook definition of the resonant frequency. For reference, the equipment I use is a Tektronix CFG253 signal generator and a Tektronix 2236 100 MHz 2 channel oscilloscope with digital frequency counter and multimeter functions.

For the rest of you what this measurement is good for is to nail down one very repeatable method to compare the location of the resonant peak between different pickups to compare brightness. It only shows the resonant frequency value, but the Q factor can be used to get an idea of the width of the resonant peak to compare fullness. When this information is combined with audio spectrums measured with a spectrum analyzer taken at a variety of common audio frequencies, the performance of the pickup can be measured quantitatively and different pickups can be compared more accurately. For a number of reasons, measurements taken with this method may differ from results obtained by other makers methods, so as always it is best to make comparisons only between results obtained with the same testing method. And don't forget the same pickup can sound brighter or darker in different guitars or even just with new versus old strings installed.

**Q factor** – this is the quality factor, which basically tells how sharp or how broad the bell shaped curve of the resonant peak is. The higher the Q factor, the sharper the peak. The lower the Q factor, the broader the peak. The quality idea in the name comes from radio design years ago when a high Q factor meant better tuning. It is just called the Q factor now. A higher Q factor does not necessarily mean a better pickup. A broader peak (lower Q) means a fuller sound. All pickups are considered low Q devices. For my own comparison purposes, I calculate the Q factor at the resonant frequency from other measurements and a standard formula. At resonance , the Q is a higher number, however, since most published pickup Q factors are taken at 1000 Hz, for the sake of comparisons the Q factor I publish is measured directly at 1 kHz and automatically recorded using the Extech meter at the same time as the inductance is measured. To get a rough feeling for the range of Q, most strat type pickups have a Q near 3 and P.A.F. style humbuckers have a Q around 2 at 1 kHz.

**Magnet Strength (Gauss) -** here is a measurement that is very useful but can be confusing because of the equipment that some makers use to measure it. The higher the magnetic field strength in the coil and at the strings, the more powerful the output, but the more likely that the magnets can cause dampening of the strings if set too close. Also, a higher magnetic strength can make a pickup sound more edgy. Weaker magnets tend to lower the resonant peak frequency, and stronger magnets tend to increase it (brighter sound). Gauss is a measure of the intensity of the magnetic field at a given location. Since the magnetic field strength drops off quickly with distance (unless conducted by polepieces) where the reading is taken is very important. Measurements are not often given, but if you do have the chance to compare any that are given, you will likely see two different ranges of measurements. Many makers use a hand held gauge made by the RB Annis company called a magnetometer. For years this has been common in the pickup trade. It will read in a range of something like 0-50 gauss. This is useful for comparisons, but it is actually measuring the strength of the field at some fairly significant but constant distance from the surface of the magnet. To me a more useful measurement is taken by using a hall-effect meter, and measured directly in contact with the pole of the magnet. This will result in a measurement more in the range of 0-1000 gauss or higher. Either method will be useful for comparisons as long as all are made the same way, but they are so different that it can become confusing to compare among different makers. So when you see one pickup that says the gauss is 50 and another that says the gauss is 1000, then you should question which method was used. They are probably similar. I believe the hall-effect measurement direct contact method is more precise and so that is the one I use. The meter I use is an Alpha Lab DC Gaussmeter Model 1, accurate to within 1% to the bureau of standards, (NIST). For humbuckers, I measure the readings at the individual slugs and polepieces and average the results.

Well, the above measurements are all pretty useful for comparing pickups. Outside of them it is more productive to begin looking at things like coil shapes and magnet structures and alloys for shaping tone. Beyond these are a few other measurements that beg to be taken but are much more difficult to interpret. I do measure and report these, but really they are only helpful to pickup designers, and not even all that important to many of them.

**A-C Resistance** - is more or less the D-C resistance plus eddy current and core losses. This is of course an oversimplification, and to say anything at all about A-C resistance starts getting into a whole lot of theory about impedance and complex numbers. Measurement frequency affects the result. I am talking here about only one simple measurement though. A-C resistance is read by the Extech meter at 1 kHz at the same time as the inductance measurement is made. This reading can be used to calculate other things, and gives an idea of eddy current losses, but unless you are a pickup designer it isn’t that useful, so A-C Resistance is hardly ever published by manufacturers. The higher the A-C resistance at a given frequency compared to the D-C resistance the more eddy current losses there are in the pickup for that frequency. Some people have a lot to say about eddy currents. Basically, they are pretty much unavoidable but when limited aren’t always all bad. They do siphon off some power, but also color the tone and tend to cut high frequencies. Sometimes a little of that is needed. There is some evidence that limited eddy currents are partly responsible for adding harmonics and richness to the tone. So they do have an impact. Eddy currents are stray currents that occur mainly in the nearby metal as a result of induction. They are not so much in the coil wire itself, though some think any tangles in the wire may contribute similar effects. The nearby metal can also affect inductance and magnetics and shield or reflect A-C fields, and all this is going on at the same time so trying to completely understand it all gets complicated fast.

