Guitar Pickups Magnetic Fields 3

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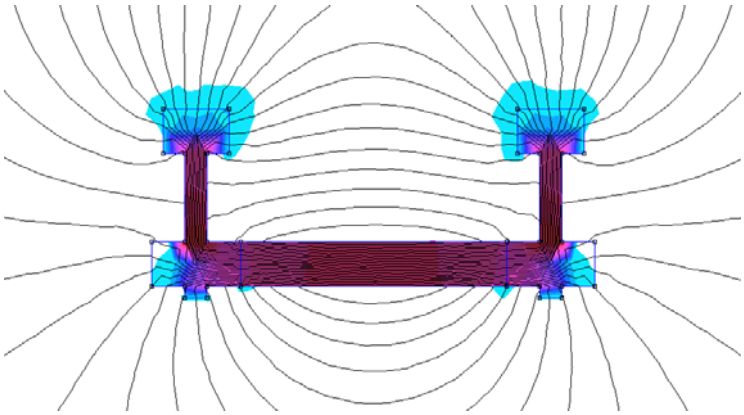
Dual Coil, Lateral Magnet (Humbucker) - Magnetic Fields

Now onto hum bucker structures. These have an entirely different structure, where the magnetic field is somewhat contained and it is this reason why they buck hum so well. Or is there a much better way?

One approach is to use a common joining magnet as in US Patent 2896491 (Seth E Lover, 22 June 1955) and in US Patent 5399802 (Steven L Blucher 21 May 1995) and this has a magnetic representation like that below, and this field is symmetrical along the strings. Structurally these two are very similar but the latter patent includes two soft iron strips to link the poles of the magnet to the adjustable pole-pieces.



To all other intents and purposes the cross section magnetic field is virtually identical as above. This one takes a little explaining, so use the lower picture as a guide!

The magnet is lying down across the bottom-middle (North to the right, and South to the left) with two iron strip plates attached at each end of the elongated strip magnet. In the two iron plates there are six vertically mounted iron screws with bit heads on them. (The heads are near the top of this representation.)

Above the screw heads are the strings, hence the ‘stretched’ magnetic field above the assembly.

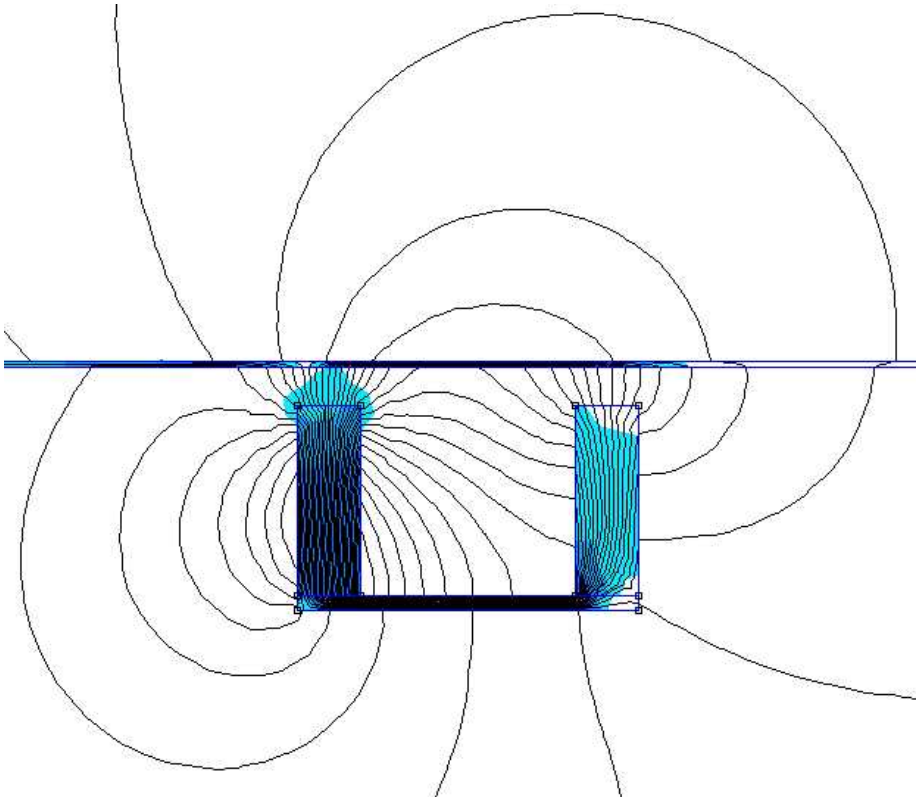
The two coils sit ‘flat’ around the screws. As the very large majority of the magnetic field is via the screws, and through the strings, this provides an efficient magnetic path with the strings – without unduly pulling them – and plenty of room for the two coils winding areas. The bottom nipples are the extensions of the screw threads!

