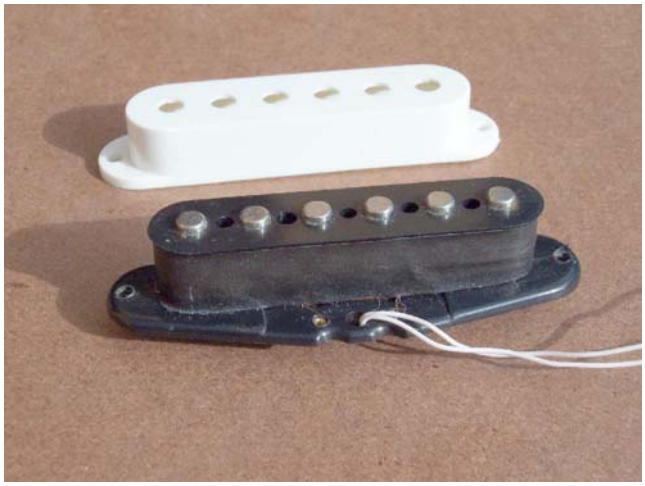
# Starting to Analyse Electric Guitar Pickups!

*Malcolm Moore*
*22-Jan-2003*

Jan 2003, 2006, July 2007

## *Background*

Some decades ago (about 1963) as a schoolkid, and loving the sounds made by electric guitars, I decided to make my own solid body guitar, for in those days there was no way that I would be able to afford one myself and I am sure that it was a long way from the top of my parents “must buy” wish list.



After pouring over several electric guitar advertisements / photos, and having tried a few electric guitars in a couple of music and second-hand stores, some physical truths came out – firstly that I was a natural left-hander, so all those guitars were back to front for me; there was an importance about the twelfth fret, and the ‘action’ – movement required to get the string down behind a fret. So the course was now rather clear that if I wanted to have an electric guitar, then I would definitely have to make it myself and convert everything to be ‘left-handed’!

With my mind now set, I saved my pocket money for several months and then purchased a machine head, (the metal winding mechanism that tensions the strings at the end of the neck), a bridge (the metal anchor for the strings) with tremolo arm, a pack of flat wound strings, a rosewood fretboard – complete with frets, a strip of plastic called a ‘nut’ to guide the strings at the end of the fretboard near the machine head, and most importantly a couple of magnetic pickups.

In the ensuing weeks, I chose some not too dense hardwood – think it was Cypress Pine by the aroma, and carved out a neck to my own (left-handed) design – without any tensioning rod to de-bend the neck as the strings can warp the neck and play havoc with the ‘action’ – and glued the fretboard to the neck.

The guitar body was much the same story, and I carved it out of a block of Pacific Maple.
I used four wood screws to join the body to the neck, and then set about working where the bridge would be located, then the pickups, volume and tone controls, switches and output jack. This electric guitar was a unique left-handed design that somewhat followed the Fender Stratocaster shape – but ‘chunky’!

As electronics was my other childhood hobby, the wiring was all too easy, so in a matter of a month or so I had my own ‘electric guitar’ – it worked, had reasonable action, and to me it sounded much the same as many others, and I hadn’t broken the bank; so I pondered – why all the dollars on these things?

(At that time I didn’t have a business mind, and I had not realised that I had worked part time for some months to come up with this, and if I was being paid for the unique construction then yes, this guitar would have been very expensive, and no I didn’t have an advertising campaign or sponsorships going, or management overheads!)

Some years later (about 1968) I reconstructed all these pieces and made a new neck and body for a 12-String Solid Body electric guitar. To my surprise this guitar also worked very well for many years and the neck did not warp having had tensioned strings left on it for about 10 years, so I questioned myself about the pickups and the neck structure.

In about 1976 I had the opportunity to purchase a right-handed bass Fender copy and me being left-handed, I made a left-handed body and fitted the right handed neck to the new body - and presto a left handed bass electric guitar - and it worked perfectly too! You guessed it - a million more questions!

As it happened, I had since then spent several years (1967 to 1984) in a telecommunications electronics laboratory that specialised in the manufacture and testing of prototype analogue transmission equipment - including amplifiers, equalisers, filters, transformers, power supplies; all using a wide range of components including valves, transistors, FETs, Integrated Circuits, SCRs, ferrite and iron cored inductors and transformers!

And if that was not enough there was engineering of digital computers, digital transmission systems, switched mode power supplies, and computer programming at all levels. This tremendous experience really bolstered my knowledge about electronic components, (especially precision inductors and a very wide range of transformers) electronic circuitry and advanced testing procedures which came into the for a few decades later.

