Magnetic Pickups: Design

In principle, magnetic pickups are related to dynamic microphones. That is, both use electro-magnetic forces; but in a magnetic pickup there is no physical coupling of a vibration and the pickup.

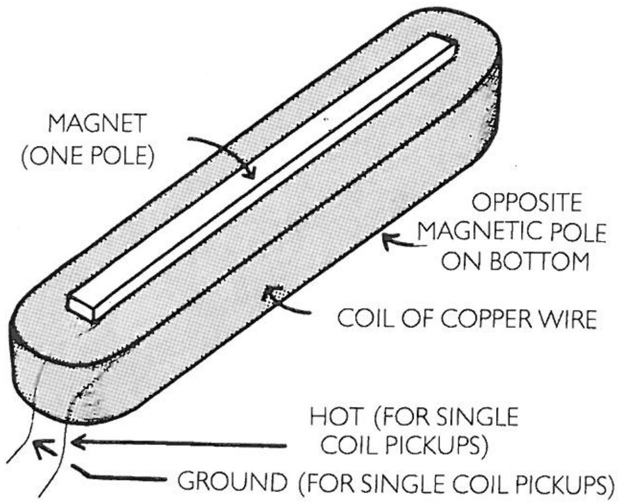
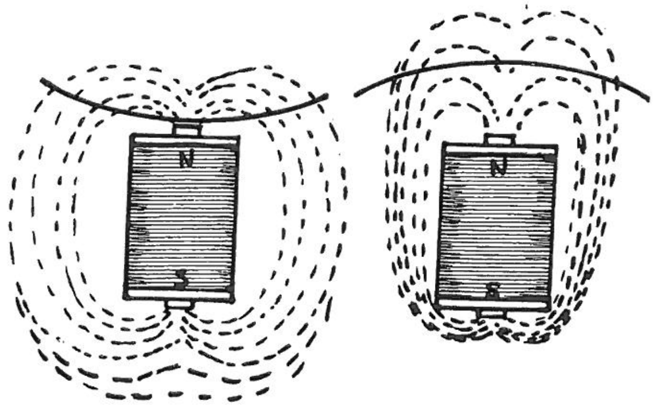


Fig. 25 The most basic form of a pickup.

A dynamic microphone is coupled to a sound source through vibrating air and the moving air actually causes the microphone element to move. A magnetic pickup picks up magnetic motion, not air motion. It is a changing magnetic situation that results in an output of changing electricity. This is how it works: If an iron string vibrates over a coil of wire that is wound around a magnet, strange things happen! All of a sudden the coil of wire is being coursed with a flow of electricity. When the strings move down to the coil/magnet, the current moves one direction; and when the string moves the other direction, the current reverses. This alternating current can be directed into an amp which will reproduce all the vibrations of the string. In other words, the vibrating string pulls and pushes against the invisible magnetic force of the magnet. This causes the magnetic lines of force to move. A way to see these magnetic 'lines' is to place a magnet under a piece of heavy paper and sprinkle iron filings/powder on the paper. Now gently shake the paper and watch the iron filings form a pattern. If a nail is then moved under the paper near the magnet, the pattern will change. A string can effect a magnetic pickup the same way. It moves the magnetic force. If you recall the dynamic microphone operation, you will remember that if you quickly move a wire through a changing magnetic force, the wire will respond with a flow of current. What does this have to do with a string vibrating over a pickup? Well, if a string is moved and the magnet remains still, the wire coil around a magnet in a pickup will also become filled with a flow of current.



1. SEE PAGE 125

Pole Pieces

A pole piece derives its name from "pole" of a magnet. A pole piece is a device that acts like a pole of a magnet and it serves as an emanating point of a magnet's flux. A pole piece acts to concentrate and direct the magnetic field so it is in an optimum shape and direction to sense (be affected by) the vibration of the strings. When speaking of magnetic pickups, a pole piece is any structure on the tope of the pickup that "aims" the force of a magnet(s) at the strings. Pole pieces can be of many shapes and sizes.

