Construction of a prototype guitar pickup

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Introduction

The electric guitar first made its debut in the early 1930's. This was made possible by the ability to detect the motion of the guitar strings and amplify the subsequent electric signal to generate a louder sound. The pick-up was invented in order to amplify the sound of the acoustic guitar. The result was an entirely new sound that changed the direction of music history and facilitated the invention of many new forms of music.[1] There are three main methods of detecting the motion of the guitar string. The optical pickup uses infrared light to detect the position of the string. A piezoelectric pickup measures the force the string exerts on the bridge.[2] A magnetic pickup, and the focus of this project, works when the vibrating string interacts with the magnetic field inducing a signal in the coils that can then by amplified, modified, and recorded. The output depends on the type and position of the amplifier.[3]

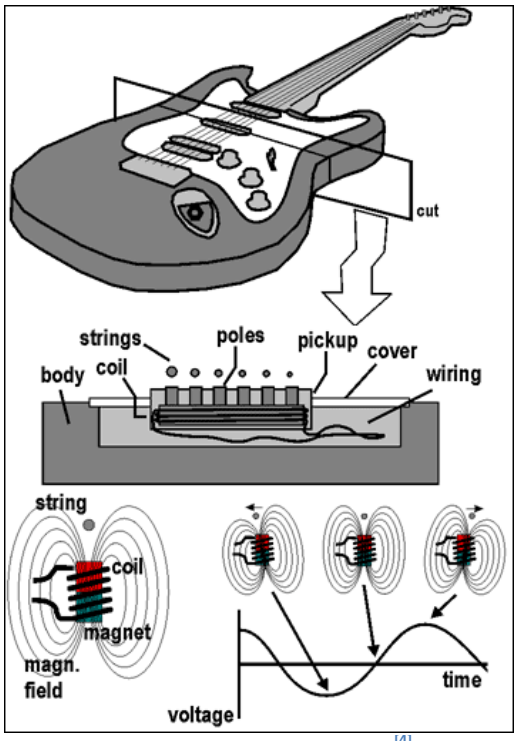


Figure 1 - How a Pickup Works[4]

Faraday's Law

Faraday's law relates the electromotive force (emf) to the magnetic flux (ϕ) through a surface S

$$emf = -\frac{d\phi}{dt} = -\frac{d}{dt}\int_S \vec{B}\cdot\hat{n}\,dA$$

In the pickup, $\vec{B}$ and $\hat{n}$ are perpendicular so the flux can be reduced to:

$$\phi = NAB$$

Where N is the number of coils, A is the area of the coil, and B is the magnetic field of the coil. Because the emf contains the derivative of the flux with respect to time, one of the components must be changing in time for a signal to be produced. The number of coils and the area of the coil remain constant which leave the magnetic field to change in time. However, the pickup is using a permanent magnet with a constant magnetic field. To create a changing magnetic field, the strings are required. The strings are made of steel which contains 98% – 99.98% iron. Steel demonstrates ferromagnetism so when the string is plucked, it produces a vibration which will produce a variation in the magnetic field that directly corresponds to the frequency of the string. That variation will then become a variation in the emf through the coil creating an alternating signal which can be amplified, modified, or recorded by other equipment. [3.4] Figure 1 shows a good representation of the physical effects of a pickup. The changing magnetic flux is shown in the bottom right of the figure. So the flux can be described as:

$$\phi = NA\,B(t)$$

Making the emf equivalent to:

$$emf = -\frac{d\phi}{dt} = NA\,B'(t)$$

Where B(t) and B'(t) are of some trigonometry function:

$$B(t) = \gamma\sin(t) \;\; and \;\; B'(t) = \gamma\cos(t)$$

Putting it together:

$$emf = NA\gamma\cos(t)$$

Construction

The following procedure for building the pickup was synthesized from two sources.[5,6] The pickup was designed so that it may easily prove and demonstrate the functionality. Some special modifications are made to achieve these goals.

The pickup can be built with the following components:

1) **Enamel coated magnet wire** – in this case 200 ft of 30 gauge wire. This makes about 600 wraps. Ideally 1000 – 7000 wraps (300' – 2000') should be used with 42 or 43 gauge wire. The thinner wire allows for more wraps to occupy the same volume.
2) **Rare Earth Magnets** – in this case 1/8" diameter neodymium magnets were used. They provide the greatest magnetic strength increasing the signal strength.
3) **Guitar to Amplifier Cord** – Using an old one with a short on one end, the cord was cut and the longer portion was used. The two wires can be separated and coiled together to be soldered to the coil.
4) **Casing –** A material must be used to hold the coil in place and will be material that is attached to the guitar. In this case, plexiglass was cut to shape with machine bolts as a structural component that also is used for the attachment of the magnets.

