Theory of the Audere Noise Cancelling Preamp

Noise – everyone hates it but what is it and where does it come from?

To a player noise is just the humming, buzzing, clicking and hissing in your signal that you do not find useful.

When players complain about noise it means they are experiencing a problem with their signal to noise ratio. This often happens when the noise level stays the same but the signal gets smaller, the ratio decreases and the noise is much more objectionable. To give you an example, let's say you are at a really loud concert and your cloths are vibrating. Do you notice the person 20 feet away coughing? No. But if you are at a quiet acoustic event that same cough might be very annoying. It is the same absolute noise level is present but the 2 examples have a very different signal to noise ratios. You will always have some noise (physics assures it) but when your signal to noise ratio is large – it is not a problem.

So how do we define a large ratio? A bel is 10x the power level. Most music is measured in dB which is decibels or 0.1 bel. You would like to have at least a million to 1 ratio (or 60 dB) of the signal power at its peak to the noise floor to have an "ok" recording. Now a million to 1 seems impressive, and it is, but the sound improvement at 10 million to 1 (or 70 dB) is very significant. The reason you need such a huge range of power is music normally includes loudness dynamics and the quiet parts still require the noise level low enough to be non-objectionable. If your style of music has few quiet parts then you might tolerate having a higher noise floor. For example, music on the radio is highly compressed to help reduce noise effects introduced by the transmission/reception process which is why the radio does not sound like a high quality recording of the same performance.

There are many ways to improve the signal to noise ratio commonly used in music. You can rely on a person working the mixing board to move the faders to optimize the situation. For example, they will move down the faders to help hide the noise when you are not playing. If the human on the mixing board is skillful and paying attention this works very well and has been used in countless studio recordings. This process can sometimes be automated by hardware with some success; a noise gate is a switching system where the signal from your bass would be muted (turned off) when the level falls below X dB. But noise gates have a nasty habit of burbling in noisy environments where there is not a lot of room (in dB) between the noise floor and the control level. A better and more expensive solution is to use an expander. The expander also has a set point like a noise gate but when the signal falls below the control level the output is gained downward by a selected ratio. As an example, if you set the control level at -70 dB and the input is at -80 dB and the expansion ratio is 1:2 then output would be -90 dB. An expander will not burble like a noise gate but I wish they had 'soft knees' which are not a common feature. Note in a DAW environment you can make this work better by setting up side chains with frequency filtering etc. but it is a lot of work.

It is always better to fundamentally reduce the noise issue before adjusting fader levels to work around it. This paper presents a better way forward to actually lower the noise.

The Noise Source and Coupling Mechanism

Two things must occur to have a noise problem – there is a source of energy and a method for this energy to interact with the target.

Often we cannot get rid of the noise source so a common way to mitigate the problem is to break the coupling mechanism. In our first example with the coughing person, if we take this person and put them in a sound proof room which will absorb the acoustic energy (sound) traveling through the air – we will not care about their coughing anymore even in a quiet environment. A music studio will have multiple sound proof rooms for this reason. But acoustic energy traveling through the air is not normally a significant problem with an electric bass or guitar.

The more common problem is we couple to electrical energy travelling through the air which is received by the pickups. The source of the interference (electrical energy) could be your computer, the air conditioner, the power supply in your amp, the stage lights or that blender in the bar. In reality the noise problem could be created by all of these and more, each contributing different amplitudes, frequencies and coming from different directions.

This electrical interference contains both an electric and magnetic field. Both can couple to your system but normally only one of these types of fields causes the vast majority of our problem.

If the noise problem is created by the electric field then the noise can be greatly reduced by inserting a grounded shield in-between the noise source and the receiving pickup. The shield breaks the coupling mechanism (the electric field drops to 0) so this type of noise problem is relatively easy to defeat. For a simple real world music example, have you ever noticed musicians with their hands on the strings in between songs to reduce noise? This is a common situation where an electric field interaction would create a problem if their hands were not on the strings. To reduce this potential problem we recommend you shield and ground your pickup cavities. See our FAQ section for more information.

If the noise problem is created by the magnetic field it is harder to fix and this is the type of problem we are addressing with our noise cancelling preamp. Unlike with the electric field, shielding is not a practical solution to a magnetic field issue at these low frequencies as it would take an insane amount of steel. The more common engineering technique is to make the magnetic field flow around the receiving node but this approach is also not practical in the case of an electric bass or guitar. So breaking the coupling mechanism is not going to work.