As the permanent magnetic fields are in opposite directions through the coils facing the strings, this forms a fairly closed magnetic path, so any change in reluctance will cause a voltage to be created on each coil, and the coils are usually connected in series so the signal is additive. As the magnetic field is somewhat constricted it is this advantage that provides the humbucking effect – hence the term ‘hum bucker’!

Dual Coil, Single Vertical Magnet (Humbucker) - Magnetic Field

As an alternate to the lateral magnet some manufacturers came up with a similar design that only has one vertical magnet in the construction - together with two lateral coils.

These humbucker designs work surprisingly well considering the rather poor engineering involved in most guitar pickups.



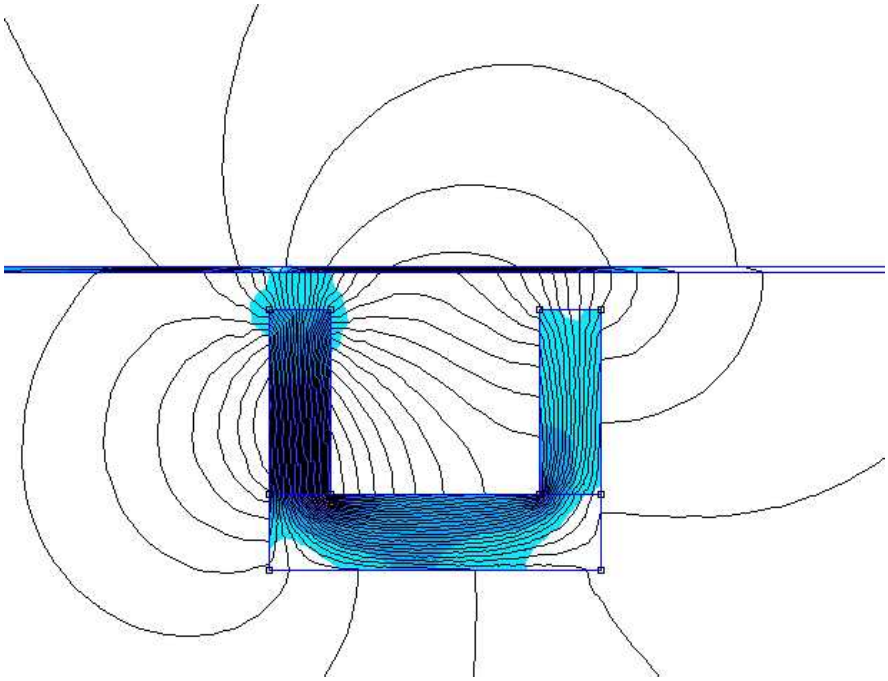
In this case the six bar magnets are mounted on the left hand side and a thin soft iron mounting plate is the lower reluctance path to the right hand side where six soft iron rods form the return path towards the strings through the air.

It is fairly obvious that the soft iron plate is close to magnetic saturation and the rods on the right hand side do not carry near the flux density of that in the six magnet rods on the left hand side. There are two coils, each wound around the two sets of six co-linear rods.

There are some interesting points about this structure in that the magnetic field is far from symmetrical but in saying that, the stray fields - like those in the other lateral humbucker diagrams in comparison to the single coil designs - are comparatively

well contained and therefore have the humbucker "tick of approval" - no matter how poor that is! Most of these humbucker designs are thrown together with plated soft iron so the magnetic leakage is often much worse that what is depicted here!