By 1984 as an Electronics Engineer, the questioning went right to the bone, but I never had time on my hands to find out – or the people to ask. This was a quaint subject, and everybody spoke passionately about the sound, using words like ‘hot’ – which I later found out meant ‘comparatively big output level’; ‘edge’ – meaning ‘resonant frequency peak above the human centre of the audio spectrum’; ‘muddy’ –

meaning ‘upper frequencies filtered out’; ‘fat or thick’ – meaning broad resonant peak below the centre (low mid-range) of the audio spectrum, and somewhat distorted’.

There are some other real ‘doozies’ that you will be sure to hear especially in music shops – and it really amazes me in how much sales staff really do not know – but create a mythical language to sell! If you hear one of these words or phrases – stop and ask for a clear definition of the meaning, that is often more fun!

More recently (2001) I have had some time and a little patience to get a much clearer picture of actually how electrical pickups work, what their limitations are and why. What I have put in this Website will seriously fly in the face of many sales people, advertisers, musicians and pickup manufacturers - but what I have put here is clearly supported by highly repeatable testing procedures with highly repeatable data - and this is the area that is very seriously lacking in this whole industry!

Most of what has been written here comes from decades of thought and the results of practical data analysis that has occurred over the last 40 years (1967 to 2007). Most of the BLACK ART myths associated with electric guitars are explained and DEMYSTIFIED - so Read On!

## *Solid Body / Neck Thoughts*

To me, there is absolutely no doubt that body/neck resonance plays a major part of colouring the sound from a stringed musical instrument, if the body has, or is, a resonator, but with a solid body guitar the sound is barely resonant and there is minimum inter-string coupling compared to an hollow/resonator body, and further the fact is that simply holding the instrument considerably damps any resonances in both the body and the neck.

Most solid body electric guitars are manufactured in two main pieces – the body and the neck, and the joint is in my opinion the weakest link – further killing the ability for the notes to be sustained.

After hearing so much talk about various guitars and the sounds from these, and knowing that the sound can be coloured by ‘tone’ controls – it started to dawn on me that the body has much less effect on the sound than the pickup itself, and further; the bridge (body anchor point) may introduce just as much variation as the construction of the pickup and body construction itself.

(2007) Every time a string oscillates, it pulls on the neck at twice the note frequency. There are two extremities in a single string cycle, so the neck gets compressed twice for every one strings' amplitude cycle - and the sting gets stretched twice for every one amplitude cycle. Think of it like a kiddies swing. For each cycle of swinging, the swing seat passes through two quasi-stable points where the amplitude is fully extended (and the swing frame stability is under maximum lateral stress).

Other documents have clearly shown that a guitar neck has a natural resonance like holding a knife handle firmly to a tabletop and then flicking the blade - the blade oscillates in much the same way that a guitar neck would oscillate. Most guitar neck manufacturers put an iron rod through the guitar neck and this rod is bowed to 'tension' the neck, and this way the neck can be adjusted to counteract warp in the neck over time (of which some is caused by the string tension).

For analysis purposes, the neck would be of infinite weight and totally rigid and without any resonances, but in practice the neck must be light and reasonably rigid -

and it will have resonances - but these will only affect notes created up to about the 7th fret and beyond that, the neck is virtually rigid. So we have to look elsewhere for so called 'flat spots'.

The only other non-considered point is the bridge - where the strings lengths are adjusted at the body end, and sometimes this is the terminating point for the strings - all rolled up in one. If there is going to be inter-string coupling, then the bridge is the obvious point - especially if the bridge connects across the strings and not directly to the body. Flat spots are the result of strings inter-coupling and giving a somewhat cancelled response for a particular note - at a particular fret - with a pickup in a particular place.

This argument is a long way from blaming the body or neck for flat spots and it points to the bridge as probably the most variable component in an electric guitar after the pickups and their electronic loadings and settings.

## *Magnetic Pickup Thoughts*

Over decades of winding and measuring several thousand coils and transformers to tight specifications, and used a wide range of magnetic materials, it came as no surprise to me that a large number/proportion of well meaning sales and musically based people would swear that the difference between similar solid body guitars is the physical construction of the neck, fret-board, body etc and a whole lot of things.

Rarely have I heard of anybody to get inside and analyse pickups for what they are and then extend that learned knowledge and predict how and why a pickup will sound like – or the background knowledge to directly compare any two virtually identical guitars and in that compare the near identical pickups with factual reasoning and no a load of sales waffle.