Sometimes the solution to a problem is to put a system into a balanced condition. You experience this every day but do not even notice it, the atmosphere is presently applying about 21 tons of force on the outside of your body but it is in balance so you do not care.

Cancellation can be used to reduce our noise problem by putting the system into more balanced state, this is the principle that humbucker pickups have used for almost 60 years – a copy of the noise is collected and mixed back into the original signal to reduce the noise. So let's look at humbucker pickups. There are three common styles to consider.

Traditional Humbucker

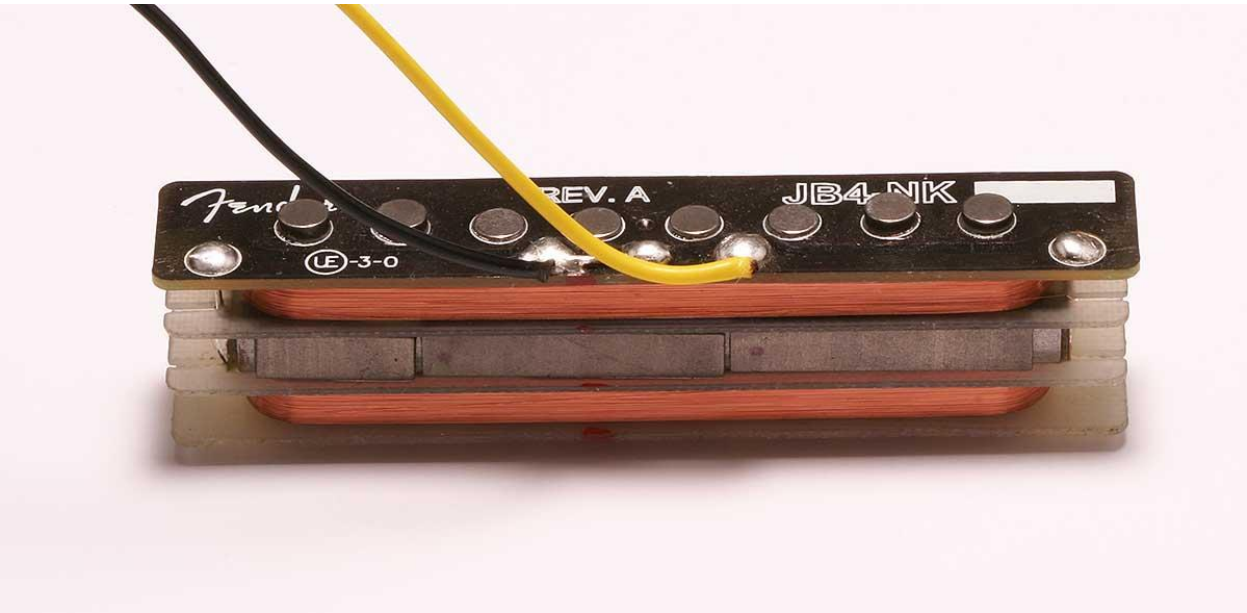
These Pickups have 2 coils placed next to each other along the string path - the 2 coils are wired in the opposite phase and the magnetics in the coils are reversed. If you think these pickups look like 2 jazz pickups glued together that's because this is often how they are constructed.

Any external noise source would be added together out of phase thereby cancelling, while the signal from the strings vibration is doubled resulting in a better signal to noise ratio. These 2 properties made them especially popular with rock players – plenty of signal power to distort the power amp and significantly less noise. However there is a tradeoff, the string's vibration is now sensed along a longer section of the string and this changes the sound produced by the pickup, effectively removing some of the high frequencies which many players want in their output.

Since so many players are looking for the original single coil sound, several alternative configurations of humbucking designs were developed to reduce the length of string sensing.

Vertically Stacked Humbucker

These pickups use 2 coils placed one on top of the other.



The 2 coils are wired out of phase with each other and might or might not have equal windings. Depending on the magnetic system design the bottom coil may add a significant volume to the strings response but often is assumed to be non-sensitive to the string's vibration.

The noise cancelling theory is that the external magnetic field passes through the top and bottom coils and cancels due to the inverted wiring.

