Electric Guitars – Electromagnetic induction in context

Contents:

Intended Reader:

The intended audience for this report is any person with a scientific background that would like to broaden his knowledge of electric guitars, particularly with respect to how the initial oscillation of a ferro-magnetic string is transduced into electrical energy and how different types of pickup designs can influence the resulting sound.

Executive Summary:

- Electric guitar pickups work by magnetizing the string whose vibration modulates the magnetic flux across a coil and therefore inducing an alternating voltage through the coil.

- In a simple single coil design mains interference is often picked up and causes a hum in the final signal. This is removed by placing two pickups next to each other with reversed magnetic field and wiring them in series with one of the signals reversed.

Introduction:

The electric guitar is a prime example of modern physics as a real life application. Since its invention in 1933 by Adolph Rickenbacker much research has been conducted to now provide a cleaner signal, more tonal control and more depth of sound. However, all electric guitars still rely on the same principle of electromagnetic induction which is explained in the next section

Electromagnetic Induction:

Electromagnetic Induction is the creation of a potential difference in a conductor moving through a magnetic field or in a stationary conductor in a varying magnetic field. In the case of the electric guitar it is the later. A stationary conductor is exposed to the varying magnetic field created by the oscillation of the guitar's strings. This induces an EMF proportional to the rate of change of magnetic flux and an oscillating current at the same frequency as the vibrating string is created.

Single Coil Pickups:

One of the most common designs for electric guitar pickups is the so-called single coil pickup. As its name suggests these pickups consist of a single coil of copper wire with usually wrapped around a single bar magnet.

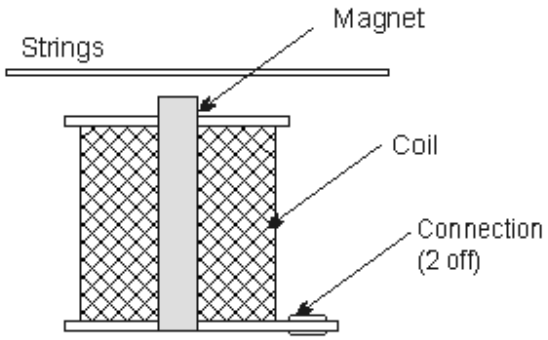

Fig.1
The basic single coil pickup

The strings are made out of a ferro-magnetic metal, usually nickel as this is very easily magnetized by the bar magnet. When the string is now played, its magnetic field moves and causes a current to be induced in the copper coil. This current is of the same frequency as the oscillating string.

There are various designs of single coil pickups that all have their own distinct sound. In this report I will focus mainly on the classic Fender single coil pickup. . In this pickup there are separate bar magnets for every string, with around 8000 turns of copper wire around each one. The amount of turns has a great impact on the final tone that is conveyed by the pickup as it provides self-capacitance which resonates with the inductance of the winding. This Resonance can make certain frequencies stand out, thereby giving every pickups its unique tonal characteristics.

Fig. 2
Pickups on a classic Fender Stratocaster. Notice the separate magnets under every string.

Separate magnets under each string allow the player to adjust the distance between the magnet and the string separately for each string. This is beneficial as it allows for different strings to induce varying amounts of current, therefore affecting the final overall tone. One usage is to adjust the magnet to a lower position for strings that are naturally at low tension (i.e. tuned to a lower note) and therefore tend to have a bigger vibrational amplitude. With the magnets lower, the current induced by these strings is lower and the high strings will be more present in the final sound.

One of the main problems of single coil pickups (in fact all electromagnetic pickups) is the presence of 50 or 60Hz mains hum depending on local mains frequency. The electromagnetic field produced by nearby mains electricity also causes a current to be induced in the coil of copper wire which results in a hum in the signal.

There are many other types of pickup with different designs that claim to eliminate this hum. One of the most common is the PAF (standing for "Patent applied for") Humbucker pickup developed in 1955 by Seth Lover for Gibson.

Humbucker Pickups:

Humbucker Pickups were originally developed to literally "buck the hum". Their design is simple yet effective. Two single coil pickups were placed next to each other with their magnets placed in opposite directions. They were then wired in series with one of them reversed. This effectively cancels out the unwanted mains hum.

Fig. 3
A replica of the original PAF humbucking pickup

Using this design also influences the resulting sound. A humbucker pickup produces a "warm" and "full bodied" sound in contrast to the "clear" and "bright" sound of a single coil pickup. The main reason for this change in sound is the due to the coils resonating at different frequencies causing a broader resonance peak. Also, two pickups wired in series will have a higher impedance which will cause some of the higher frequencies to be more accentuated.

Other types of Noise Reduction Pickups:

Since the invention of the single coil pickup many pickups have been developed that promise to remove the unwanted mains hum while maintaining the desired clarity of single coil pickups.

Such attempts include the Lace sensor pickups that do not have coils wrapped around single magnets, but have a magnetic "comb matrix" that creates an even magnetic field along the entire pickup. This allows for a weaker magnetic field to be used and therefore resulting in less noise as well as less magnetic pull on the strings.

There are other types of transducers that do not rely on electromagnetism, such as the piezo pickup that is attached to the guitars body and relies on the ability of crystals to generate a potential difference in response to applied mechanical stress.

More recently, there have also been optical pickups that sense the interruption of a light beam by the string. However, these are usually found in bass guitars where the strings oscillate at lower frequencies.

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