Guitar Pickup Measurements 3

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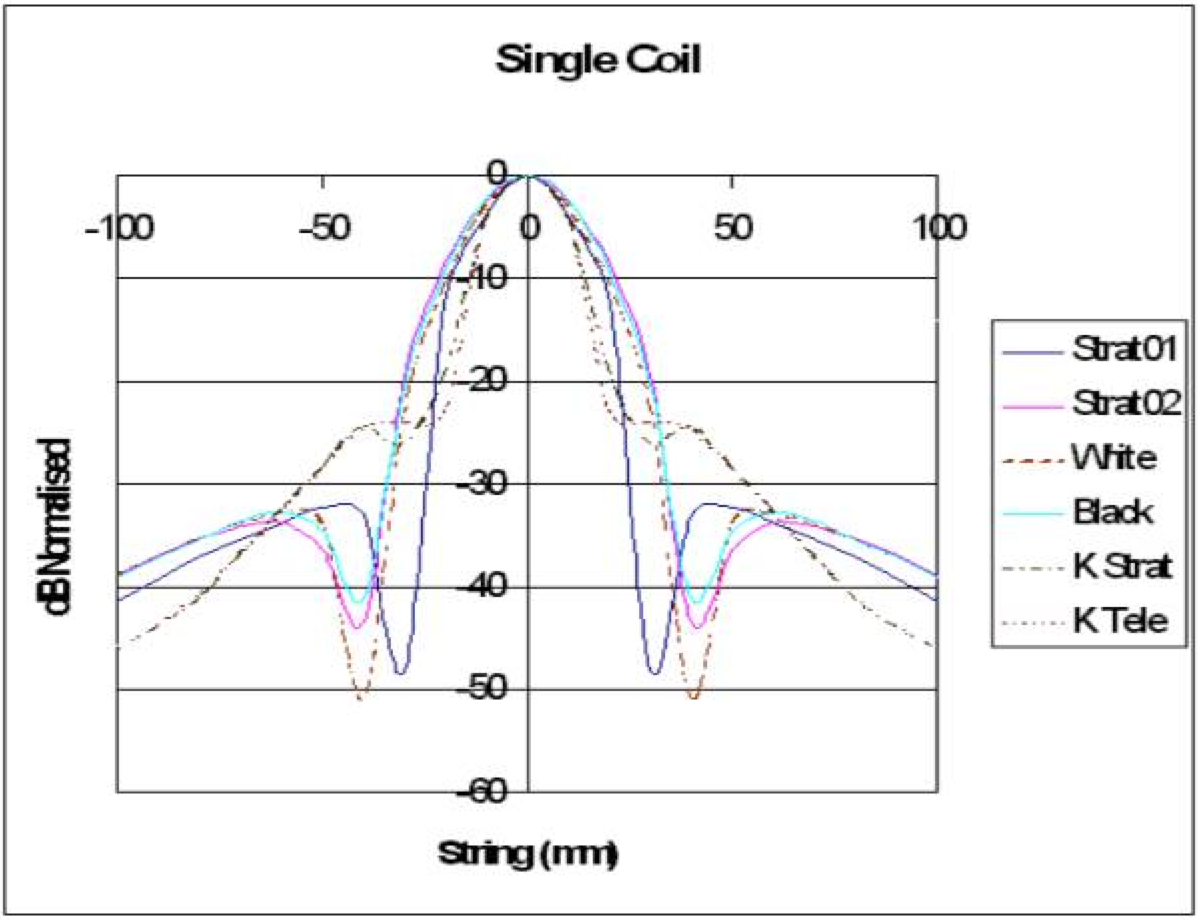
Sensitivity Along the String

In this case, the tests performed were as though only one part of the string was vibrating at nominally 400 Hz, and the load was ultra-high impedance, so the frequency response between different pickups would not have been an issue.