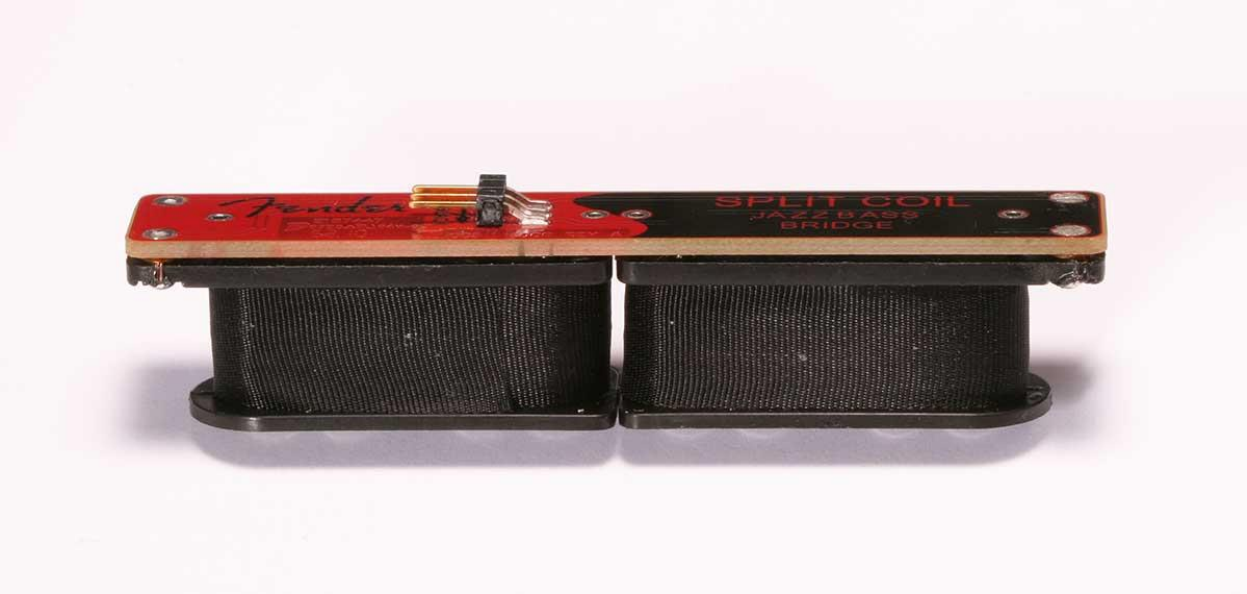
One Issue with this pickup configuration is the top coil structure shielding the bottom coil from sensing the external noise source. Another issue is the decreased coil height changes the pickups inductance and thereby it's sensitivity and frequency response plus the magnetic structure modifies the response of the pickup to the string's vibration.

Due to their touch response and sound tradeoffs this style of pickups is not viewed as very desirable by many bass players.

The world's major bass manufacture has changed the magnet type 3 times on this style of jazz pickups. Maybe the 4th revision will sound closer to their single coil pickup which is their stated goal.

Side by Side Humbucker

These pickups use 2 coils placed next to each other but across the strings.



In the case of a 4 string bass the E & A strings share one coil and the D & G strings share a 2nd coil. The magnets and winding in the 2 coils are reversed.

The noise cancelling theory is that the same external magnetic field passes though both coil sets and is cancelled by the out of phase coil wiring.

Issues with this design include the magnetic field reversal in between the 2 coils, which greatly reduces the string's response in this region. The magnetic wire size must often be decreased to fit 2 sets of coil wraps in between the magnets in the center area where the coils meet or the number of wraps must be reduced – either technique changes the pickup's sensitivity and frequency response. These pickups tend to work much better in basses with an even number of strings. When an odd number of strings are used on a bass (aka the popular 5 string) then the coils are different sizes (unless the pickups are made artificially wide) which negatively affects their ability to cancel noise which often drops to around 12 dB.

While it is not a exactly like a real single coil – IMO the above Fender 4 string jazz pickup (model Super 55) is much better than any of the stacked Fender Noiseless pickups.

It should be noted; when this pickup arrangement is not forced into a straight line the tradeoffs can be reduced. The modern P bass pickups are a good example. The 2 coils can be optimized without the size constraints and for the odd number of strings the 2 coils are more often constructed with the same coil area to pickup equal amounts of noise for cancelation. The tradeoff is the strings must now be sampled at different distances from the bridge which will change the sound so it will not sound like a traditional jazz pickup.