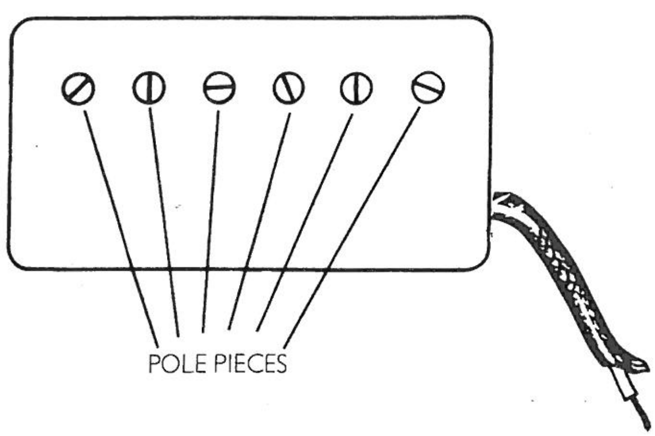


Fig. 29 Pole pieces.

2. SEE PAGE 125

A pickup may have a single metal bar as a pole piece (the ES 150 Charlie Christian pickup), or six individual adjustable height, slotted-screw pole pieces (the Gibson "Laid Back" pickup), or twelve adjustable height, allen screws (the DiMarzio "Super Distortion" pickup), or more than twelve (the Carvin and John Birch pickups). Even if a pickup does not have visible pole pieces (the Schecter Superock), it will still have unseen internal pole pieces.

Wire Coils

The windings of wire around a magnet are often spoken of in semi-mystical terms. When trying to determine how many coil turns to use on a pickup, you can always wind to 6,500 turns which is a magic number for some pickup manufacturers. Although some people may speak of arcane creations, many facts are known and have been proven. For example, the more coil windings around a magnet, the more the magnetic pulsations will be sensed, i.e., more windings increase amps, and so the more powerful a pickup will be. Keep in mind that the closer the wire is to the magnet, the more sensitive the coil will be. This is because the magnet's field of effect doesn't extend too far out from it. If a coil of large sized wire were used, the resulting bulging coil would have many wire turns a good distance away from the magnet. For this reason, small diameter wire is used which allows for a small coil to be tightly wrapped around a magnet.

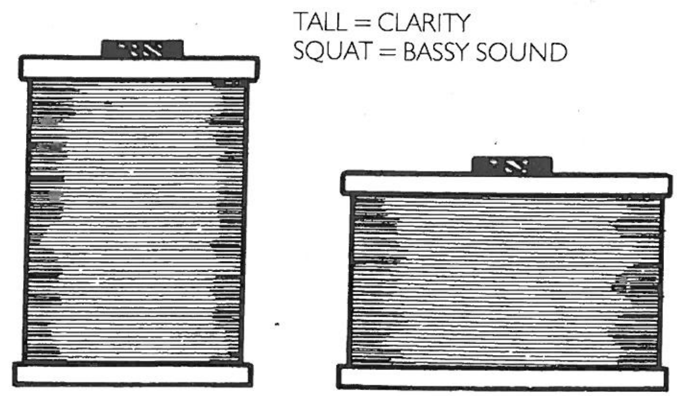


Fig. 30 Pickups can be thin and tall or short and wide.

The diameter of the wire most commonly used is 42 gauge.[3] However, pickups are made with wire anywhere from 36 to 54 gauge. The finer the gauge, the more sensitive a pickup will be. Unfortunately, as the gauge gets smaller the price of the wire starts to skyrocket. Rickenbacker once used 54 gauge, but the cost made the price of the guitars so expensive that they were not competitive in the market. Many guitar players didn't appreciate all the work that Rickenbacker put into it. Wire for pickups is finer than the hair growing on your head and it breaks **very** easily.

The wire used is solid copper which is rather weak material. It's coated with a poly-synthetic or some other insulating substance to prevent windings from shorting out. For years the standard coating on magnet wire was lacquer, but lacquer tends to chip and crack; therefore, newer synthetic coatings are now used.

3. SEE PAGE 125

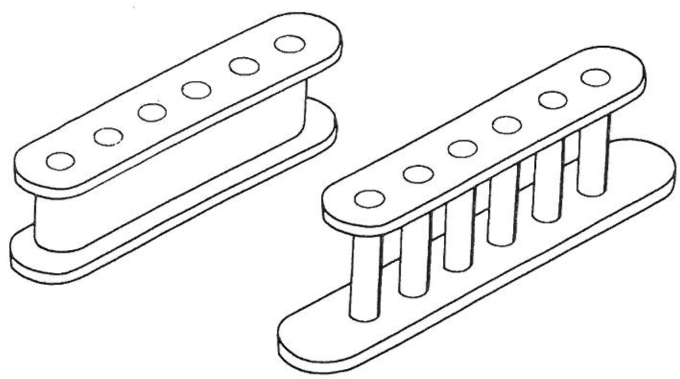


Fig. 31 Bobbins

Bare wire cannot be used because the coil windings would short-out causing a reduction in induction and therefore, output. The wire must conduct like one very long wire.

