Working of Guitar Pickups

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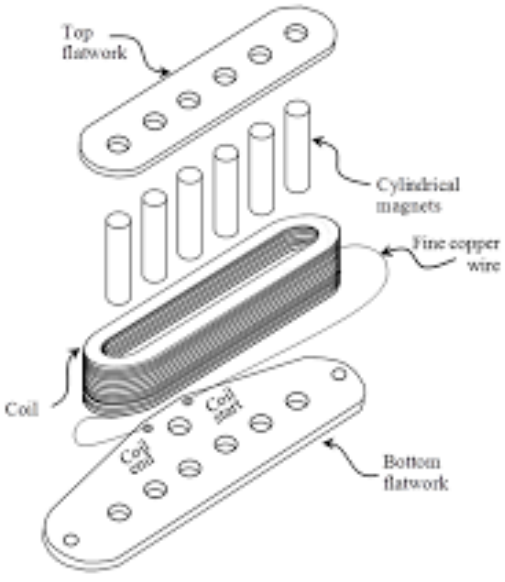
Pickups are essential transducers used on electric guitars (and acoustic) to “pickup” the vibrations of the string and convert them into an electric signal which can be amplified with an amplifier.

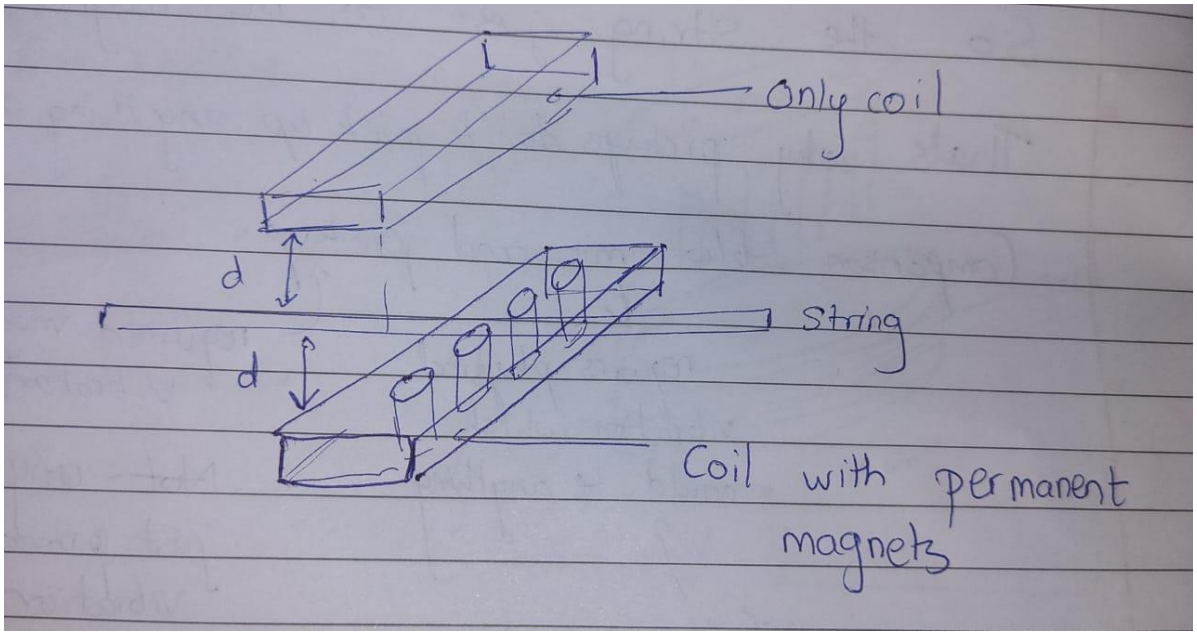
Their structure is:



1. Architecture of a conventional single coil pickup

The common misconception in the music community about their working is that the strings of the guitar cut the magnetic field produced by the magnets which produces currents in the coil.

But that is not quite true. We can look at a relatively simple experiment for this. We use a normal guitar and attach another pickup on top of the strings such that this pickup (pickup A) and the one already on the guitar (pickup B) are equidistant to the strings. Pickup A has the same construction but does not have any magnets.



Now, if we look at the outputs generated by each pickup, we will find that the intensity of sound produced is the same! There is no significant difference in the sounds.

The true origin of the field fluctuations are the strings itself. The strings are actually made of ferromagnetic materials like steel or nickel. A primary property of ferromagnetic materials is that they align themselves to external magnetic fields thus becoming a magnet themselves.

