Wideband Guitar Pickups

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The electric guitar pickup market is a fickle beast that I usually try to avoid. The reason is simple. There are far too many participants whom have absolutely no background in electromagnetics. It seems that every guitar tech with a sewing machine motor thinks they can wind "vintage" pickups armed with some over simplified instructions they found on the web. At a recent guitar show in my area there was actually a pickup 'manufacturer' selling Gibson style humbuckers that were random wound. On a popular guitar pickup winding video the pickup manufacturer, a guy who is very knowledgeable in the field of guitar pickups, admits his shortcomings in electromagnetic theory. It's very hard to take a science to the next level when one, lack of fundamental background and two, perception of ancient magic that can't be done better, slow the progression.

While there are pickup manufacturing companies that do make pickups slightly different from what was done in the 1940's and 50's, the 'improvements' are negligible. A refreshing break from this stagnant paradigm was Erno Swaan's 'Animal Magnetism for Musicians' book which at least provided the reader with a plethora of different ideas for pickup topography. Not all of the included suggestions make for good sounding pickups but that wasn't the point which was to simply show varying approaches to the same problem.

My involvement in electromagnetics began with pickup winding back in the early 80's when only few were doing it. I didn't start to really study electromagnetics until I got involved with high quality audio input transformers and filter coils after closing my guitar shop in the 90's. What follows is an old school technique that is a new and different approach to winding pickups. It is based on science rather than internet voodoo. The described technique is derived from winding protocols that were pioneered first by Western Electric and Bell Labs and later improved upon by Ercill Harrison, Chief Engineer at Peerless Transformers at the time of the Altec Lansing acquisition. While a guitar pickup is an electromagnetic transducer and a transformer is an electromagnetic transformer, the action of the coil portion is similar. First we need to start with a little background.

The technique Fender used to wind early strat pickups involved a person sitting in front of a primitive winding machine laying the wire on the bobbin in a random fashion. In later years when automated winding machines were needed to keep up with demand and improve quality control, it was found that the earlier random wound single coil strat pickups (and others) complimented the sound of the instrument better and players preferred those pickups. In the previously noted popular pickup winding video the very informed instructor notes this phenomenon but sadly doesn't seem to understand the underlining reasons. The culprit here is capacitance, pure and simple.

A capacitance is created when two conducting elements with a voltage potential difference which are in close proximity are separated by a resistive element or space. In an actual capacitor there are two conducting foils separated by a resistive membrane with a specific dielectric constant*. The type and thickness of the foil, and, type and thickness of the high dielectric membrane determine the final capacitance of the component after they are rolled up together. This capacitive action isn't restricted to foils, the same thing happens when two conductors such as pickup wires are wound together. Adjacent wires with an enamel coating, which has a specific dielectric constant, plus the microscopic air space between the wires (air is a resistance) create capacitances that add up over thousands of winds. These incurred capacitances increase as the voltage differential between the conductors increases. In practical terms this means that two wires adjacent one another in the same layer which have almost no voltage potential between them will create very little stray capacitance. On the other hand, wires adjacent one another in the layers above and below have more voltage potential between them therefore they create more capacitance. The diagram in Figure 2 shows the capacitance created when a coil is machine wound. There are a total for four wires in adjacent layers touching each individual wire in the middle layer. That means there are four capacitances created there and just think about how they add up after 60 or so layers. Remember that the capacitance of the coil is added to the circuit just like the tone capacitor. It is the same thing as ***always having a tone cap in your sound***.

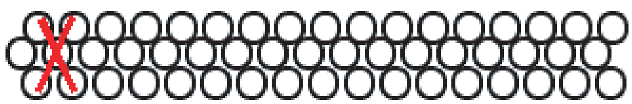

Figure 2. The capacitances created between layers in a standard progressive machine wound coil.

So why does a random wound strat pickup sound better? When you random wind you simply wind in more air and the conductors often cross over each other rather than run the length of the turn perfectly parallel with the wire next to it. Over the high number of turns this lowers the effective capacitance of the coil moderately so the high end of the pickup isn't rolled off as much by it's own internal capacitance. It's that simple, there is no other voodoo involved. The problem with this approach is consistency from pickup to pickup. With standard industry practices automated winding might impart a slightly higher capacitance but it also provides consistent results.