G	R	G	R	G	R
22	16.2	35	331	48	6750
23	20.3	36	415	49	8420
24	25.7	37	512	50	10600
25	32.4	38	648	51	13400
26	41.0	39	847	52	17000
27	51.4	40	1080	53	21200
28	65.3	41	1320	54	27000
29	81.2	42	1660	55	34300
30	104.0	43	2140	56	43200
31	131	44	2590	57	54100
32	162	45	3350	58	68000
33	206	46	4210	59	85900
34	261	47	5290	60	108400

G=AMERICAN WIRE GAUGE #
R=RESISTANCE IN OHMS "per 1000 ft."

Fig. 32 Resistances of copper magnet wire.

Resistance

How much wire to wrap around a bobbin is a difficult question to answer. The exact amount has to do with what kind of sound you are after and what kind of amp you are going to use. The skinnier a wire is, the harder it is for electricity to flow through it because of less surface area. In addition, the longer a wire is, the harder it is for electricity to flow all the way along it. These restrictions to flow are called **resistance.** Notice on the gauge chart that as the gauge number gets bigger, the wire is getting smaller, and the resistance increases.[4] Although some people measure the amount of wire in a coil by counting wire turns, many pickup manufacturers rely on using d.c. resistance as a means of judging how much wire to put into a coil. Generally, more windings give more output. When you get past a d.c. resistance of approximately 16K ohms, additional windings (wire turns) begin to strangle a pickup's output through the extremely high impedance of the coil. There are some fairly well accepted amounts of windings on a coil for a pickup:

Single Coil Pickups:
Clear tone = 3 to 6K ohms
Medium tone = 6 to 9K ohms
Loud heavy tone = 9 to 14K ohms*
Humbuckers (both coils):
Clear tone = 4 to 7.5K ohms
Medium tone = 7.5 to 9K ohms
Loud heavy tone = 9 to 14K ohms*
*These pickups would be high-output distortion models.

These preceding assigned tonal qualities are generalizations applicable to most pickups, but there are exceptions such as clear sounding high d.c. resistance Lawrence pickups.

Fender Stratocaster = 6K
Fender Starcaster = 12K
Lawrence AT-170 = 14K
Bartolini Acoustic = 2K
Gibson "Original" = 7.8K
Gibson S-1 = 5.38K
Schecter Z+ = 10K
Schecter F500T = 7.5K & 14K
DiMarzio X2 N = 14K

Fig. 33 D.C. resistances of some popular pickups.

When to use #43 wire and when to use #42, can be a very important decision. For example, if #43 is substituted for #42 (and the pickup is wound to the same d.c. resistance) a pickup is liable to have a thinner, more treble sound with less power. This occurs because the higher resistance of #43 will mean that the pickup coil would have less windings to equal the same d.c. resistance, and therefore it would be smaller than if #42 were used. It is interesting to note that the first Telecaster lead pickups had a wire gauge of #43, later this was changed to #42 wire.

High frequencies have a harder time flowing than low frequencies because high frequencies use up a lot of energy with their fast wave fluctuations. What all this means is that if you make a big coil winding of small size copper wire, you could have a powerful loud pickup, but the trebles won't all get through. Remember this: high output pickups have many windings and a fat loud sound, but some trebles will be lost. If a minimum of winding is used, the pickup's output will be lower, but the sound will be quite clear with increased treble. Some companies use high induction magnets to reach out for trebles, but this doesn't completely solve the problem of treble loss. Bill Lawrence, founder of Lawrence pickups, recommends using low magnetic induction with a high Q coil for a more balanced tone.

Impedance

Impedance is the resistance to alternating currents and the output of a pickup is an alternating current. The measurement of a pickup's impedance is important because it reveals the tonal quality of a pickup.

Impedance is determined by the constraining influence of a magnet's field on a coil. If the magnet is

4. SEE PAGE 125

put in sideways instead of vertical, the magnetic field will form around a coil differently, and this will affect impedance. One problem with impedance is that as frequencies rise, trebles are impaired. This impedance/ resistance problem is most evident in humbucking pickups since they use two coil bobbins. Humbucking pickups have more windings than single coil pickups and the added windings increase the impedance and resistance.