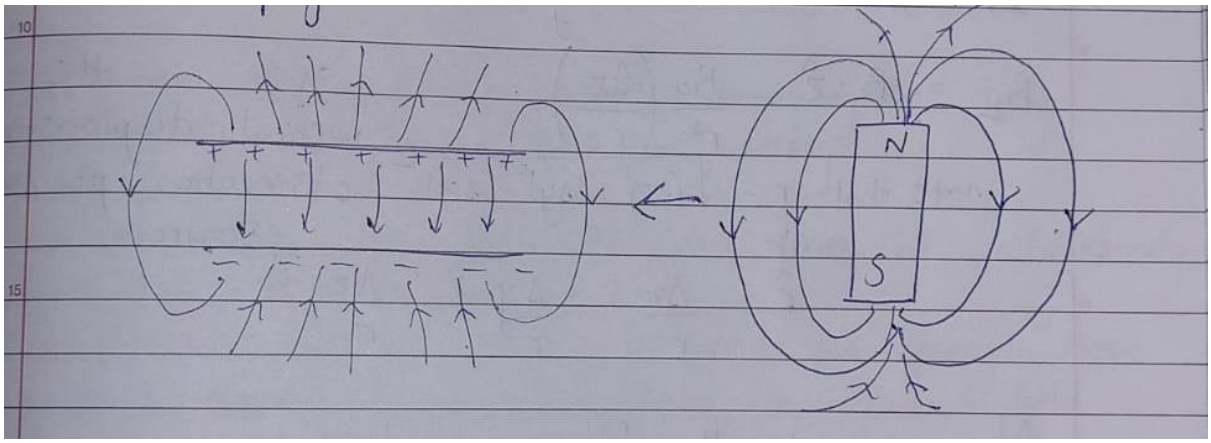
So, in our case, the string is magnetized by the permanent magnets in the pickup. The string then becomes like a line of infinitesimally small magnets aligned in accordance to the permanent magnets. The field produced by this magnetized string is what influences the coil in the pickup!

When the string vibrates, the flux due to it at the coil changes and by faraday's law the changing magnetic flux induces a current in the coil. This current is then passed through an amplifier which then produces sound.

Calculations:

The calculation of the magnetic fields can be done at an elementary level with some approximations.

The permanent magnets in the pickup can either be modelled as a solenoid or as a non-physical model. The math for a solenoid of finite length becomes to complicated and so we use the non-physical model which makes use of magnetic monopoles.



The north and south poles of the permanent magnet are modelled as magnetically charges plates with equal and opposite magnetic charges. We are assuming the existence of magnetic monopoles! In the source review article this was mainly validated by the accuracy with which such a non-physical model approximated observation.

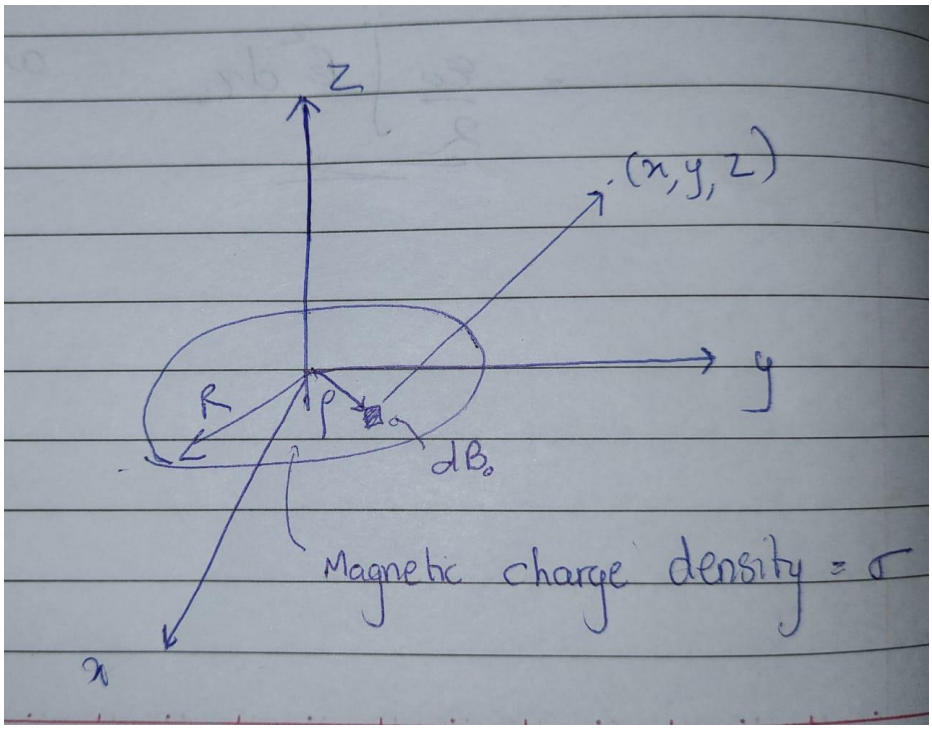
But now, this allows us to use math which is similar to the math in electrostatics which simplifies things for us.

With these simplifications, we can invoke the inverse square law

$$B = \frac{B_o}{r^2}\hat{r}$$

Where B_o represents the magnetic monopole, analogous to the charge in electrostatics.

Now we consider a disk of radius R, representing the plates mentioned above, with magnetic charge density σ:



Then, the field at some (x,y,z) is given by:

$$dB = \frac{\sigma\, da}{r^2}\,\hat{r}$$

$$B = \int_0^{2\pi}\int_0^{R} \frac{\sigma\rho\, d\rho\, d\varphi\, \hat{r}}{z^2 + (x - \rho cos\varphi)^2 + (y - \rho sin\varphi)^2}$$

This has to be solved numerically with a software.

Now the intensity of magnetization in the string is given by:

$$\vec{I} = \chi\vec{B}$$

Where χ is the magnetic susceptibility of the string. The acts like the new magnetic monopole representative and can be used in similar calculations as above to get field at any point (or field at the coil for us) due to the magnetization of the string.

Sources: American Journal of Physics **77**, 144 (2009); doi: 10.1119/1.2990663

https://www.guitarworld.com/gear/how-does-a-guitar-pickup-really-work