# Constructing P90 Pickups

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## Introduction

The goal of this project was to build P90 pickups that as closely as possible, recreate the sound of classic P90 pickups such as 1952 Gibson Les Paul P90s. Since we have extensively measured the electronic properties of several 1952 Gibson Les Paul P90s, the data from these measurements can be compared to the data from the pickups we have constructed. Of course, the most important test will be to install our pickups in a guitar and compare their sound with manufactured P90 pickups. Nevertheless, it is still instructive to compare the complex impedance measurements (for more information on complex impedance measurements, see my senior thesis entitled "The Electromagnetic Properties of Electric Guitar Pickups").

This report will describe in detail the design of P90 pickups and the methods involved in constructing P90 pickups (specifically, the winding and potting methods). Building pickups proved to be an iterative process, so the problems encountered during this process will also be discussed in detail. Complex impedance measurements were taken and a least squares fit of the parameters in the 4-parameter pickup model was carried out at each step of the pickup construction. These results will be discussed and compared with data for P90 pickups that were previously measured. This report can also be used as instructions for building P90s, because we were successful in building P90s that have electronic properties similar to classic P90s.

**Pickup Design**

P90 pickups consist of a coil of wire wrapped around a plastic bobbin, 2 AlNiCo bar magnets, a spacer (for the magnets), 6 pole screws (one resting below each string on the guitar), a metal base plate, and a plastic pickup cover. Although P90s have dimensions similar to hum bucking pickups (much wider than Fender single coil pickups), they are actually single coil pickups. P90s have been used in a wide variety of guitars, including certain models of the Gibson Les Paul.

Normally, an electric guitar has two pickups: one lying close to the neck of the guitar and one lying close to the bridge. Because the amplitudes of guitar string oscillations are significantly larger near the neck than near the bridge, there should be roughly 5% fewer turns of wire on the neck pickup than on the bridge pickup. This way, the two pickups will have roughly equal output. Using American Wire Gauge (AWG) 42 wire, there should be approximately 10,000 turns on the bridge pickup and 9,500 turns on the neck pickup.

For guitars with a neck and bridge pickup, pairs of P90 pickups can be designed to have a “hum-cancelling” effect (which reduces unwanted noise caused by nearby electronic devices) similar to hum bucking pickups. In order to produce a hum cancelling effect, the bridge and neck pickup must be reverse wound and reverse polarity. If the neck pickup is wound clockwise, the bridge pickup must be wound counter clockwise and vice versa. Similarly, if the magnetic field of the neck pickup is oriented North to South (from top to bottom), then the magnetic field of the bridge pickup must be oriented South to North and vice versa. Although there are several ways to make a pair of reverse wound/reverse polarity pickups, all are equally effective for hum cancelling (i.e., the combination of a neck pickup clockwise wound with South/North polarity and a bridge pickup counterclockwise wound with North/South polarity is equally effective as the combination of a neck pickup counterclockwise wound with North/South polarity and a bridge pickup clockwise wound with South/North polarity). If the pickups are not built reverse wound and reverse polarity, the guitar will produce a large amount undesirable noise when playing. In order to produce the correct magnetic field within the pickup (i.e., the field lines flow through the coil), the magnets should be oriented as shown in Figure 1 below.