If the thin soft iron mounting plate were to be replaced by a thicker plate, then the structure of the magnetic field takes on a more symmetrical shape:

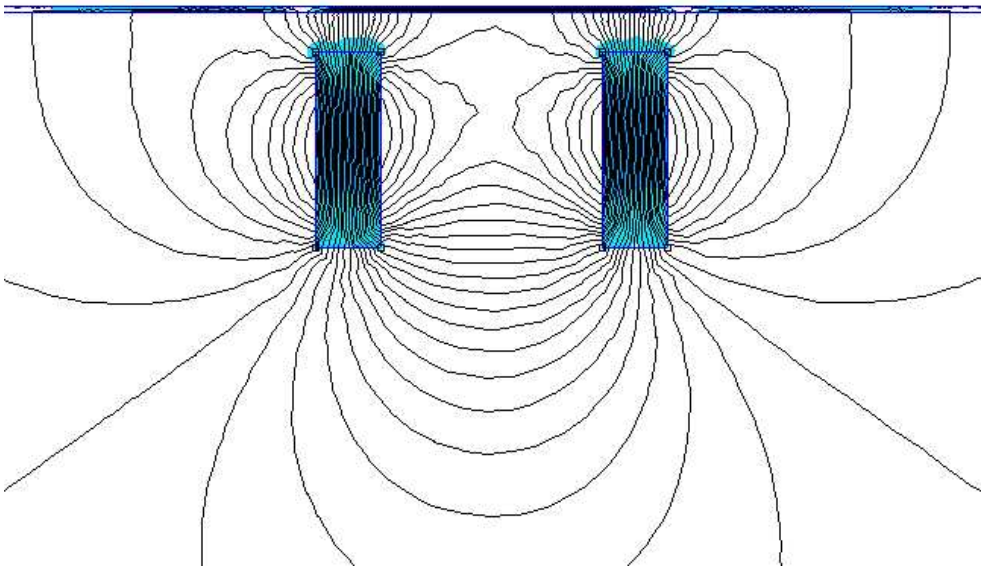


The magnet retains much the same flux density, but the flux density in the now thicker plate is not saturated and the rods on the right hand side are now with a higher flux density, so this simple improvement should make a very significant improvement in the sensitivity of this type of pickup, and its ability to not be affected nearly as much by distant electromagnetic fields.

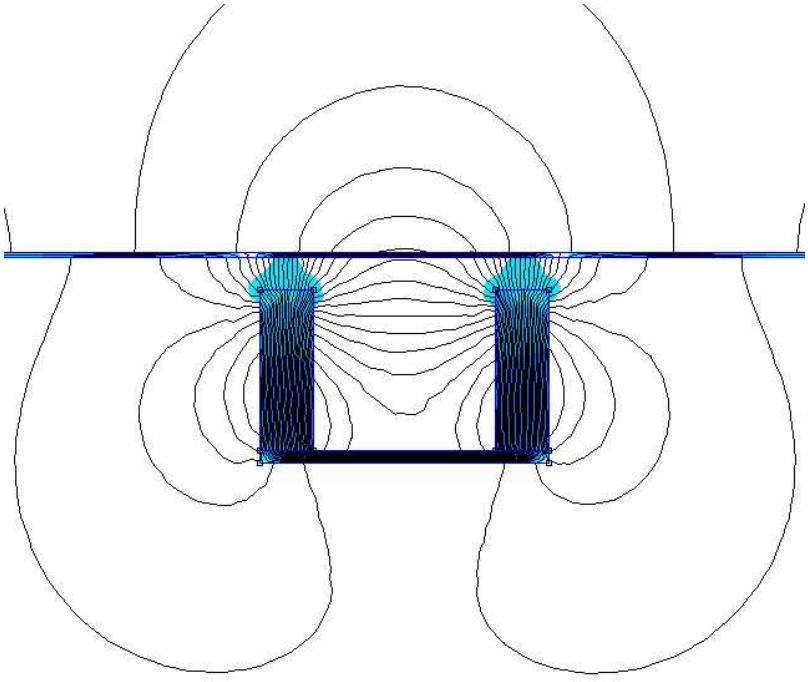
Dual Coil, Dual Vertical Magnet (Humbucker) - Magnetic Field

As another alternate to the lateral magnet some manufacturers came up with a similar design that only has two vertical magnets in the construction - together with two lateral coils. These humbucker designs also work surprisingly well considering the rather poor engineering involved in most guitar pickups.