Two sets of tests were done, one at 10 mm and the other at 5 mm. The Exciter was positioned and the pickup then positioned opposite and spaced by 10 mm, then on the 'y' axis, the pickup was stepped in 10 mm increments as though the moving part of the string was further along the string.

Instead of producing a whole set of figures, these results are graphed as below:



This is a very interesting picture as it shows that with single coil style pickups, the magnetic path is focussed and by about 10 mm away from the poles (along the string) the signal is already down by about 3 dB and falling!

Somewhere between 38 and 50 mm away from the 'y' axis on the pickup, the phase reverses and there is a null, then it rises to be about 33 dB down then continue to fall away at about 16 dB per 100 mm. (*July 2007* This null is caused by a doublet magnetic field in the source, and the response should be a 'simple' bell shaped curve.)

The Kinman pickups are different, as these are both vertical Hum Buckers, and by about 25 mm away they have their null, sit on a short shelf at about 25 dB down then fall away at about 45 dB/100 mm and at about 80 mm offset (with about an 8 dB advantage over the single coil pickups) then fall away at about 16 dB/100 mm.

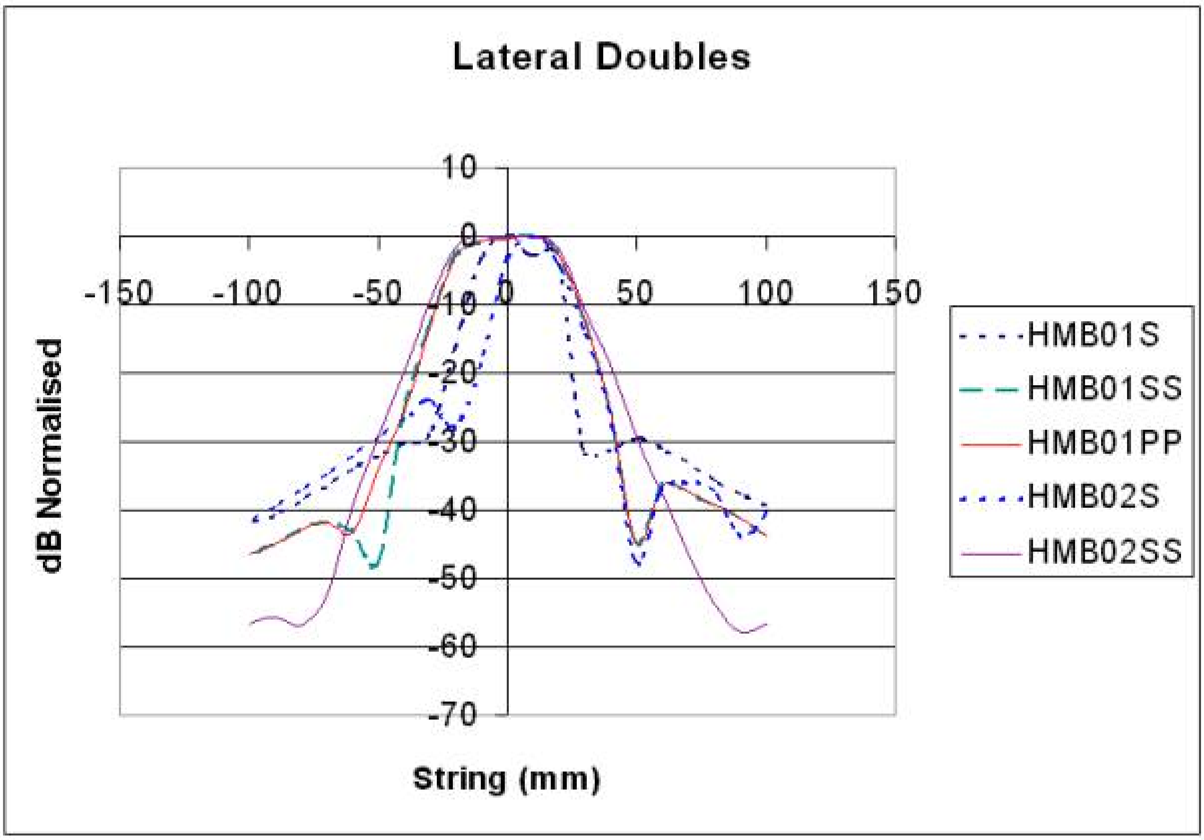
(*July 2007*) There is something very special about vertical Hum Buckers sensitivity responses that need to be understood, and it is much easier if you also have a knowledge of antennae theory - in particular Log-Periodic antennas (like those used for some household television antennae).