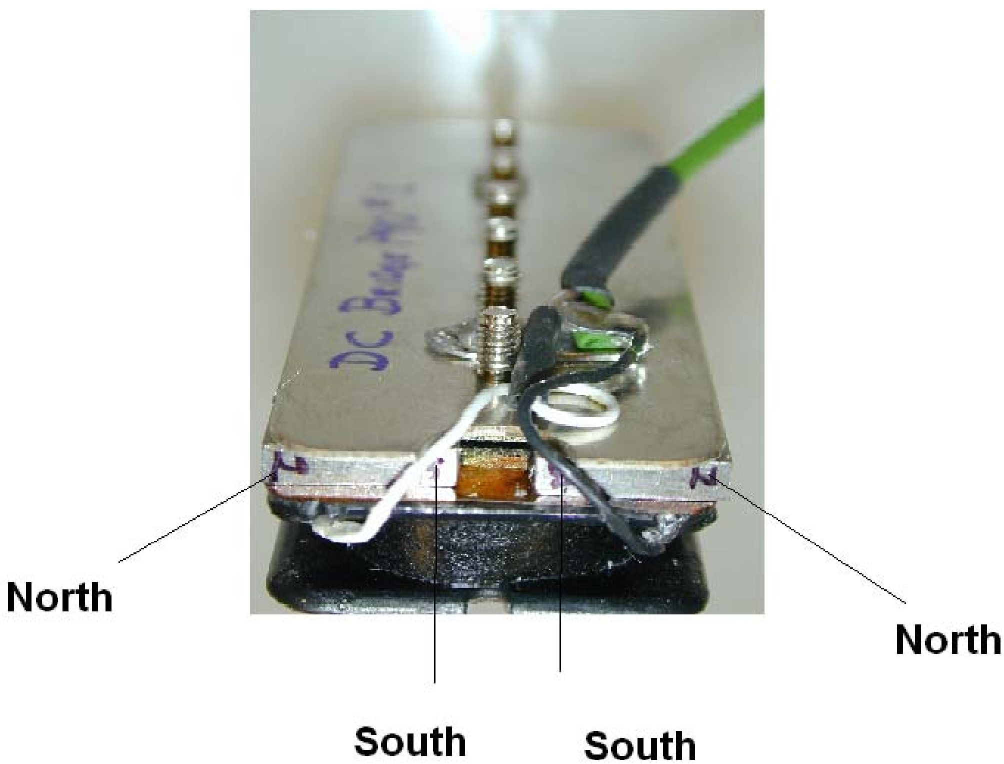


**Figure 1.** Orientation of pickup magnets. When the North poles face each other or the South poles face each other, the magnetic field lines will flow through the center of the coil and back around to the outer edges of the magnets. The pickup in this picture is a bridge pickup with the South poles facing inward. The corresponding neck pickup should have the North poles facing inward in order to produce a hum cancelling effect.

In the presence of an intense sound field, a pickup coil can vibrate and become microphonic. This is an undesirable effect that can be prevented if the pickups are potted. Potting the pickups means immersing them in wax (allowing the wax to fill in any pockets of air in the coil) in order to prevent the parts of the coil from moving relative to each other. Potting pickups is especially important for loosely wound coils, because loosely wound coils have more room to vibrate than tightly wound coils. It should be noted that some pickup manufacturers pot the *entire* pickup rather than just the coil, in order to prevent any type of vibration. However, this shouldn't be necessary as long as the pickup is structurally sound (i.e., all screws are tight and there is little room for parts to move relative to each other).

The two ends of the pickup coil's wire (lead and ground) must be attached to coax cables, which connect to the guitar's potentiometers. The lead end of the wire is at the outermost part of the coil and the ground end is at the innermost part of the coil. The ground wire should make contact with the metal base plate of the pickup. There are many ways this can be done.

All of the parts needed to construct P90 pickups can be ordered from Mojotone (although we only purchased some of our parts from there). The bar magnets used in this project were purchased from a private vendor on eBay. We purchased both AlNiCo III and AlNiCo V bar magnets with dimensions 3" X .5" x .125" (slightly longer than most pickup magnets, in order to prevent magnetic field cutoff near the low E and high E strings). Two 32,000 ft. spools (one 42 gauge and one 43 gauge spool) of oxygen free, high conductivity copper wire were purchased from MWS Wire Industries. Bobbins, base plates, magnet spacers, pole screws, and pickup covers were all purchased from Mojotone.