Finally, getting to the ***Wideband Pickup***. Unfortunately most products that make their way to market do so by being cheap, fast and easy to manufacture. Gimmicks in advertising and slick marketing are usually the only way to differentiate one product from the next. Wideband pickups are ***not*** fast, cheap or easy to manufacture. They also require expensive winding machines and vacuum potting equipment.

What is a wideband pickup and why would you need one? Many occasions require a clean, open sound and you can't have an articulate dirty sound without starting with a clean sharp signal. With bass pickups clean sound and wide frequency response is absolutely essential. Wideband pickup winding employs techniques that are used to create the highest quality wideband transformers.

When these techniques are applied in guitar pickups the internal capacitance leakage of a pickup coil can be reduced dramatically. The winding practices used for wideband transformers are far more time consuming and there are more places for things to go wrong. The final product ends up being very expensive. In the case of a bass pickup, wideband p-bass pickups eliminate the need for onboard EQ or active electronics. I have a standard reissue American P-bass here with wideband pickups that rivals the sound of my Alembic Model II (seriously). On a Strat or a Tele wideband pickups really shine.

Let's have a look at the way wideband transformers are made to reduce internal capacitance. There is more than one winding in audio transformers and a technique called interleaving helps reduce capacitance between windings. Pickup coils only have one winding per bobbin or one full winding on top of a second so interleaving isn't required. Wideband transformers are definitely wound on automated machines. The machines are very accurate and the windings are done layer by layer. Looking at the diagram in Figure 3 it can be seen that by comparing the winding topography to the diagram in Figure 2 there are half the number of adjacent wires in Figure 3.

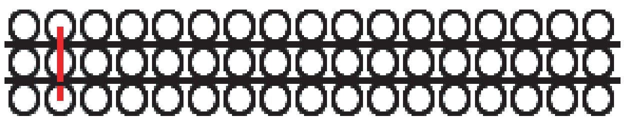

Figure 3. The capacitances created between layers in a layer wound coil. Note that each wire in the middle layer only has two adjacent wires in the layers above and below.

Normally when one layer is wound over another the wires settle in between each other as in Figure 2. When a wrap of a material with a dielectric resistance is wound between the layers the windings can be wound ***directly*** on top of one another. Theoretically this should produce a coil with about half as much internal capacitance however it doesn't work quite that well in practice. The dielectric wrap is only thick enough so that it supports the layer that is wound upon it. Obviously when we're talking about wire that is .07mm (AWG 42), and the object is to lay one wire directly over the one laid previously, a very accurate machine and a *skilled* operator is required. Vintage materials for the interlayer insulations varied but the two most common were Glassine, and a type of Kraft paper that is only .00075" thick. The dielectric action of the interlayer insulation increases dramatically if the finished coil is vacuum impregnated with an electrical potting wax. This operation has to be done under high vacuum to draw the wax into all of the pores of the insulation throughout the entire coil. This is one of the secrets of the best vintage audio input transformers.

Winding a wideband P-bass pickup set:

Now that I've laid down a foundation for the wideband pickup idea I'll show how I wind one using a P-bass pickup as an example. First, I don't use P-bass magnets. I make wideband P-bass pickups using the longer J-bass magnets creating a 1/2" winding width rather than the narrower winding width of a standard P-bass pickup. There is massive poppycock on the web about stout pickups being fatter sounding, utter voodoo. The actual physics here is simple, the closer a winding is to the core material, the better it couples electromagnetically to it, period. The longer magnets of the J-bass means that you can get more wire windings closer to the core (magnets in this case) than a squat coil with a narrower winding width. Since my winding machines are used mostly for audio coils I don't want any part of them to get magnetized so I use non-charged magnets and charge them after the coils are wound.