Generally, the minimum amount of windings are those windings which produce a needed impedance figure that is compatible with an amp being used. Since d.c. resistance figures of pickups are fairly well correlated to the impedance (alternating current [a.c.] resistance) of most pickups, we can use resistance as an informative guide to a pickup's behavior. It certainly doesn't hurt that d.c. resistance is a lot easier to measure. Few people have the necessary equipment to measure a.c. resistance. Pickups with a resistance of 6,000 to 12,000 ohms are generally considered high impedance, whereas 1,500 to 4,000 ohms is generally referred to as mid-impedance. Pickups around 2,000 ohms could be plugged into a low impedance or a high impedance amp, but they are not quite at home in either because they are neither high nor low. Below 1,000 ohms is generally low impedance. For information about the impedance of a particular amp, check with the manufacturer.

Hand Winding

The term "hand-wound" is rather misleading because a person is not employed to hand wrap magnet wire, turn by turn, around a bobbin. Rather, a person is engaged in hand guiding a wrapping machine. Due to poor operator training, it is common for simple winding machines to wind coils which are flared. In order to produce coils of a desired shape, some manufacturers use hand guided winders, whereas other companies use new sophisticated machines which follow pre-set parameters.

Resonance Peaks

Virtually all electronic devices have one frequency that will cause them to oscillate more easily than any other frequency. This would be the natural resonant frequency of a device. The center of the resonant band is called a resonance peak.

Coils used in pickups have resonant peaks. If a pickup has a peak of 6,000Hz, the sound of the device will be more treble than if the device had a peak of 1,000Hz.

Some people feel that resonance peaks are the best indicator of the sound of a pickup. DiMarzio has said: "We feel the resonant peak may have more relevance than impedance or d.c. resistance because it will definitely give an indication of frequency response. It will provide a good idea of the type of timbre a pickup will create. The voltage may then determine how pronounced the effect will be."

For more information on the factors which raise or lower resonant peaks, read the sections on Bartolini, Lawrence, and Armstrong. Basically, more windings and lower gauss lowers the frequency of the resonance peak; less windings and higher gauss raises the peak.

Humbucking Pickups

A single bobbin of wire around a magnet will make a pickup. This device will pick up the motion of a metal string vibrating above it. Unfortunately, it can also act as an antenna and pick up nearby stray electrical waves: the hum of fluorescent lights, 60 cycle hum, radio stations, automobile spark plug systems, etc.

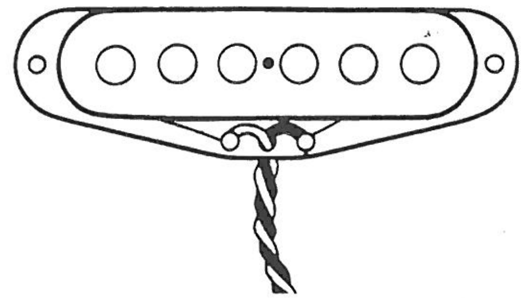


Fig. 34 Single coil pickup.

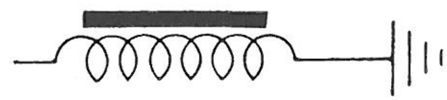


Fig. 35 Schematic diagram of a single coil pickup.

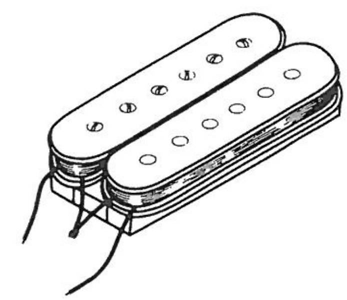


Fig. 36 Dual coil humbucking pickup.

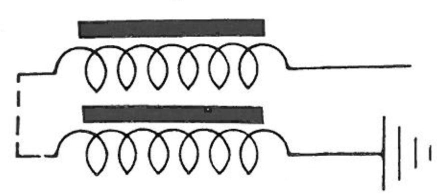


Fig. 37 Schematic diagram of a humbucking pickup.

Until 1956, hum was just something that had to be accepted with electric guitars. At that time, Seth Lover, who worked for Gibson, devised an anti-hum pickup called the humbucking pickup which cancelled out hum. Imagine it in this way: Ocean waves are high spots between low spots. If you could evenly combine these high and low spots, you would have a flat, quiet ocean, i.e., the waves combined out-of-phase. A humbucking pickup combines two waves of interference and puts them together out-of-phase.