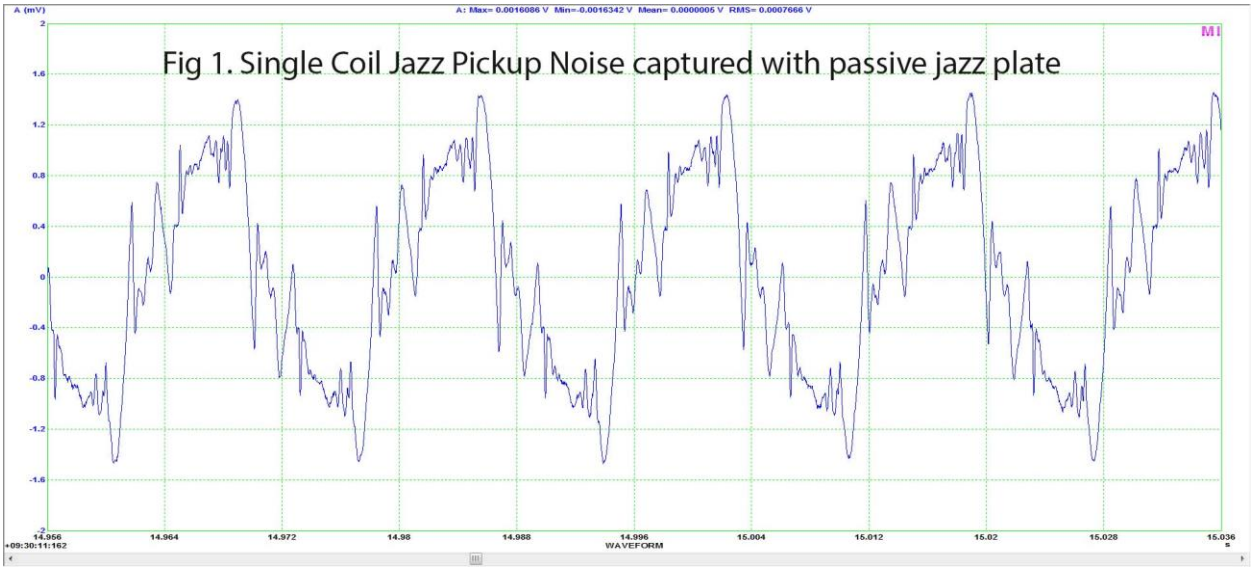
A Better Way

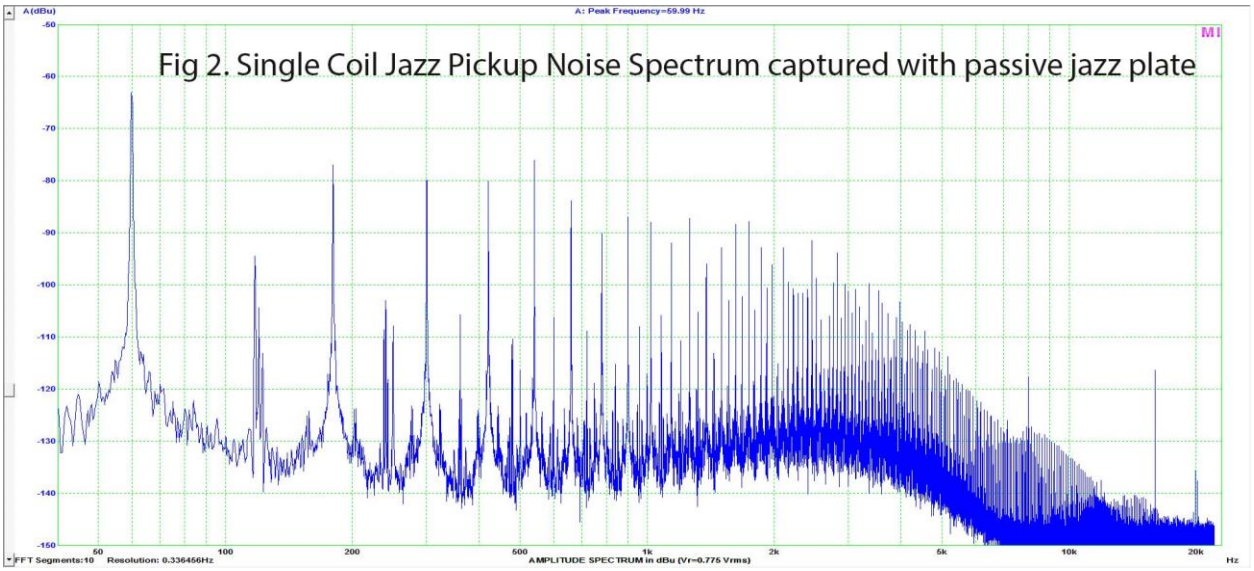
Pickup makers of the Vertical Stacked and Side by Side Humbucker designs all argue about whose design is the closest to a real single coil pickup sound - the gold standard. But all these humbucker designs have negative tradeoffs which is why many professional players still have basses with single coil pickups. They need that tone.