Figure 2 – Materials used in construction

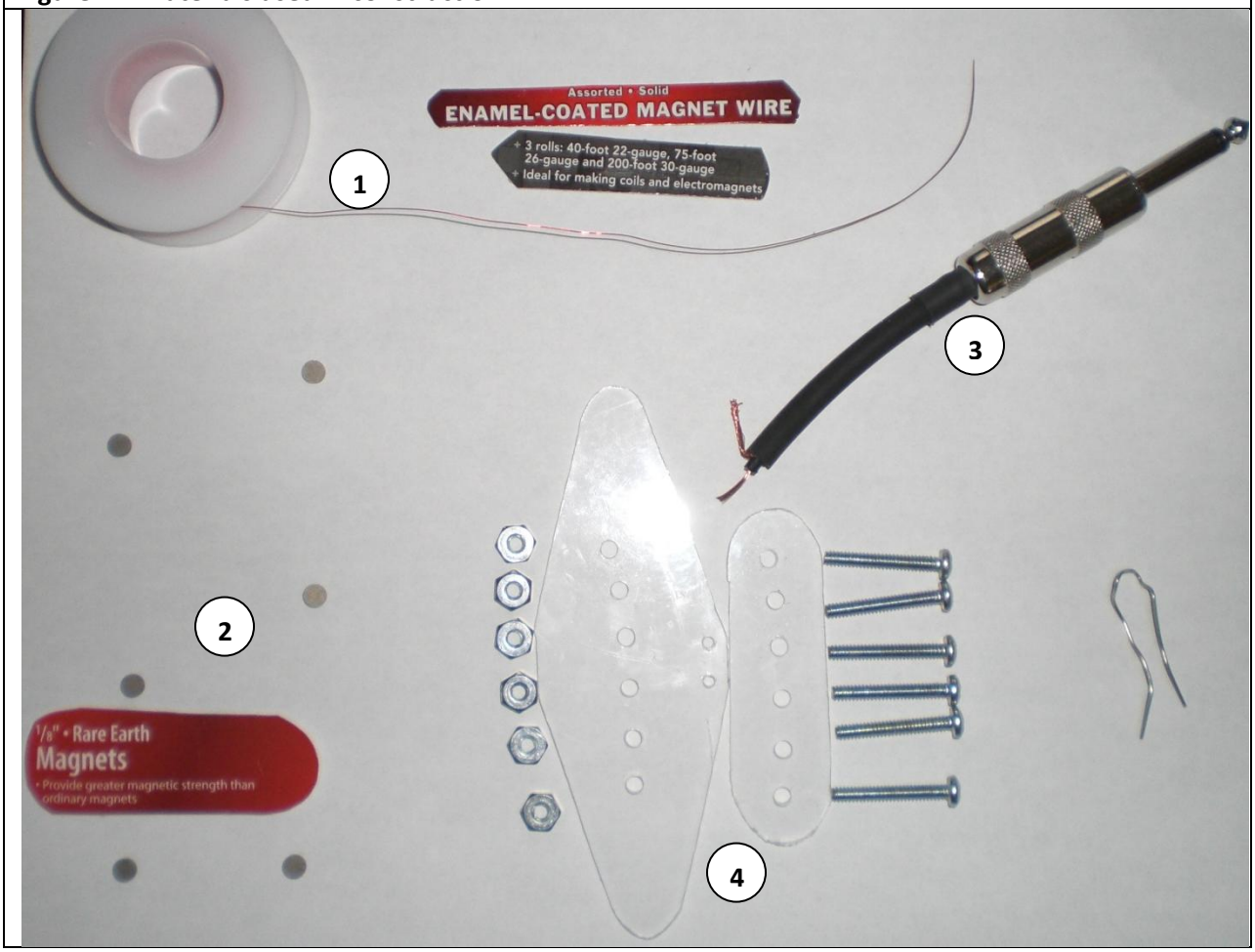
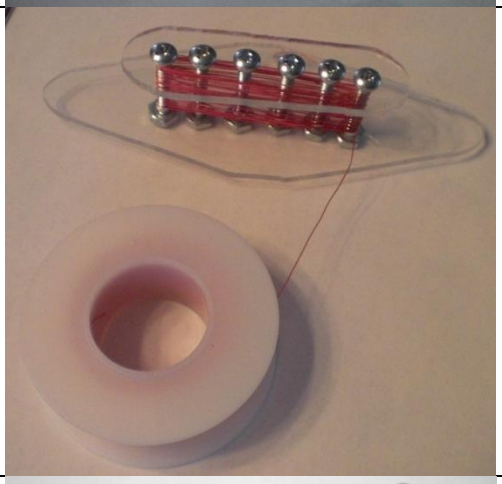
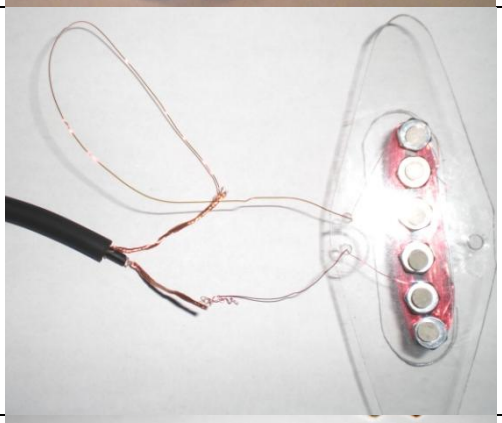