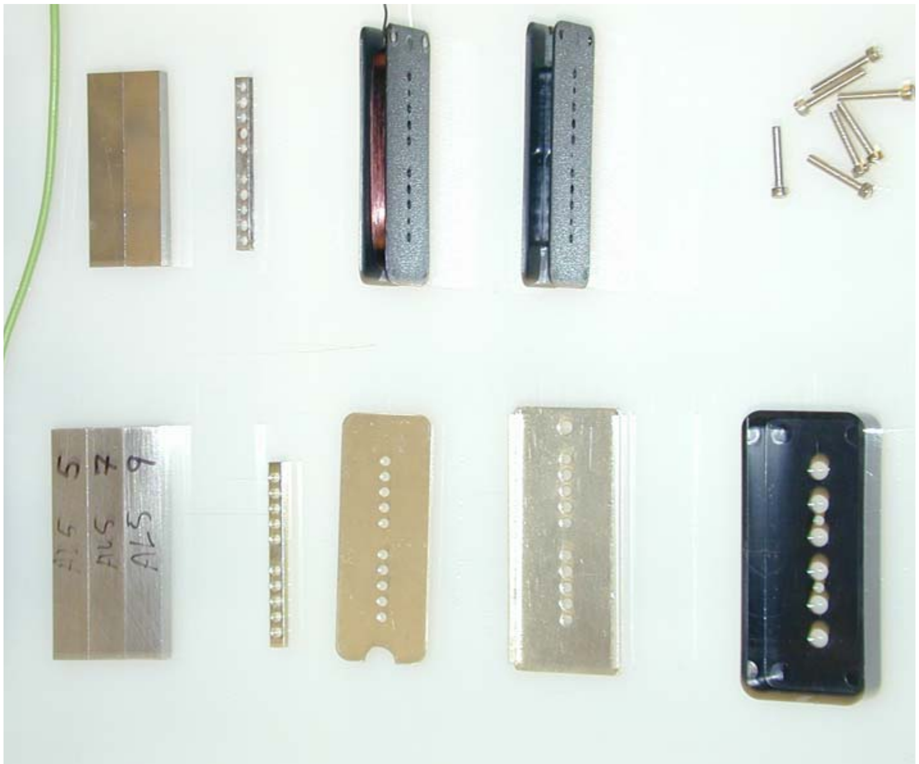

**Figure 2.** Individual pickup parts, including bobbins, base plates, bar magnets, magnet spacers, pole screws, and pickup covers.

## Pickup Winding

Many factors must be taken into consideration before winding pickups. 42 gauge and 43 gauge wire are very thin (.0028” and .0024” diameter, respectively). Putting the wire under too much tension while winding a coil can easily cause the wire to snap. However, there must be *some* back tension on the wire while winding in order for the coil to be sufficiently tightly wound. In addition, it is important that the tension is kept more or less constant throughout the winding. For example, if the inner part of the coil is less tight than the outer part, it can cause the inner wire to fold over on itself. It is important to make sure the wire is fed into the bobbin properly, and doesn't catch onto the outside of the bobbing during winding (this may also cause the wire to snap). Another consideration is how the wire comes off the spool. If it is pulled off the spool (causing the spool to rotate about an axis perpendicular to the direction the wire is being pulled), a large amount of back tension is introduced due to the moment of inertia of the rotating spool. On the other hand, having the spool of wire sit on an axis parallel to the direction the wire is being pulled and simply *unravel* off the spool causes the wire to twist, introducing defects to the wire.

An electric motor was used to wind our pickups (see Figure 3). The motor rotates the bobbin, which is held onto the winding machine with two screws. The motor's speed can be regulated with a knob, and the digital display shows the number of times the motor has turned since the last reset (and hence, the number of turns of wire). Before winding, 2 eyelets must be set into the bobbin (one for each end of the coil). The start end of the coil should be taped down *onto* the outside bobbin (leaving about 12 inches to work with). The spool is placed on an axel located about 3 feet behind the winding machine, allowing it to rotate as it unravels (see Figure 4). This axel should be oiled in order to minimize the tension caused by the friction between the spool and the axel. The wire should be held down (by hand) onto the bar located directly in front of the winding machine in order to direct the wire into the bobbin and to regulate the tension.

It should be noted that although 42 gauge wire is strong enough to wind using this setup, 43 gauge wire is not strong enough to rotate the spool of wire. If 43 gauge wire is used, the wire should *unravel* off the spool, as described previously.