To get an understanding of this structure, here are two magnets (one North at the top the other South at the top) near a string:



This is not much different that a pair of single magnet pickups put beside one another. The magnetic fields are interacting and pulling into each other to dramatically reduce the amount of external interference. Once a thin iron sheet is placed to join these fields then the large majority of the magnetic fields would pass through the soft iron to again dramatically reduce the external magnetic field.



As shown here the vast majority of the stray field is captured and linked to the adjacent rod magnets leaving very little external fields other than that near the strings.

Note there are three areas where the strings are drawn to the magnets (the low magnetic areas are just outside the line of the magnets).

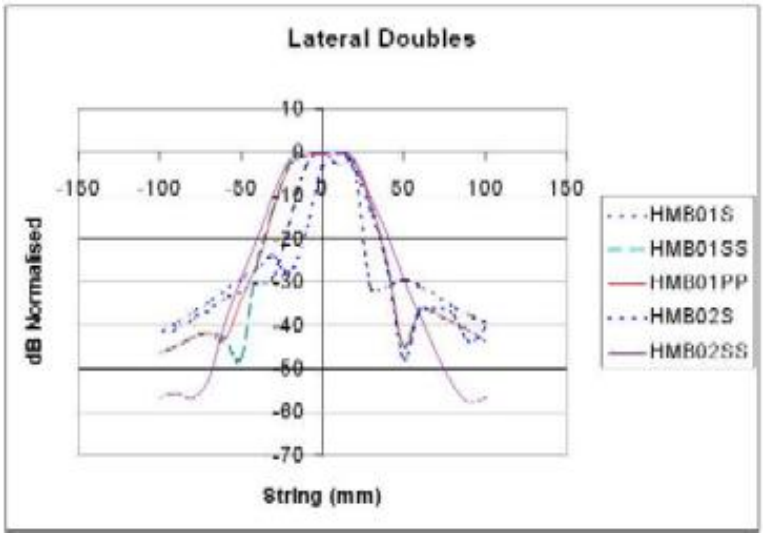
Lateral / Humbucker Sensitivity

The above is a representation of the y-z plane through the middle of a typical hum bucker pickup coil arrangement. There are a few very obvious differences with this and the single coil structure.

There are two magnetic structures relatively close to the strings (on top), and with the soft iron joining plate (across the bottom) holding both the magnets (left hand side) and soft iron pole pieces (right hand side) this makes a relatively 'closed' magnetic circuit that has a far more limited extraneous magnetic field than the simple 'single coil' approach.

This is another reason why this structure is a much better hum bucker than a single coil style pickup.

The magnetic field is virtually symmetrical, but with pickup coils on both pole pieces, variations in magnetic field strength (flux) caused by relative (predominantly vertical) string movement will induce onto the coils.



A little decoding is needed here to explain what the index means:

HMB01S	Humbucker, 01, Single coil only
HMB01SS	Humbucker, 01, Series Aiding connected pair of coils
HMB01PP	Humbucker, 01, Parallel Aiding connected pair of coils
HMB02S	Humbucker, 02, Single coil only
HMB02S	Humbucker, 02, Series Aiding connected pair of coils

Looking along the strings for sensitivity measurements it is obvious that the sensitivity falls off after about 20 mm from the centre of the structure (between the two pickups), so we know that the pickup will react to strings near the pole

pieces/magnets – in a very similar fashion to the single coil pickup – but over a slightly wider length.

This is as per the Hum Buck 01 pickup used in these experiments and it has series connected coils giving a total resistance of about 8.45 k ohms (dc) and a total inductance of about 4.59 H at 1 kHz.