The Log-Periodic antenna has a “multiple anti- phased dipoles” and these are spaced to act like a mirror, so it has a “directional response” that is very similar to that of a vertical Humbucker.

The Vertical Humbucker has an 'anti-phased' coil mounted further away from the strings than the main pickup coil, and this is what causes the notch at about 15 mm off centre, and the steeper skirt - and that is why it is comparatively noiseless - compared to the single coil pickup coil.

(2005) With lateral (side-by-side) Hum Bucking pickups, the story is again slightly different, because the magnetic field extends along the strings between the magnet pole pieces and not ‘through and back as in a single coil pickup.

When we use the exciter coil (and it aligns with the centre of the Hum Bucker pickup ‘x’ axis field) then there is a null position and gives a very false set of readings. By avoiding the null reading, and normalising to the maximum levels for each set of readings, the following set of curves follows:



Unsurprisingly, the string is sensitive over a longer length (about 45 mm) before the response drops off and this is because there are two sets magnets for each string - where they have an additive effect over the pickup and a subtractive effect beyond the pickup.

The 'skirt' appears to drop off very quickly and forms a false null because of the exciter coil's (doublet) field. The real response follows the more gentle curve that is about 40 dB down by 100 mm off centre of the pickup.

(July 2007) What is surprising is that the 'skirt' shape is virtually identical to that of the single coil pickup (when it is offset by the magnet head spacing), and this indicates that the magnetic coupling is rather poor.

This lateral pickup will however not sound like the Strat pickup because the interaction of the magnetic field with the string is 'skewed' across the face of the pickup, from one row of magnets to the other row of magnets or iron pole piece, but in the case of the Strat; the magnetic field sits up like pineapple leaves from a single row of magnets - more later.

In the above graph, the legend with the suffix ‘S’ means the one coil is acting as a single coil, which is (naturally) offset from the zero axis, as the centre of the two coils was used as the measure reference.

Note the second bump near the centre – caused by induction into the other pole pieces. These responses are however very similar to the Strat curves.

The two curves with the legend suffix ‘SS’ indicate a Series aiding Series connected pair of windings, and these have a characteristic flat top (after removing the null reading from them).

(*July 2007*) Note that the shape of the skirts is virtually identical to that of the Single Coil Strat, and even the HMB02 has a somewhat similar shape.

The reading with the legend suffix ‘PP’ indicates a parallel (aiding) connected pair of windings, and this curve also is flat over the top with clean skirts down to about -35 dB, and this is a voltage ratio of about 56:1.

The ‘notches’ in the ‘greater than 25 mm offset area’ are where the voltages developed on the two coils cancel each other out and as the distance is increased the signal becomes out of phase.

The fact that the symmetry is poor beyond the immediate active area indicates that the symmetry in manufacture is not there either – but with this being quieter than 35 dB down – who is to be concerned about this?