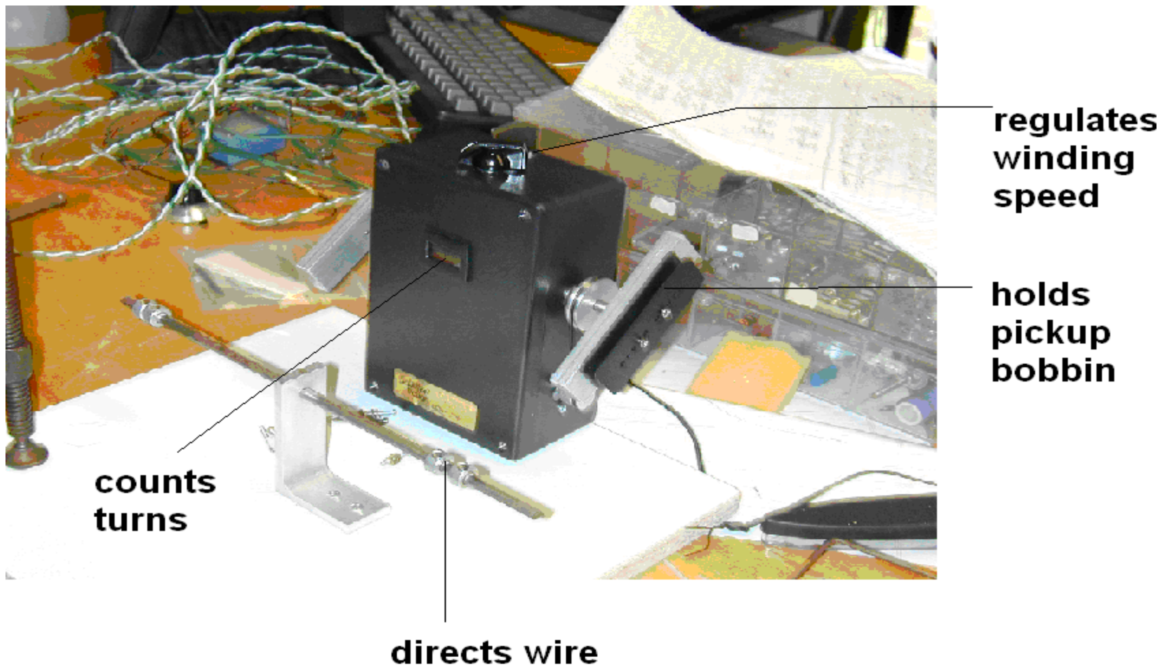


**Figure 3.** Pickup winder. The wire is pulled off the spool and held down (by hand) on the metal bar and fed into the rotating bobbin.

