Interfacing Guitar Pickups and Sound Amplifiers in a Digital Effect Pedal

By Alan Cepeda, ECE '23

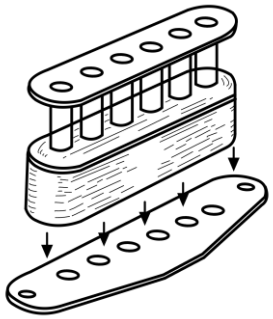
Introduction

The mechanical advantage of this project stems from making use of the guitar's pickups and the internal amplifier of a *Focusrite Scarlett* audio interface to output an altered guitar signal. From the first moment the string is plucked to the final moment in which the speaker's coils vibrate, these two elements—the pickup and amplifier—are instrumental to the clarity of the processed audio signal. This paper will cover their importance in this project in a nontechnical manner and discuss the results of the integration in this project.

Overview of Guitar Pickups

Guitar strings and pickups work in unison to produce the screechy, iconic sounds of an electric guitar. Take strings out of the equation and nothing produces the sound. Take pickups out of the equation and the sound has nowhere to travel to—plucking would merely result in a vibrating string which produces a sad, metallic noise. Depending on the model of guitar being played, there exists one to three pickups usually placed on the fretboard in varying configurations. Configurations aside, pickups function under the same principles by converting string vibrations into electricity, much like speakers, using coils. To do so, a pickup detects disturbances in the net magnetic field produced by the sum of the magnetic fields created by the electrically-charged strings. Once detected, it 'registers' these disturbances with the sound amplifier by creating a miniscule current that gets further amplified down the chain until the altered guitar signal is outputted from the speaker internal to the sound amplifier. To do so, however, the signal must first be routed into a bobbin, the first of two components within a pickup.

Two Components—Bobbin & Coil



Bobbins consist of a two-plate casing. The casing places the two plates parallel to each other and is traditionally made of a material that avoids electrical conduction outside of the pickup.

Figure 1. A basic diagram showcasing a pickup's internal components.

These casings have six tapped holes in which six magnetic bars are inserted. These magnetic bars are then wrapped in enameled wire to produce six solenoids. Enameled magnet wire is chosen to provide a thin layer of insulation around the solenoid, which can be beneficial for induction. Then, more of the same enameled wire is then wound around the bobbins in between both plates to create the coil. The coil is created to form an inductor, encased between both of the plates. Another magnet is laid underneath the bobbin and coil to induce changes in the surrounding magnetic field. Because another B-field is introduced, the existing fields undergo pole reversal every time a string is plucked. This generates a current through the six coils of wire and causes the existing magnetic lines to diverge, magnetizing the strings. This movement disturbs electrons in the enameled wire and induces a current in the coil, which is outputted to a sound amplifier.

Sound Amplifiers

Though the guitar pickups are internal to the guitar, the sound amplifier is external and just as necessary as the pickup. As mentioned in the introduction, the *Focusrite Scarlett* audio interface contains a built-in three-stage sound amplifier. These three modules—a preamp, a power amp, and a speaker—are responsible for outputting amplified versions of the incident wave sourced at the strings on a fretboard.

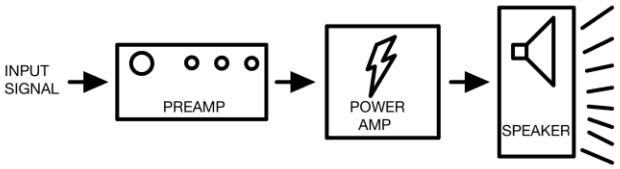


Figure 2. A non-technical look at the three stages found within a single sound amplifier module.

Three Stages—Preamp, power amp, speaker

The preamp contains circuitry responsible for shaping the guitar sound and delivering it to the second module, the power amplifier. In this stage, parameters such as gain, bass, mid, treble, and volume can be controlled by the user with knobs found on the casing. The circuitry in a preamp that allows it to do so contains transistors configured in a common source topology. In contrast with the preamp, the power amp module contains *two* different amplification stages, configured as a common emitter and a common collector in series, to be able to amplify the signal with a voltage that is high enough to output. This amplified signal is then routed to the third module, the speaker. In this stage, the speaker turns a largely-noiseless, amplified signal output into audible sound. It does so by feeding the signal into a wire coil, which allows the soundwaves to propagate via compression and rarefaction into a speaker cone. This propagation produces sound because current accumulates in the coil and the coil becomes an electromagnet, whereby its magnetic polarity flips as the current alternates. However, its actual polarity is fixed, so it alternates in attracting and repelling the coil, causing the coil to vibrate. Being that it's glued to the cone, the cone produces sound waves.

Use in Project

Integrating the guitar with the audio interface proved to be challenging. This is because while we needed the audio interface to output the final, digitally-altered signal, we also needed the audio interface to feed the input signal into the System-on-Chip and the ADC (connected in series). This was so that the signal could be altered with a distortion effect, for example, in a digital setting. The signal was then routed to a DAC to convert the signal back into an analog signal and output it once more into the audio interface, so that the sound could be played through the internal speaker.

Conclusion

Multistage amplifiers offer better amplification with the overall output gain amounting to the product of the three gains in each stage. On top of an improved gain, they offer better performance with a high input impedance, high linearity, improved bandwidth, and a lower output impedance. The *Focusrite Scarlett* was chosen because it satisfied all of the aforementioned requirements and allowed all inputs and outputs to be centralized and contained in one module.

References

1. Hunter, Dave. "The Anatomy of the Pickup." The Guitar Pickup Handbook: The Start of Your Sound, Backbeat Books, New York, 2008, pp. 24–48.

2. Nicholas G. Horton & Thomas R. Moore, "Modeling the magnetic pickup of an electric guitar," American Journal of Physics 77, (2009): https://doi.org/10.1119/1.2990663

3. Paiva, Rafael Cauduro Dias de et al. "Acoustics and modeling of pickups." Journal of The Audio Engineering Society 60 (2012): 768-782.

4. Sunnerberg, Timothy Douglas, "Analog Musical Distortion Circuits for Electric Guitars" (2019). Thesis. Rochester Institute of Technology. Accessed from https://scholarworks.rit.edu/theses/10066

5. Wu, Ming C. "EE105 – Fall 2014: Microelectronic Devices and Circuits." Department of Electrical Engineering and Computer Sciences at UC Berkeley. A 3-Stage AC-coupled Amplifier Circuit , Sutardja Dai Hall, Berkeley, California