There is an opposite magnetic polarity field in each coil, and nearby and inside the coils are magnetic

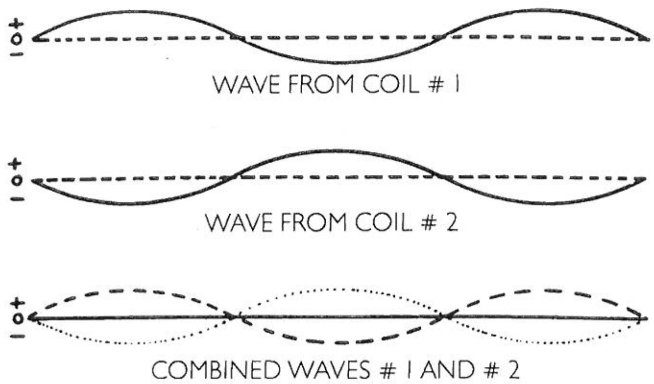


Fig. 38 How a humbucking pickup combines wave forms.

conductors. This means that the top of one coil is magnetically north and the top of the other coil is magnetically south. If you look at the series and the parallel diagrams, you can see that the positive connects to the negative. You would expect that this would cancel the signal, but your expectations are only half right. Half of the pickup's signal is cancelled – the hum half. The coils of a humbucking pickup are wired out-of-phase so that any signal received by them is cancelled, but the opposite magnetic polarity of the coils puts any signal magnetically sensed, back into an in-phase signal.

In summary: A humbucking pickup acts in the following manner – **any signal (i.e. hum) "seen" by the coils is cancelled, and any signal (i.e. string vibrations) "seen" by the magnetic poles is accepted.**

THE LINKING OF COILS IN A HUMBUCKING PICKUP

Traditionally, the two coils of a humbucking pickup are linked together in a series circuit; however, the coils can also be linked in a parallel circuit. When describing series or parallel wiring within a pickup, the only concern is with the paths of resistance and not the actual electronic positive to negative connections. This is because these positive and negative points become inverted when passing through opposite magnetic polarities in the humbucking pickup's two coils. The following diagrams show (1) the linking of two coils in a series humbucking mode, and (2) in a parallel humbucking mode.

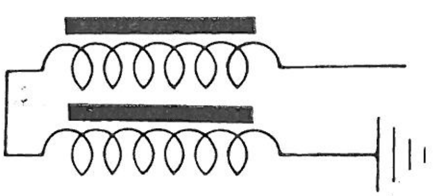


Fig. 39 Schematic diagram of a humbucking pickup (series linked)

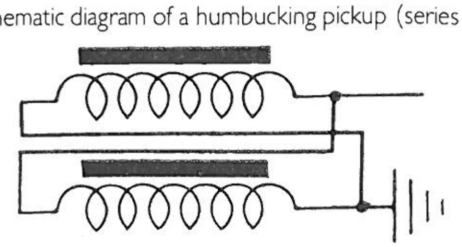


Fig. 40 Schematic diagram of a humbucking pickup (parallel linked).