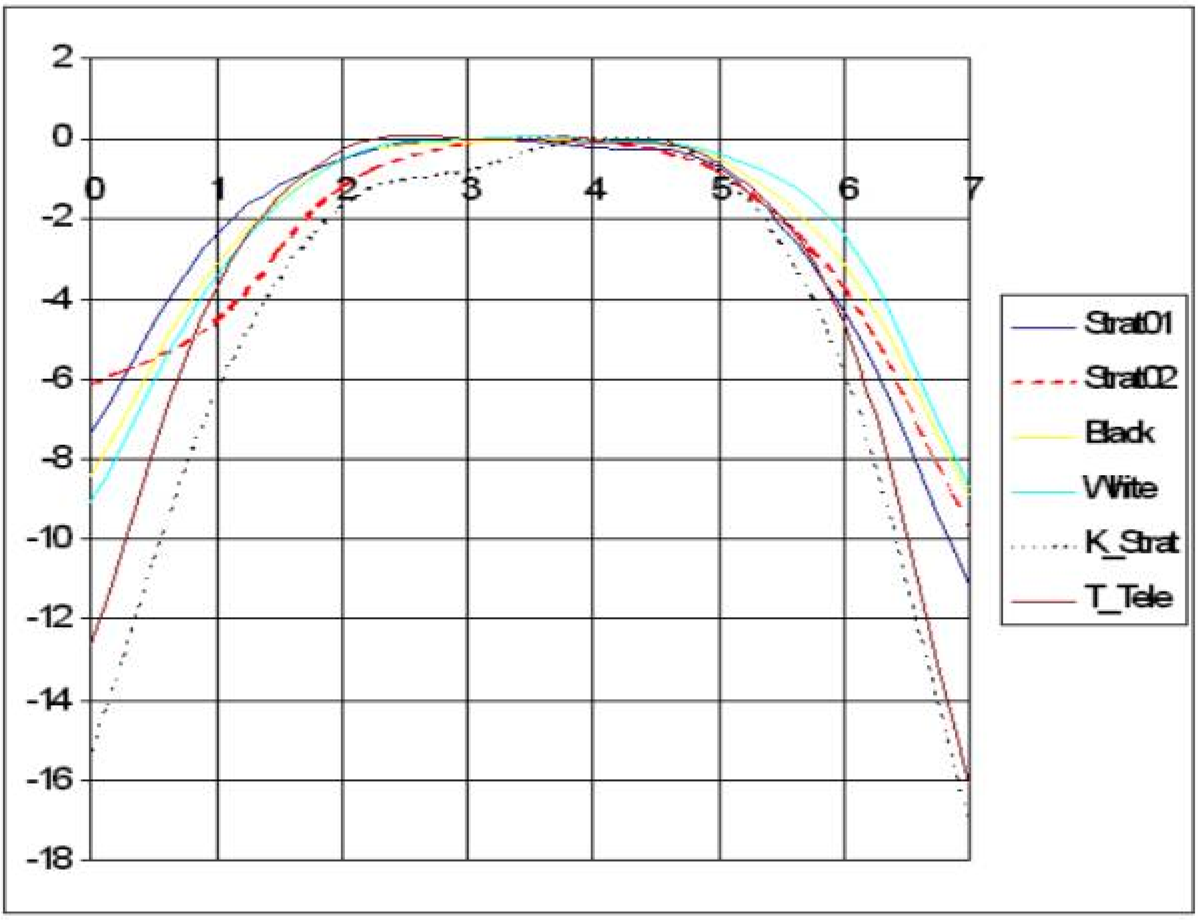
Well, a Hum Bucker is supposed to remove as much background noise as possible, and without a symmetric construction then it is compromised from the start!

Sensitivity Across The Strings

By placing the exciter coil close to the pickup face, then stepping the pickup pole by pole and past by one, a fair estimation of the relative (vertical) string movement with relation to each pole in the pickup.

Again the same 'centre of axis rule' applies for lateral Hum Bucker coils so they were not done with the exciter coil.