Figure 3 – Procedure for construction

1) The stock was cut to the dimension by making a CAD drawing, printing to scale then tracing onto the plexiglass stock.
2) The machined glass can be assembled with the machine bolts as shown in the first figure.
3) The magnet wire can then be wrapped onto the framework. The first 10 or so coils can be wrapped by hand to start the coil. The start of the wire should be kept out for use later (insert into one of the two small holes at the top of the stock.
4) Making the coils is tedious by hand and subject to inaccuracy. Using a coil winder is a much more efficient method. Using a drill press, attach the pickup- coil so that it can be spun quickly. Set up a clamp and axle to hold the pre-wound coil in place as the pickup-coil is wound.
5) Let the coil winder spin until all the wire has been used.
6) Sand the two ends of the wire that makes up the coil. This will remove the enamel coating to ensure a good connection.
7) Cut the amplifier cord into two pieces (make one of the pieces long). Make absolutely sure you don't want it for anything. Separate the two wire components out.
8) Carefully solder the two ends of the coil to the two ends of the amplifier cord. Make sure that the two wires do not cross. This will short the pickup causing it not to function properly
9) Using electric tape, insulate the exposed wires and attach to the frame of the pickup.
10) Last, the coil can be dipped into hot candle wax and wrapped with a final coat of electric tape to make the final product. Great care needs to be taken during this step as the hot wax is hot. After dipping into the hot wax scrape quickly while the wax is not completely solidified.
11) Attach it to the frame of an electric or acoustic guitar (that uses steel strings!) and plug into an amplifier to test.





Conclusion

The coil worked as described in picking up the emf by vibrating the guitar strings. There are several parameters that can be thought about more deeply to produce a better functioning pickup.

- **N (number of turns)** – The number of turns increases the emf with direct proportionality. The number of coils should be kept at a reasonable amount. Typically, N is between 1000 and 7000. The pickup in this project is around 600. This would explain a slightly weaker signal.
- **γ(Strength of permanent magnetic field)** – Rare earth magnets were used during this project which are very strong. Using incredibly strong magnets can cause the wire to be dampened by pulling on the steel string too hard. Reducing the strength of the magnet removes this effect but also reduces the signal strength. A balance should be found for the magnetic field.
- **A (Area of the coil)** – This will remain nearly constant as the spacing of the strings and size of the coil will be hard to adjust.
- **Placement and number of pickups** – Placing pickups near the center gives a stronger signal. If pickups are placed at a location where harmonics can occur, then no sound will be heard. It is best to have an arrangement of pickups for the best possible signal.

A careful balance of these parameters will create the best pickup design with a series of pickups on the body of the guitar. There are many ways to create a good signal, thus there are hundreds of types of pickups and pickup arrangements.

References

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[5] Instructables. Make A Guitar Pickup. January 2008. 1 April 2009. <http://www.instructables.com/id/Make-A-Guitar-Pickup/>

[6] DIY Happy. How to Make a Guitar/ Bass Pickup. 7 April 2006. 1 April 2009. <http://www.diyhappy.com/how-to-make-a-guitarbass-pickup/>