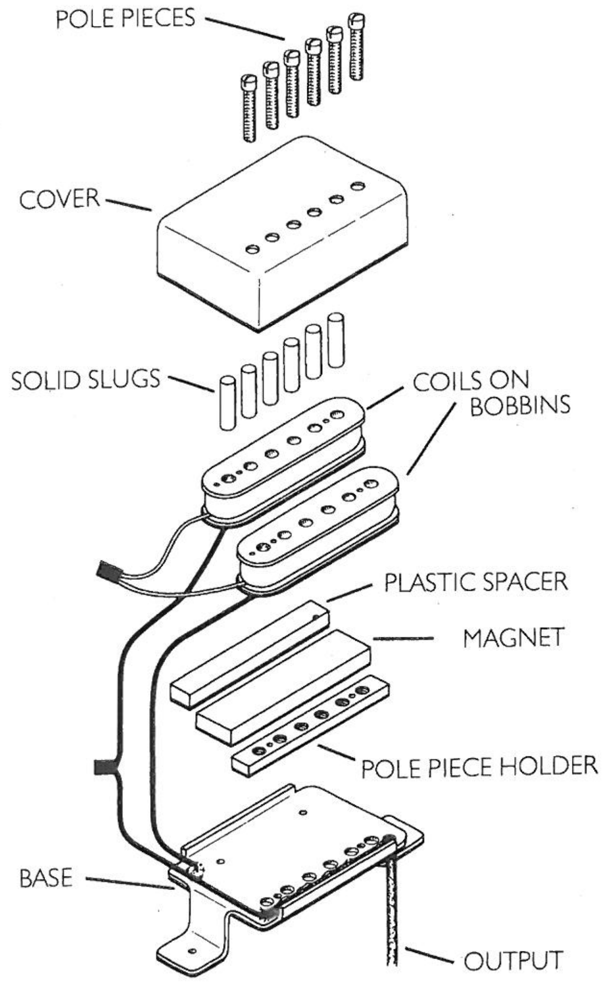


Fig. 41 Exploded view, a new Gibson Humbucker (series linked).

Series Linking

Notice that a series humbucker has the white insulated outer coil leads from both coils joined together. The leads coming from the inner portion of both coils have black colored insulated wire, and the black wire from the coil with the solid slugs becomes the hot output lead. The black wire from the coil that has the adjustable screw pole pieces is soldered to the base plate of the pickup. The braided shield of the coaxial pickup output wire is also soldered to the base plate. The base plate is used as a connection between the grounded shield and the black wire. This base plate connection effectively and efficiently forms a ground connection to the black wire and the entire metal case surrounding the pickup. Having the case of the pickup included in the ground circuit, helps to shield the pickup from receiving electro-static hum. Humbucking pickups can cancel 60 cycle per second hum, but not electro-static hum which is manifested at 120 cycles. Therefore, a pickup needs a metal shield to cancel electro-static hum.

Note: Either of the black wires from the coils could be grounded, or either could be hot. The diagram and the description given is the choice made by Gibson.

Parallel Linking

Parallel linking of a humbucking pickup is as follows:

The inside lead of the first coil is soldered to the outside lead of the second coil, and then an output wire is soldered to this junction. Then the outside from the first coil is soldered to the inside lead of the second coil. Another lead is then soldered to this junction. This results in two output leads, either could be hot or ground, the choice is arbitrary. A parallel linked humbucking pickup is not mechanically linked as two series configurations. As previously mentioned, parallel linkage is not concerned with the actual electrical connection, but rather, the parallel **relationship** of the paths of resistance.

There are some drawbacks to both series and parallel linkages. In series linkage, there is a loss of high frequencies, and it is almost impossible to achieve an overall sound that is clear and delicate. In parallel linkage, the output level is reduced considerably, and it is virtually impossible to create a solid, beefy sound. A common double-pole/double-throw switch can be connected to most humbucking pickups to enable the player to achieve both of these sounds on one guitar by flipping the switch. See the wiring section for instructions on installing a series/parallel selector.

The Electronic Function of Series & Parallel Pickup Circuits

When two equal resistances are linked in parallel, the resultant resistance is one quarter of the sum total. When two resistances are linked in series, the resultant resistance is the sum of the two individual resistances. For example, if one 4,000 ohm coil is wired in series with another 4,000 ohm coil, the total resistance of this device will be 8,000 ohms. In parallel linkage, if one 4,000 ohm coil is wired in parallel to another 4,000 ohm coil, the overall resistance of this device will be 2,000 ohms. Impedance measurements of these devices will react in a similar way to the resistance measurements. At this point, it is helpful to recall that high impedance and resistance tends to impair trebles and cause intermodulation distortion (lack of sound clarity). Also keep in mind that an increase in impedance often relates to an increase in induction, and this induction increase correlates very well with an increase in output.

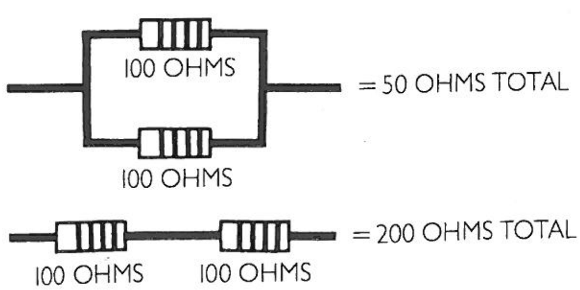


Fig. 42 Parallel and series resistances.

Series vs Parallel Linkage

Series and parallel each have their own distinctive sound. The series sound is characterized by high volume with a good degree of bass and a favorable signal-to-noise ratio. A parallel sound is characterized by less volume, very bright and clear trebles, and a less favorable signal-to-noise ratio.