As before, the results were put on an Excel spreadsheet and then graphed as the picture tells the stories much better in these cases. Here are the single coil pickups:

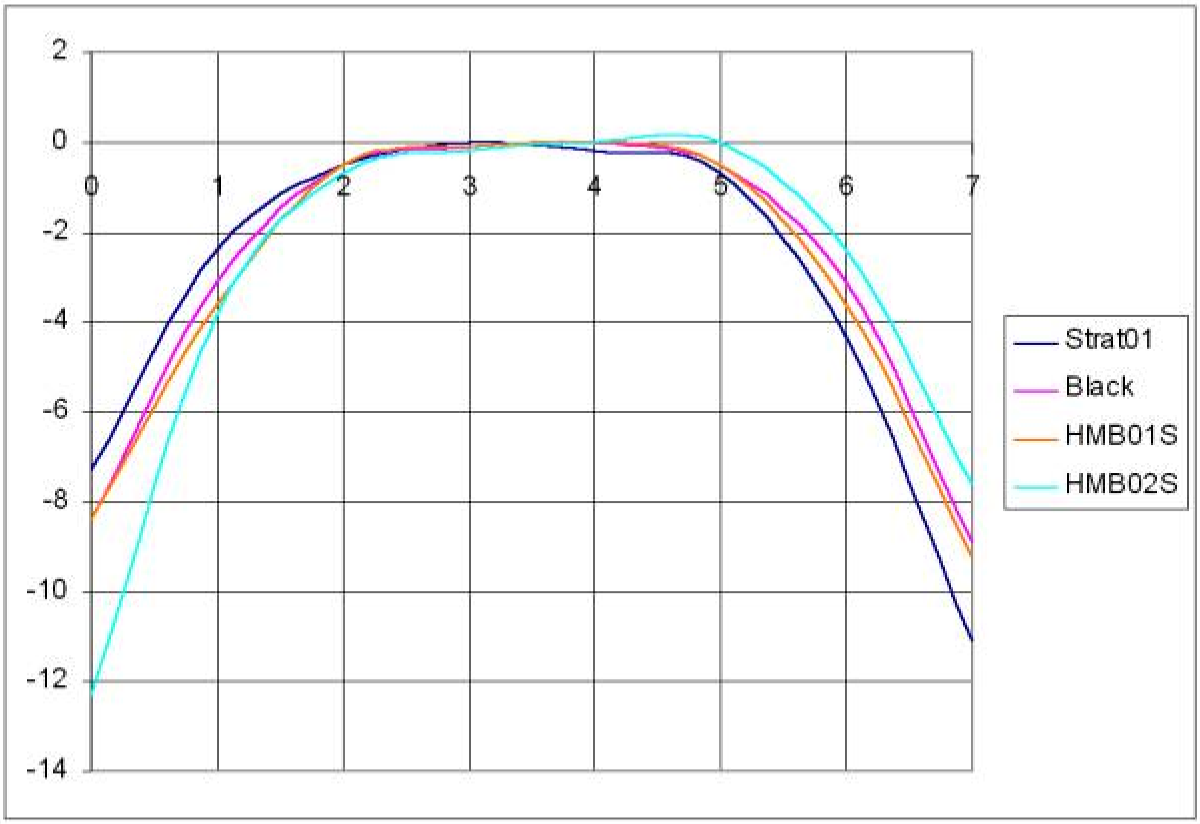


Again this is an interesting graph as it shows that most results are within +0.1 dB, -0.8 dB for magnet pieces 2,3,4 & 5, and that poles 1 & 6 are typically about 4 dB down, and the exceptions are the staggered pole pieces with varying height, and that would be expected as there are a few millimetres difference here. But the difference in level measured with adjacent poles is incredibly small, except at the extremities (poles 1 and 6).

In the second case the response with the Hum Buckers acting as single coils also had virtually similar sensitivities, and there were no surprises there. This tells the story that the pole strength appears to fall off with the outer extremity strings.

The fact that the fret-board is slightly curved, and that in most cases the magnet as form a flat plane, the centre four poles will be fractionally away from the strings in comparison to the outer strings.

To exercise that point slightly, a second set of readings was done at nominally 10 mm from the pole faces of the pickups and the graph shows below:



The non-normalised figures show that there is about a 2.5 dB difference in levels between 10 mm and 5 mm, and this difference drops to about 2 dB at pole pieces 1 and 6.