As one example of how these factors interplay to affect tone, a metal baseplate in a pickup affects inductance and reflects some of the A-C field created by the vibrating strings (that would otherwise be wasted) back into the coil increasing volume and brightness compared to a nonmetal baseplate. (think of a tele bridge) This effect is more powerful than the eddy current losses created at the same time which would tend to darken the tone. So the eddy currents in the baseplate cancel out only a little of the brightening effect. On the other hand, in a covered humbucker, because of their location between the coil and strings, metal covers shield the coil somewhat from all A-C fields, including the A-C field coming off the strings and do cut output slightly and darken the tone in addition to reducing interference. Nickel silver baseplates and covers have less eddy current losses than brass ones and thus are brighter. Now if all that didn't scramble your brain a little, you might have missed something.

**Capacitance** – the distributed capacitance of the coil has an effect on brightness and indirectly on many other factors. It has to be calculated, and can't be measured very meaningfully by a meter for frequencies below the self-resonance frequency. I do sometimes calculate the distributed capacitance from other measurements on my test reports, and it is useful for my own comparisons but just realize that measurements taken with any meter directly can be off significantly. The capacitance measurement given my test reports is taken with the Extech meter at 1 kHz and automatically recorded during the test procedure. It is an indication only, but I publish it that way because it is more comparable to the figures that might be given by others. The capacitance affects the frequency of the resonant peak. Fundamentally, the natural resonant frequency of the pickup is inversely proportional to the square root of the product of its inductance and capacitance. So, all else being equal, the more distributed capacitance a pickup has, the darker it is and the lower the resonant peak.

**Output –** there is not a standard way that pickup makers use to measure output. Each maker has their own test method, if they use one. Most of them, like me, use some kind of a driver coil setup. Without installing the pickup in a guitar and using a mechanical string picker it would be difficult to get consistent results by measuring the output voltage when the guitar is actually being played. Even then, much care would have to be taken to ensure the pickup height and the strings are consistent each time. A driver coil can more consistently simulate the electrical fields produced by the vibrating strings. To get an idea of relative output levels I measure the output of the pickup under test compared to a typical strat pickup tested under the same conditions. I have constructed a test set that consists of a small solid state amplifier that drives a coil of wire which I put in contact with the pickup. A signal at 1046 Hz from the signal generator is fed into the amplifier. The output of the amplifier feeds the driver coil which causes the pickup to generate output when the driver coil is put in contact with it. The driver coil is wound on a wood frame with index holes for the polepieces so it can be aligned accurately in the same position each time. For each test, I adjust the gain on the amp to get a precise 100mv output from the reference, measured with the oscilloscope (measuring RMS AC millivolts). The driver amp has a 10-turn pot fine gain control installed so that this adjustment can be done precisely. Then without changing the amp or the signal generator, I connect the oscilloscope to the pickup under test and put the driver coil in contact with the test pickup, to measure its output. The reference standard is an import strat bridge pickup that I use exclusively for this test. For example if a humbucker measures 170mv in this test the output of the humbucker is roughly 1.7x of the output the strat pickup would have under the same conditions. This gives an output value the average player can at least relate to. The 100mv levels approximate the actual output levels that have been measured by myself and others on pickups installed in a guitar and played. In the case of a humbucker I measure the slug and screw sides separately with the cover off and average the results. This test is only a rough guide to the perceived output that a pickup will have. For the testing to make a calibrated set, I use a different method which involves installing the pickups in a guitar and measuring the sonic output through a regular amp with a sound level meter.

**Spectrum Analyzer Plots** – when in use, the pickup is excited by electrical fields generated by the magnetized strings alternating at the frequencies of whichever strings are being played at any given time. It responds through inductance with a certain output level at those frequencies and also at harmonics of those frequencies. Some of the harmonics are coming from the strings and guitar, but even when a pickup is being excited by a pure tone from a signal generator, the harmonics are present due to natural ringing in the resonant circuit of the pickup. The resonance and electrical characteristics of the pickup determine the number and strength of these frequency peaks. Harmonics add richness to the tone, but if too strong relative to the fundamentals the sound becomes perceived as more thin. So it is useful to look at how the harmonics compare to the fundamentals when the pickup is being excited by a pure tone. Measurement of this can be accomplished with a spectrum analyzer. When the pickup is excited by an electrical signal at the fundamental frequency of a given note, the resulting spectrum gives an idea of how the pickup will respond when excited by a string played at that note. I also find the spectrums very useful in getting a visual picture for comparing pickup performances relative to a known example. A set of spectrum plots is also somewhat similar to the "tone charts" that may have been published in the past, but much more detailed and precise. Of course, a spectrum plot made with a test set cannot give a complete picture of how the pickup will respond in use because of other factors such as the size of the magnetic window, and the effects contributed by the guitar, amp, and cables. I use a Hewlett Packard 3580A audio spectrum analyzer and the Tektronix CFG253 signal generator for this, and use the frequency meter of the Tektronics 2236 oscilloscope to set the frequencies precisely. I capture the waveforms on the spectrum analyzer with a camera. This is mostly useful as a qualitative way to compare the performance of my reproductions to the pickups in my reference library, i.e., the standards they are supposed to clone. For custom work, I record on your test report the measured waveform plots at several frequencies, along with similar plots for a comparison pickup if you selected one, or an example of the type from my library if you didn't select a specific model. The frequencies are:

At the self-resonance peak frequency
At the note A 440 Hz – the standard tuning reference
At the note C2 65.4 Hz – the lowest note usually written for cello
At the note C4 261.6 Hz – middle C on a piano
At the note C6 1046.5 Hz – roughly the highest female vocal note
At the note C7 2093 Hz – the highest note usually written for clarinet
At the note C8 4186 Hz – highest note on a piano

Capturing waveform plots is quite time consuming, so to keep costs down on stock models I check the waveforms against representative screen shots from the same model number pickup, but print the standards on the report instead of spending the extra labor of setting up the camera and importing the photos into the report. If this has been done, it will be so noted on the report. Within a given model, the test waveforms don't vary substantially. These standard waveforms are still very representative of your pickup's response because if the test waveforms don't match the standards for that model I rework or reject the pickup. All of the numeric measurements on each test report are the actual test data for that serial number.

**Magnetic Window** – This is a term that is used to describe the length of the strings that are magnetized by the pickup's magnets. While this is not usually given by any kind of a specification, it is an important factor in determining the tone that will result in any given pickup design. The strings have a complex vibration when played and the amount of string length that is magnetized affects the frequencies of the electrical field that is generated. For example, the more length of string that is magnetized, the more opportunity for the lower frequency (longer wavelength) vibrations to affect the field. If a pickup has a short magnetic window it is going to be brighter, and if it has a wider magnetic field it is going to be a little darker and more full. Most single coils have a smaller magnetic window than humbuckers, and this is one of the main factors that influence the difference in their tones. Some other design factors can influence the size of the magnetic window, besides magnet alloys and strength. Examples are the metallic baseplate of a telecaster, jaguar "claws", double screw poles instead of slugs on humbuckers, and so on.

**Understanding Phase –** This is not so much of a specification as an effect of how different pickups are connected together. Depending on in which direction the windings are done and the magnet polarity, when the signals from two different pickups are combined they can either buck or boost the other's signal. When pickups are wired out of phase, you get a hollow, slightly lower volume, treble kind of sound. The out-of-phase sound may be desired, and has been exploited at times- for example by B.B. King, and by T-Bone Walker before that. In fact, some people install a phase switch to get it, or intentionally hard wire a pickup out-of- phase. But ordinarily, pickups are wired in-phase. So, if your pickup is not performing as expected when wired in a guitar it may just be out-of-phase. A simple way to check phase of pickups out of the guitar is to use an analog (the cheap needle type) ohmmeter and a chunk of metal or a magnet (a screwdriver held horizontally will do). You can use a digital meter but you have to look quick and note the sign. Set the ohmmeter to D-C ohms and connect it to the pickup. Use the zero and scale setting or if necessary use a resistor in series with the pickup to get the needle somewhere off zero or near the middle of the scale. Then bring the metal or magnet near the pickup (wave it over in the same direction) and notice which direction the needle moves. Do the same to the other pickup. If the needle moves in the same direction both times, the pickups are in-phase.

The two things that control phase relationships are magnet polarity and coil winding direction. Pickups have been designed with various phases over time, or by different makers, so for example if you have an early strat type single coil with north polarity and you wire it normally in with most pickups that have south polarity it is going to be out-of-phase. You could swap the hot and ground on one to get them in-phase with each other. On single coils, that's easy enough. Another option would be to re-magnetize it in the opposite direction. (Never try to push the magnets in or out though, unless you want a dead pickup.) On humbuckers, unless you have leads with the coil connections and shield separated, swapping wires is going to mess up the grounding and shielding effect of the cover, and it is better to "flip" the magnet over. It isn't too hard to do and there are instructions all over the internet for it, mainly just loosen the baseplate screws and slide the magnet out and turn it around then slide it back in and re-tighten the baseplate screws (don't tighten too much though). If the pickup has been potted, or if it has a cover soldered on it's a little more involved. If you end up needing to reverse a humbucker magnet and aren't comfortable doing it yourself, I can do it for you. I can also re-magnetize a single coil in the opposite direction to accurate gauss specs.

It is easy enough to check the magnet polarity at the polepieces with a hiking compass, if you think you have a pickup with a magnet that may have been flipped. The red (north seeking) end of the needle will point to the screw poles (which have south polarity) and the other end of the needle will point to the slug poles in a normal humbucker. Same way with a single coil – the north seeking end of the needle will point to south polarity magnets. You just have to remember that the geographic north pole of the earth actually has south magnetic polarity. This naming convention was invented by Flemish compass makers hundreds of years ago just to confuse future guitarists. They knew the GPS would eventually come along and cut into their compass business, and schemed to make a lot of money over the confusion this naming convention created by selling convenient little clear plastic tube type magnet polarity testers to guitar supply houses. Unfortunately, plastic tubes hadn't been invented yet, so the project was shelved for decades, until the company was forced to close when their sundial market was devastated by the invention of daylight savings time. But the confusing magnetic pole naming they created lived on, along with the 32 compass point names they are also still smirking about.



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