Placement of Pickups

The location of a pickup will affect the tone as well as the overall volume. When a pickup is very close to a bridge, bass tones are greatly reduced. Pickups that are closer to the end of the fretboard than the bridge will give a fuller, less treble sound and vice-versa. The bridge pickups on Telecasters and Stratocasters are angled so that the treble side of the pickup is closer to the bridge than the bass side. If the bass side were as close to the bridge as the treble side, the bass would be very thin and weak.

A pickup near the end of a fretboard is referred to as a **rhythm pickup,** i.e., the pickup is suitable for playing full-sounding chords and rhythm patterns. A pickup near a bridge is referred to as a **lead pickup,** i.e., it's suitable for playing sharp, clear single notes that stand out. When closer to the bridge, lead pickup positions yield less output because the energy level of a string is lower. If two identical humbuckers are used on a guitar, the lead position pickup will have less volume than a rhythm position pickup. In order to equalize the difference in volume, guitars with two humbuckers often use rhythm and lead pickups which are different in tone and output. If there is a pickup in-between the rhythm and lead positions, it's referred to as a **middle pickup.**

Three humbucking pickups on a guitar are superfluous to many players because it can be difficult to find a place to pick the strings without having a pickup in the way because they fill the entire area from the bridge to the end of the fretboard. In addition, three simple humbuckers will give less tonal variations than a single tapped humbucker. One tapped humbucker could give ten distinct sounds.

When two magnetically identical humbuckers are used, it's common to turn the lead pickup around. This is done so that the magnetic poles of one pickup don't interfere with the poles of the second. If pickups were both installed so that the south pole coil of one pickup was contiguous to the north pole coil of another pickup, the volume and full tone of the pickups would be impaired.

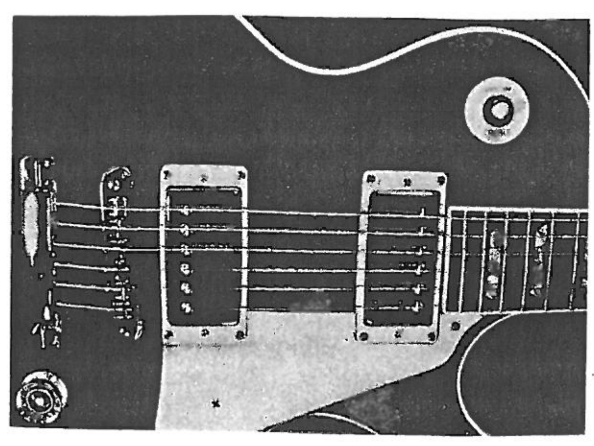


Fig. 43 Orientation of pickups on a Les Paul.

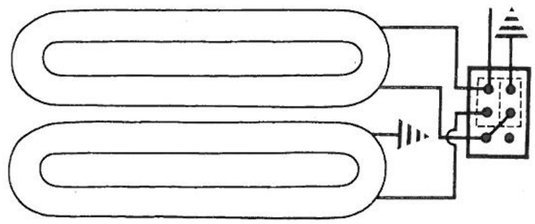


Fig. 204 Humbucker in parallel.

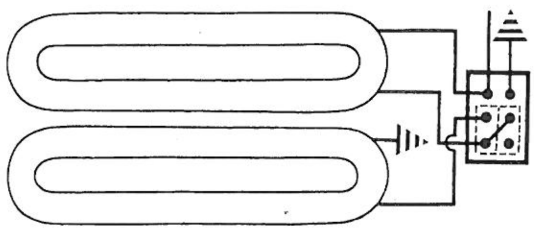


Fig. 205 Humbucker in series.

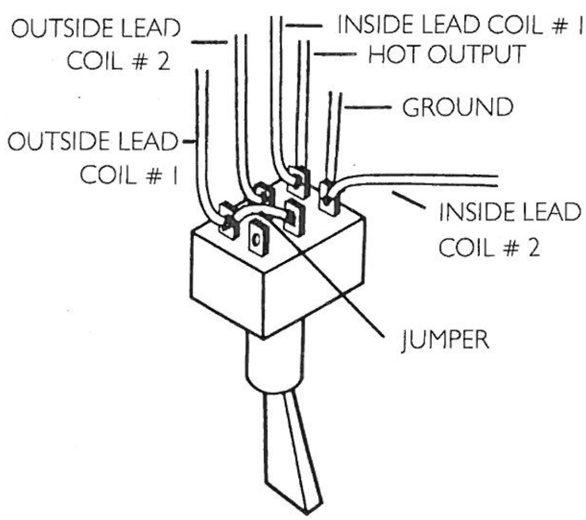


Fig. 206 DPDT switch used as a series parallel selector.

