Guitar Pickup Sensitivity and Amplitude

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Introduction

The problem with pickups is that the sensitivity is rather poorly understood, and this short document provides a brief discussion and explanation of what affects pickup sensitivity and why sensitivity is such a vexing issue.

Understanding Sensitivity

The pickup coil sits in the magnetic field, usually rather close to the permanent magnet(s) that set the general magnetic field strength (magnetic potential). When the magnetic field strength is varied, this induces a voltage into the coil - proportional to the number of turns in the pickup coil, the instantaneous velocity of the string movement normal to the field strength gradient, and proportional to the relative change in overall magnetic potential caused by the proximity of the magnetic string in the magnetic field.

So, if the coil is not positioned to have the majority of the affected magnetic field passing through the coil, then the sensitivity of the pickup coil is compromised - or less sensitive than it could be.

Effect of Differing Turns

Taking a hypothetical example of a pickup coil having say 10,000 turns on it and it produces say 1000 mV peak-to-peak sinusoidal voltage. If another coil was wound with the exactly same external dimensions but with very slightly thinner wire (or more likely, very slightly thinner polyurethane / lacquer insulation) and say 11,000 turns is wound on instead to fill the bobbin, then this coil in the identical position to the previous coil would produce 1,100 mV pp (into an open-circuit or very high impedance load). In terms of Decibels to compare the relative output levels from the otherwise identical pickups, the answer is:

Comparative Level (dB) = 20 log (1100/1000)

= + 0.828 dB (relative to the 1000 turn coil)

Now considering that it is difficult to notice a 3 dB level change, in practice it would be very difficult to notice this level change.

Effect of Spectral Response

If there were significant changes in the spectral response for example by forming a resonant peak in the response, or a lower spectral response, or distortion in the amplification stages then the level may appear different. All these situations are very unlikely, unless these were 'engineered in' (usually by knob tweaking) - but this is hypothetically flat frequency response pickup coil.

Effect of Coil Position

If the coil position was changed so that it sat off-centre to the maximum magnetic field strength, then the coil could be in say a 75% maximum field strength position. In other words 25% of the changing field is not associated with the coil. In this case, the comparative change in level would be:

Comparative Level (dB) = 20 log (0.75)

= -2.5 dB (relative to the first position)

So the relative position of the coil, its shape and size are all very important factors, and the position of the coil being moved several millimetres relative to the magnetic field; when it has to be considered that the magnets themselves are quite small (10 to 20 mm long), this can cause a significant change to the output level.

Another way of looking at this is that: if say 90% of the permanent magnetic field is not associated with the relative string movement, then this 90% of stray field is susceptible to external noise interference!

Pickup Interfacing 101

Electromagnetic guitar pickups were first 'invented' about 1937 [1] when crystal microphones were the norm, phonograph records used crystal pickups, and the nominal amplifier input voltage level was 100 mV, terminating in 1 M ohm. (These days this voltage level is referred to as "Line In" and/or "Line Out".)

The standard connection was to feed this signal from a guitar directly into the 'Phono' input of a valve amplifier, which suited crystal pickups – because it was 'high impedance', typically 1 M ohm. To get sufficient signal level, several thousands of turns had to be wound onto the pickup magnets!

Single Turn Pickups

More recently some guitar pickups have come out with one or two turns on them and these one or two turns feed directly into a small transformer. This guitar pickup structure is very similar to what most dynamic microphones have in them (the guitar pickup coil connected to a very small sized step-up transformer)!

This structure has a few advantages in it that the guitar pickup coil (of one or two turns of very thick copper or aluminium) is very simple construction, and the step-up transformer has a very low parasitic inductance and resistance, so the frequency response is very wide. These two in combination get the best from both worlds of a wide frequency response and a reasonable output level to work with.

Understanding Root Mean Square

The standard unbalanced Line In/ Line Out voltage level is 100 mV rms (root mean square). The normal test equipment includes a low distortion and constant level sine wave at nominally 820 Hz as the "level" reference.

The rms value is the mathematic equivalent of the heating value if a constant direct current was used to provide the same heat. In other words, this is an equivalent POWER level.

[1] http://www.ampix.org/albums/userpics/10040/pat2087106.pdf

It just so happens that with a sine wave, the rms equivalent is 0.707 of the Peak amplitude, or looking at that another way, the Peak level is 1.414 (or root 2) times the rms level. So the peak amplitude is 141 mV, and if we consider the peak to peak exertion, it is simply twice this value or 282 mV pp, and this is nearly three times the original number - but these all refer to the same sine wave.

Attack and Peaks

The percussive effect of guitar music has a leading edge to sustain ratio of somewhere between 12 dB and 24 dB, which in round figures puts the typical lead edges about 18 dB above the average levels, which in mathematical ratio form is about eight (8) times the sustain level, or in voltage terms means that the 100 mV is really 800 mV and the peak to peak exertion is really 2240 mV pp.

Amplifier Input Stages

Most (valve) guitar amplifiers use a 12AX7, or 12AU7, [2] or similar double triode in the first stage and these valves are usually biased at about -2 V (grid-cathode). So when we use an electric guitar into this first stage we will be driving the pre-amplifier fairly hard - and this topic will be covered too!

With a FET as the first stage the typical biasing is about –2 V to –3 V so a virtually identical situation exists as for the valve pre-amp.

If an op-amp is used as the first stage then you can be assured that the gain will be tied down to between +/- 6 dB, typically a unity gain amplifier so the gain is 0 dB and the volume control often incorporates the feedback loop so hard overloading is rather difficult (unless of course a fuzz box is included up the front of the pre-amplifier)!

[2] http://www.guitaramplifierblueprinting.com/12ax7.html