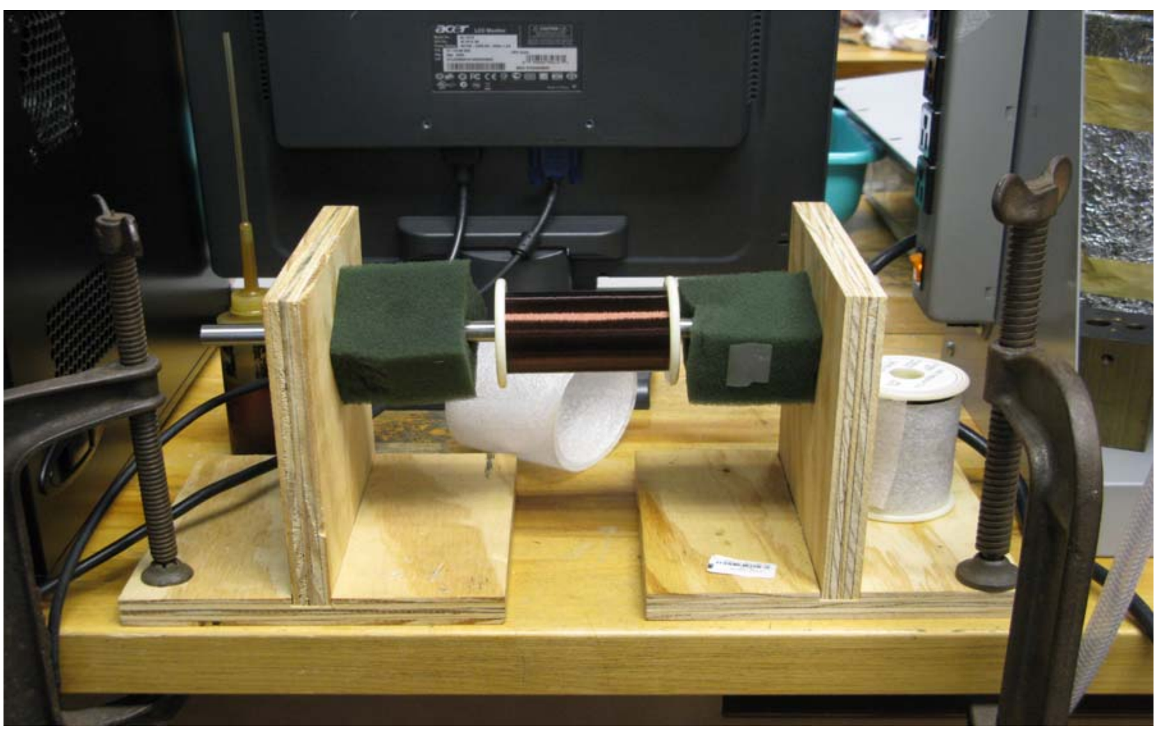

**Figure 4.** Spool turns as the wire unravels off the spool.

**Pickup Potting**

After the coils are wound, the lead and ground wires of the coil should be soldered to their respective eyelets and connected to a small length of insulated wire and, as shown in Figure 5 below.

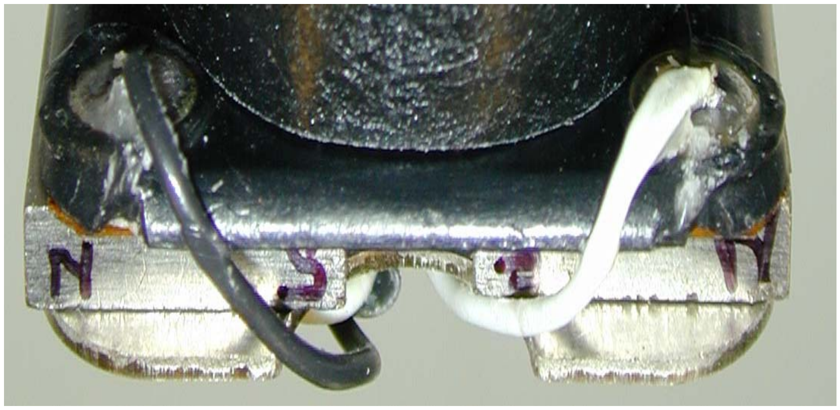

**Figure 5.** Insulated wires (color coded) attached to lead/ground of coil.

The pickups are potted in a liquid mixture consisting of 20% beeswax and 80% paraffin wax. A Crock-Pot slow cooker filled with water is used to heat the wax mixture, which sits in a smaller glass jar resting in the water. The temperature should be kept just above the melting point of the mixture (~140º F), and monitored closely (the flashpoint of paraffin is 395º F!). At the temperatures used in pickup potting, the bobbins can warp. In order to prevent the bobbins from deforming, the coil is clamped between two metal plates (as shown in Figure 6). This is attached to a string so the coil can be dipped into and pulled out of the wax. The coils should be dipped into the wax mixture until air bubbles stop coming to the surface. Gently shaking the coils while they are in the solution can help speed up this process. It takes ~30 minutes to completely pot a pickup.

**Figure 6.** Setup for potting pickups.

**Completing the Pickups**

After potting, protective tape should be wrapped around the pickup coil in order to protect it from damage. The magnets and spacer can be placed directly onto the bottom side of the bobbin (i.e., the side with the eyelets). All six pole screws then should be screwed in from the top of the bobbin, and through the holes in the spacer. The base plate is attached (and holds the magnets in place) with two screws that are screwed in from the bottom. The ground wire should make electrical contact with the base plate, as shown in Figure 7. Both the ground and lead wire of the pickup are then attached to coax cables, which connect to the potentiometers in the guitar. The plastic pickup cover should then be able to slide right onto the pickup. The pickup is now complete!