So with a slightly curved fret-board, the centre strings are typically about 0.5 mm closer to the edge pole pieces, and this would give an almost unnoticeable difference in comparative string levels.

The shape of these curves bears a close resemblance to band pass filters like those used in dial-up modems, ADSL filters, Television picture and sound channels, FM receivers etc.

Minimising the error across the fret-board/pickup conjures up the maths developed by Chebyshev[1] with "equi-ripple" in the pass-band to minimise the overall error.

The Hum Buckers – wired as single coils, act just like other single coils and they all tell the same story that the pickup is too narrow for the strings, and it should extend by another 2 poles to provide a field with minimised magnetic fringe effects. It is also obvious that the errors in placing the pickup at the extremities is far larger than placing the pickup with poles as the references – and this is shown by the spread in values on the sides of the graphs!

[1] http://en.wikipedia.org/wiki/Chebyshev_filter

Conclusions

Loose Coupling

Putting a magnet near a vibrating string makes an almost imperceptible change in the pitch and sustains qualities of the vibration, and from that we have to understand that the magnetic field is very loosely coupled to the vibrating string.

Putting an electromagnetic guitar pickup close to the (magnetic) strings also makes an almost imperceptible change in the pitch and sustains qualities of the vibrations.

Because the sustain factor shows that an electric guitar string will sustain form several seconds, and the fundamental frequency is typically 120 to 800 Hz, the ‘Q’ factor typically about 2500.

If this magnetic field interfered with sustaining vibration then the sustaining would quickly drop to much less than a second. ***As this does not happen, the electromagnetic guitar pickup is by its very nature a very loosely coupled transducer.***

Electronic Emulation

Emulating the physical string movement in practice as a constant amplitude waveform is extremely difficult – mainly because of physical resonances in the audio band.

An alternate approach by utilising a transformer winding with an open magnetic path has a similar effect as a moving magnetic string, and ***the test equipment designed here is virtually flat over the audio frequency range, making it an ideal exciting tool for practical measurements.***

A second exciting device using a resonant iron bar has been created and this is frequency range limited – but because it is used in a known virtually flat frequency response area, this can emulate constant string vibration with good precision.

Mini Tutorial on dB

The mini tutorial on dB was included here as from this point most of the results will be in decibels. To stabilise results, a reference send level was created at 0 dBV and a reference frequency was chosen at nominally 400 Hz.

Tests with the high number of turns other transformer half showed that this (240 V) winding had a self-resonance at about 11.5 kHz, and that the low voltage windings had self-resonances well above the audio band – making the low voltage windings very suitable for unequalised measurements, greatly simplifying the measurement process.

The output level verses separation distance followed a curve that closely aligned with the shape of a Gaussian normal distribution.

Frequency Response Tests

The emulation coil (or exciting coil) together with real pickups in a controlled bench situation produced frequency response results that were highly repeatable, and that followed the predicted results in the earlier experiments.

These pickups all generally follow a family of second order responses that can be pre-determined by measuring the pickup internal resistance and inductance together with known loads of resistance and capacitance.

Transient responses match with the frequency responses and some examples have been shown.

This technique removes the 'black art' of pickup sounds and places the frequency and transient responses directly into highly predictable engineering terms.

Pole - String Sensitivity

When measuring along the line of the strings, single coil pickups are sensitive for about 10 mm either side of the centre of the pole pieces.

For lateral hum bucker pickups, this sensitivity follows a similar pattern also extending about 10 mm past the nearest pole pieces with a flat sensitivity between the two pole-piece arrays.

The sensitivity across the strings is virtually flat with the exception of the outer two pole-pieces, which are relatively about 4 dB down. ***So the pole pieces do not need to be directly under the strings, but extend out beyond the strings to get a more even relative response.***

Comments and Corrections are welcome