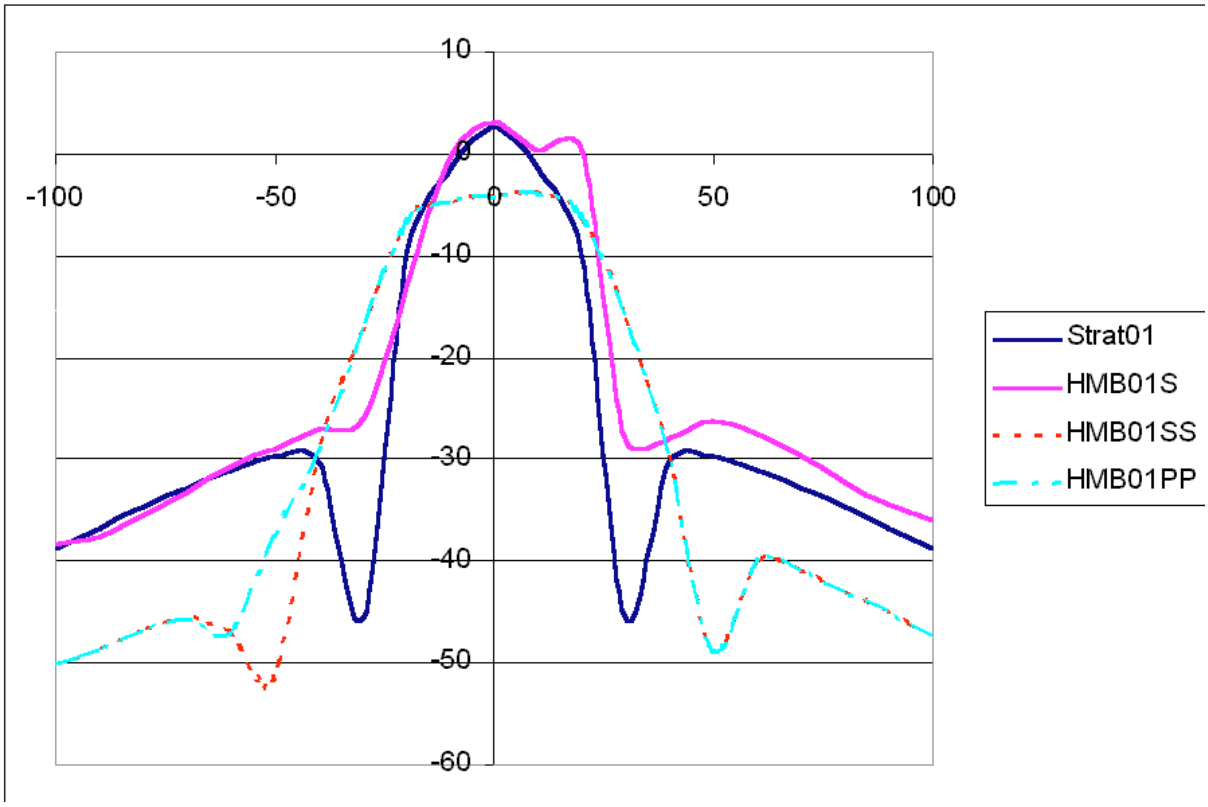
With the coils connected in series aiding, this pickup will have a smooth (or muffled) sound suitable for cool Jazz or Blues. Alternatively if one pickup coil is used by itself, it will have a response similar to that of a single coil pickup, but because of the extra 'metalwork' the inductance is marginally greater, so it will still have a slight muffled sound.

The frequency response can be radically changed by the load and that will be explained later.

By putting the second coil in **additive parallel**, the external magnetic field will be a little bit tighter because if the higher mutual inductance, the internal resistance will be halved, and the internal inductance dropped by about a third, and this should be a very lively pickup with a high isolation to external electromagnetic fields.

Humbuckers – Along the String

Going one step further by looking along the strings with different families of pickups, another set of non-normalised curves emerge as below:



This is particularly interesting as the Strat, and the hum bucker wired as a single (HMB01S) form a nice pair with the extra metalwork of the hum bucker putting a 'bump' on one side of the sensitive curve (caused by the second pole piece).