Earlier in this book the operation and tonal difference of series and parallel wiring were covered. In this section, diagrams of switches for series/parallel linking are given. The most common switch for this purpose is a DPDT switch; however, an Omni Pot is valuable for this use because no hole has to be drilled for a switch.

Splitter Switches

Splitter switches are used with dual coil pickups, i.e., humbuckers. If you want the extra tonal possibility of a single coil "Fender" sound from a humbucker, you can simply use only one coil of the pickup. All you need to do is add a switch that allows only one coil to be engaged. That is, you split the pickup. The only drawback of this new single coil sound is that it is not humbucking.

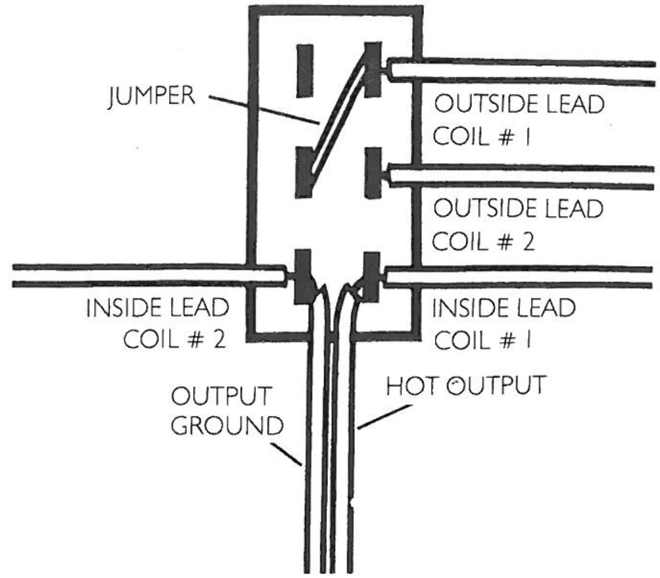


Fig. 207 DPDT series/parallel switch, DiMarzio style.

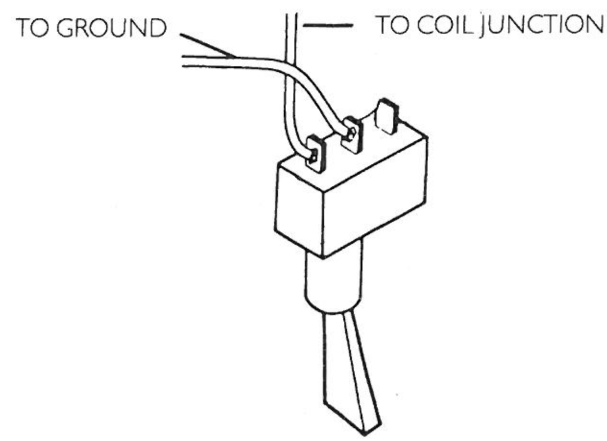


Fig. 208 An SPDT splitter switch.

A simple DPDT switch will allow the splitting of a coil. A DPDT position will allow three selections: (1) coil #1, (2) both coils as a series humbucker, and (3) coil #2.

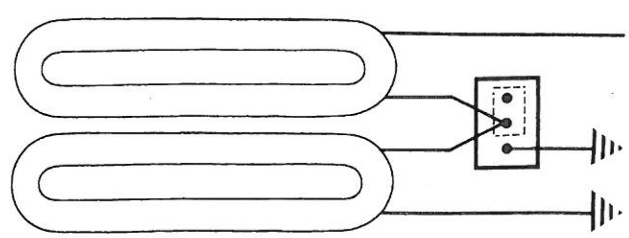


Fig. 209 Humbucker with both coils on.

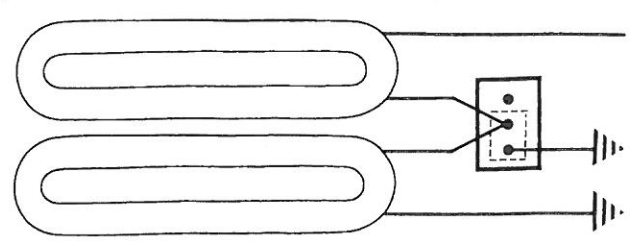


Fig. 210 Humbucker with only coil # 1 on.