The photo in Figure 4 shows the basic setup on the machine. There are no margin guides setup like one might use to wind a random strat pickup. The programmable traverse is used to accurately wind the layers progressively to and away from the machine. High quality, layer wound audio coils are not wound on a bobbin (generally). Originally they were wound on long spindles with a dozen or so coils being wound at the same time. The coils would then be separated by cutting through the spaces that were left between them. When winding layer wound audio coils with interlayer insulating material between layers it is standard practice to leave a margin at each end of the winding. This is contrary to the way bobbin coils are wound which is normally from side to side with the wire wound right up to the bobbin walls. When I wind wideband pickups I leave a very slight margin at both ends of the wind. This is done because I wind wideband coils with as much tension as practical on the wire which keeps a nice tight coil when you are winding one wrap of insulation between each layer. The interlayer insulation is cut wide enough to just fit between the bobbin walls so it is slightly wider than the winding width.

Layer wound coils require extreme patience and skill to wind. Modern materials such as the poly tapes and wraps that most manufacturers use for ease of manufacturing do not perform the same way that traditional materials do which is especially true with the interlayer insulation. The type of Kraft paper used is .00075" thick and basically tares if you look at it too intensely. Seriously though, it has to be glued to itself after it's wrapped and it must be wrapped as tight as possible without taring it. Also when 70+ layers are being wound the glued overlaps of the insulation add up and create a bulge so the overlaps have to be spread around the coil as the winding progresses. All of this makes a pickup set that normally could be wound in under an hour and turns it into a day+ long project.

For P-bass pickups I use AWG 42 wire which, as mentioned, has a nominal diameter of .07mm. On layer wound pickups I work with a 1mm margin at each end of the layers with an 85% fill on my winding widths.

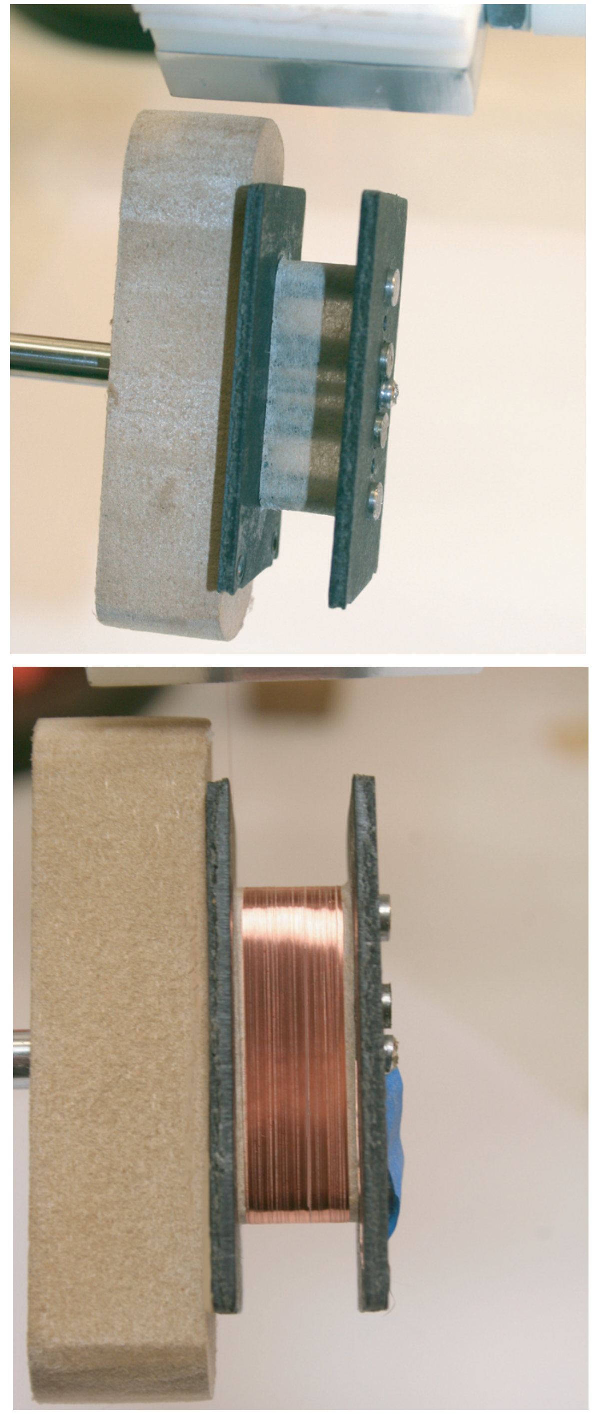

Figure 4. Top: P-Bass bobbin on the winder. A layer of insulation is used between the magnets and the wire. Bottom: First layer wound. The margins are exaggerated to better illustrate the technique. The margins prevent the bobbin walls from spreading as the windings build.