The two 'notches' are caused by the fields interacting as they go through an angle where the phase reverses because the effects from the exciter (string) on each coil is reversed and almost equal.

The second pair of curves is particularly interesting as these are the hum bucker connected as a series (HMB01SS) and as a parallel (HMB01PP). Both have exactly the same sensitivity as each other, and also about 8 dB less than the single arrangement.

Effectively, the along string sensitivities agree with each other, and considering that this is near the noise floor for this test arrangement, the non-alignment near the null on the left hand side is barely a concern.

What is interesting is that the maximum levels are virtually identical and with a bit of appropriate engineering, switching in the buck coil as a parallel will give the Country & Western 'twang' as this will have half the internal resistance and about two thirds the inductance of the single coil.

A little myth that needs exploring: If it is not already obvious, the two side-by-side coils in a Hum Buck arrangement are not highly coupled, and in fact they are rather loosely coupled to each other and putting them in parallel does not quarter the inductance as you would expect if they were tightly coupled.

The 'twang' comes from the internal inductance being lower in value, in relation to the resistance of the volume pot to how it was before and this should be a strong sign that output frequency response is heavily controlled by the load on the pickup, including the cable and amplifier input impedances. More on that later!

Conclusions

By performing finite element analysis on a range of pickups, this has shown that there is a high degree of correlation between the measured results for relative level and the magnetic structure. It is not the absolute magnetic field strength that matters but more the change in magnetic field strength with the movement of the vibrating string that is the prime cause for producing voltage from the coil.

The position and path of the magnetic field therefore is of a prime importance and this explains why 'Strat' pickups with longer magnets seem to be more sensitive than 'Strat' pickups with shorter magnets - as the longer bar magnets appear to be relatively closer to the strings - because of the shape/extension of the polar fields from the bar magnets.

The ferrite bar single coil type pickups - with their soft iron pole pieces make up what is effectively 'longer' magnets than the simple bars and although these pickups seem to have a generally slightly higher inductance; these pickups appear to be more sensitive than the simple 'Strat' design.

The Dual (Lateral) Coil hum bucker structures with the magnet centrally located and with pole-pieces to guide the magnetic path through the strings have a naturally far more efficient magnetic path than the single coil 'Strat' and 'Ferrite bar with pole pieces', and it is this structure that also assists with hum bucking, as the stray magnetic circuit is considerably circumvented by the much tighter magnetic circuit.

Because these magnetic fields are somewhat enclosed, this is probably the reason why these pickups in dual coil mode appear to be less sensitive than the single coil pickups by about 8 dB.

The Hum Bucker pickup in single coil mode operates almost identically to the 'Strat' and Ferrite based single coil pickups, and it is because of the extra pole pieces in the second coil of the Hum Bucker assembly do create a secondary magnetic circuit, that the 'along the string' figures do not match exactly the 'Strat' and Ferrite single coil structures.

The dual coil Hum Bucker when connected in Series (aiding) and in Parallel (aiding) both came out with the same level (terminated in 1 M ohm), and this lends itself for considerable further development.

Not only is the level consistent, but the 'along the line' suppression very consistent, and that leaves external impedances (volume, tone controls, cables etc) as major players to 'colour the sound' from these pickups.

With series aiding connected coils, these pickups tend towards the Jazz/Blues dull/muffled sound, and with parallel (aiding) connected coils, these same pickups lend towards the rock/country sharp/twangy sound, and all this can be dome by changing the load resistance and capacitance to pre-known conditions - removing the need to excessive adjustments - without a reference.

There are several other magnetic structures that could have been tested, but it seems that most manufacturers seem to be stuck on the rule of one or two pole pieces per string gives an aesthetically pleasing product - and that is what sells!
The very simple tests done here have shown that with a little structured analysis, pickups could be manufactured to be far more sensitive that they currently are and that the need for external hum-bucking could be considerably reduced. With this in mind, it might be worth looking at the polar sensitivities of various pickup assemblies, and better understand just how sensitive these pickups are to external electro-magnetic fields.

Comments and Corrections are welcome