I am well aware that variations in guitar construction can make differences to the sound, but I am far more acutely aware that subtle differences in sound also start with the construction standards of a pickup – not whether it has been dipped in wax or whatever, but by subtle differences in the coil construction or magnetic circuit can make a profound difference to the sensitivity and spectral response of the pickup.

Having engineered and constructed special pre-amplifiers that sit in the guitar body, it was more than obvious to me that the resistive and capacitive values of the volume and tone controls and cable, and amplifier input impedance all play major factors to the sound – far beyond that given credit by those selling solid body guitars.

For decades, having considered the wide variations of sounds that can be sucked out of pickups, simply by changing the loading and /or position – it finally got the better of me and I decided to find out as best I could what makes some pickups work ‘better’ than others – and why.

There is also the Golden Fleece – to come up with the perfect magnetic pickup, and meaningful date about pickups is extremely scarce! There is so much data lacking in Patent records that these documents are almost farcical - but they are well meaning.

## *Method and Approach*

There are several different approaches that could be taken and each will give a little bit of data that can be analysed into information. The most common approach is ‘just listen’ and make an “informed” decision on how it sounds. Having been there like everybody else, I decided that a little more in-depth analysis would tell me a wealth of

meaningful information about these pickups and then by analysing this array of information some meaningful knowledge would come forth.

To start with, there are several different types of pickups, single and multiple coils, Alnico and Ferrite magnets, some with pole pieces – so these pickups need to be categorised into types so that comparisons can be draws with reasoning and not just sales waffle.

My first break-up of pickups is based on the number of coil structures – so there is 'single coil' as a stand-out physical entity, and there are a group of multiple coil pickups. The multiple coil pickups are in most cases 'engineered' to minimise hum from not too distant electro-magnetic fields, and these are usually called "Humbuckers". There are nominally two types of Humbuckers: lateral coil and vertical coil.

## *The Hum Dinger Speaker*

(In the early days of radio 1898, loudspeakers did not have permanent magnets, so Oliver Lodge invented a loudspeaker that had a 'voice coil' set in an annular magnetic field that was created by an electro-magnet.

The coil for this electro-magnet doubled as a power filter choke that connected to the high tension voltage feed to the valves, and as the current was full wave rectified from the power transformer secondary winding it had a ripple in it at twice the mains frequency.

This coil had a thick iron rod as the centre and a virtual 'cup' to return the magnetic field to the front where it had a thick iron front plate with a round hole a few mm larger in diameter than the central iron rod, and this formed an strong magnetic annular ring for the voice coil to move through. As this coil formed part of the mains filter, the magnetic field had 'hum' in it from the rectifiers – so the hum was heard from the speaker cone!

By including a small second coil – connected in reverse – and wiring this coil before the first filter capacitor, the current variations were much larger – but in reverse, and by having the right ratio of turns, the high tension current was smoothed and the audible hum was 'dinged' or cancelled – hence the word "Humdinger".)

## *The Hum Bucker Pickup*

In guitar pickups the Hum Bucker pickup works for a very different reason than the Humdinger Speaker. A distant interfering source (for example the sharp edged electromagnetic field from fluorescent lighting) passes evenly through both coils and apparently forms a cancelling output and that 'bucks' the interference. How the two coils do not 'buck' local interference (string movement) is another story that is covered later!

So, really, the Humbucker pickup is simply a pickup with a somewhat tighter magnetic field. Because of this simple characteristic the Humbucker pickup is able to much better cancel out interference from distant electromagnetic sources like ballast inductors and fluorescent tubes, and the buzzing from lighting controls using Triacs for phase switching to control stage lighting brightness.

## *Understanding the Windings*

Another approach is to look at the coils themselves and make some sense of the resistive and inductive values that exist, and then put these values into a generator

model that can replicate the expected frequency response. This approach wipes an amazing number of beliefs and shows that there is a rather simple unified approach to quantifying pickups.

### *Understanding the Magnetic Fields*

The third approach is to look at the magnetic fields produced by the magnetic structures, and this gives a real insight into the reasons why some pickup structures are low output, while others are so susceptible to external interference. This really exposes many myths, and opens up a Pandora's box of issues.

By putting all these approaches together, most of the mysteries abut pickups are explained and it then becomes rather straightforward to understand what is really going on! But first – how does the magnetic pickup work?


**Comments and Corrections are welcome**