That means that the machine's pitch is not set to .07mm, the dia. of the wire. If the pitch was set to .07mm the wire would pack too tightly from side to side. In layer wound coils a little space between the wraps of wire is standard practice. Here is the quick math:

.5" (12.69 mm) wideband P-bass bobbin width
minus 2mm (1mm margin at each end of winding) =
10.69 mm Winding Width
10.69 mm / .07mm (wire dia.) = 152.714 turns = 100% fill
152.714 *X* .85 = 129.807 turns = 85% fill
10,000 (no. of turns p-bass) / 130 tpl (turns per layer) = 76.92 Layers

So 77 Layers @ 130 tpl will give the standard Fender specification for p-bass pickups. Note: I build mine to a slightly different spec.

You can see how winding 77 layers one at a time with an insulation wrap applied in between each layer adds up to a major time investment. Remember that has to be done for each coil of the pair... and there's more work to come.

The next step in the process requires a good high vacuum oven. When very fine magnet wire is layer wound there is a considerable amount of air wound in the coil even with fairly high winding tension. Also the untreated interlayer insulation has minimal dielectric qualities. Wideband transformers and pickups receive four main attributes when they are vacuum potted and they are:

1) The pickup is potted which helps with noise and microphonics.

2) The vacuum draws the potting wax into every crevice of the coil and impregnates the interlayer insulation which improves it's dielectric properties considerably reducing capacitance.

3) Any air left in the coil is sucked out and the microscopic spaces between the individual winds of wire are filled with wax rather than air (remember the winding has an 85% fill), again gaining a dielectric improvement.

4) Removing the air from the coil draws all of the layers tighter to the core which improves coupling.

The process of vacuum potting begins with baking the coils for several hours under low vacuum (Figure 5). That bakes out any remaining moisture from air humidity and the water based adhesive used to glue the interlayer insulation wraps. Baking the moisture out of a coil before potting is essential whether a vacuum is used or not. Potting a coil with moisture in it, even air humidity, seals the moisture in which will eventually make the coil fail. After several drying hours the coils are placed in a container containing melted electronic potting wax and the container and coils are subjected to very high vacuum until air bubbles stop surfacing in the wax. The vacuum is released and the oven is opened and the coils pulled out of the container.

Figure 5. Here is a shot of the vacuum oven. A good quality two stage vacuum pump is used to create enough vacuum to pull the wax into all of the winding layers.

The container is removed from the oven and the coils are placed on a tray and put back in the oven. The oven, still at 200, is then brought back to full high vacuum. After an hour at 200 the oven is turned off but the vacuum is not released and the oven is allowed to cool for 12 hours or until room temp. The vacuum is released and the coils removed from the oven. This whole operation is done before the pickups are wired so that comes next.

I wind p-bass pickups with reverse windings and reversed magnet poles. Good automated winding machines keep very accurate wind counts so the coil match is good enough so that shielding is not needed on these. Two coils can actually be stacked on the winder using a spacer between them. The spacer has holes to accommodate the magnets and the traverse can be setup to wind two windings side by side at once. Winding in this fashion assures an absolute match between coils but it makes the winding even more challenging. Shielding guitar pickups is a subject that requires it's own consideration so I'll address that in another paper.

By using the techniques described in the previous text instrument pickups with very clean, extended response can be wound which will exceed the performance of traditional pickups with ease. Most always eliminating the need for excessive effects or EQ.

Note:

* The Dielectric Constant is derived from the resistance of a given material. Different materials and varying thicknesses provide engineers with precision resistive elements to incorporate in their designs. In a capacitor the size and thickness of the membrane between the two conductive foils determines the capacity of the part (this is a simplified explanation).