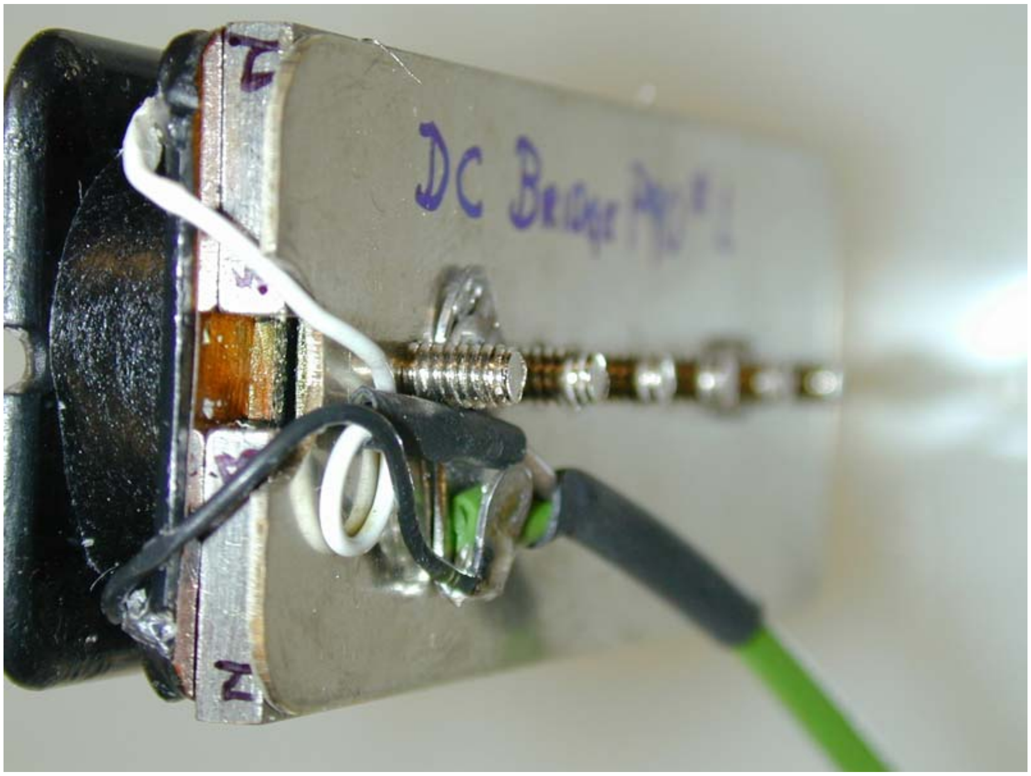


**Figure 7.** Finished pickup (without cover) viewed from the bottom. The ground wire (black) makes electrical contact with the base plate. Both the ground and lead wires are attached to coax cables.

**Pickup Measurements**

Complex impedance measurements were taken at each step of the pickup construction (i.e., bare coil, potted coil, coil with magnetically permeable materials, coil with magnetically permeable materials and magnets, and the complete pickup with and without a coax cable attached). These measurements were taken by measuring the complex current and voltage across the pickup in the frequency range 5-20005 Hz with two lock-in amplifiers (the complex impedance is computed at each frequency using Ohm's law $Z = V/I$, where V and I are the complex voltage and current, respectively).

The location, width, and height of the Z resonant peak tell a lot about the overall sound of a pickup. For example, the resonant peak of bright sounding pickups is located at a higher frequency than the resonant peak of more deep sounding pickups. A good indicator of whether or not our pickups have successfully captured the tonal properties of classic P90s is to compare the data from complex impedance of a pair (neck and bridge) of our completed pickups with the data from a pair of 1952 Gibson Les Paul P90s. Table 1 (below) shows this comparison.

| | Resonant frequency | Quality factor (Q) | Magnitude of Z at resonance |
|---|---|---|---|
| My P90 (neck) | 6795 Hz | 2.954 | 0.551 MΩ |
| My P90 (bridge) | 6455 Hz | 2.961 | 0.654 MΩ |
| Les Paul (neck) | 7775 Hz | 3.747 | 0.930 MΩ |
| Les Paul (bridge) | 6405 Hz | 3.302 | 0.747 MΩ |

**Table 1.** Comparison of the resonant frequency, quality factor (a higher value of Q means a narrower resonant peak), and the magnitude of impedance at resonance (higher values mean the pickup has higher output) for my P90s and a pair of 1952 Gibson Les Paul P90s.

The data shows relatively good agreement between my P90s and the 1952 Gibson Les Paul P90s. It worth mentioning that the Les Paul P90s we measured are fitted with a 12 inch coax cable on the neck pickup and a 6 inch coax cable on the bridge pickup, while my P90s have 16 inch and 8 inch coax cables on the neck and bridge pickups, respectively. Adding longer coax cables causes the overall capacitance of the pickup to increase, which shifts the resonant peak down and lowers the output. This is part of the reason our pickups have lower resonant peaks and lower output than the Les Paul P90s we measured.