So the obvious question for Audere is:
How do we design a preamp which could reduce the noise problem while still allowing players to use the single coil pickups they love?

Step 1 was to collecting real data to understand just how hard the problem would be to solve.

The following waveform and spectrum graph is the noise collected by a typical single coil pickup using a passive plate in a fairly low noise commercial location with the bass point in a lower noise orientation.





This looks ugly! The traditional hum bucker was designed 60 years ago and did a good job at cancelling 50/60 cycle power line noise and the first few overtones which were the main problems at that time when the number of significant overtones were limited due to “soft” tube diodes.

Today a player must deal with many more overtones of the power line and other high frequencies that are generated by switching power supplies etc. We needed to cancel the noise at both low and high frequencies.

After looking at this frequency spectrum we realized that a filtering scheme was not going to work. It is easy enough to build a comb filter to hit the fundamental and all the overtones but the phase effects would make it sound awful. A filter can be made with a Digital Signal Processor to remove the phase problems but the delay would be way too long for most players to deal with.

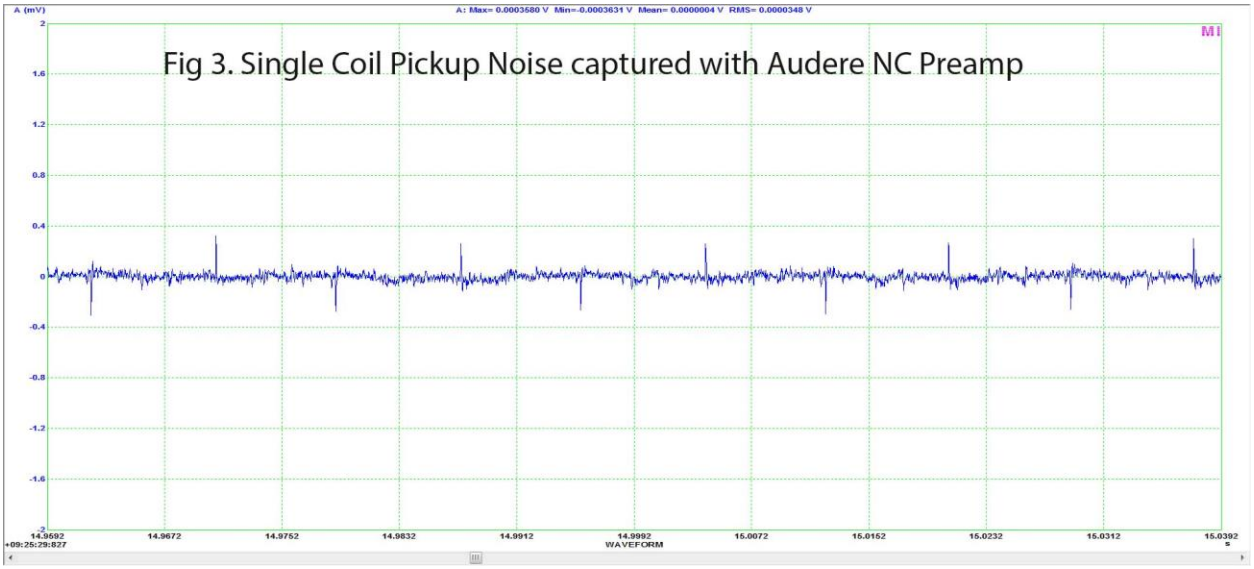
So the preamp solution would have to be a noise cancelling design like used in a humbucker pickup but without the negative tradeoffs.

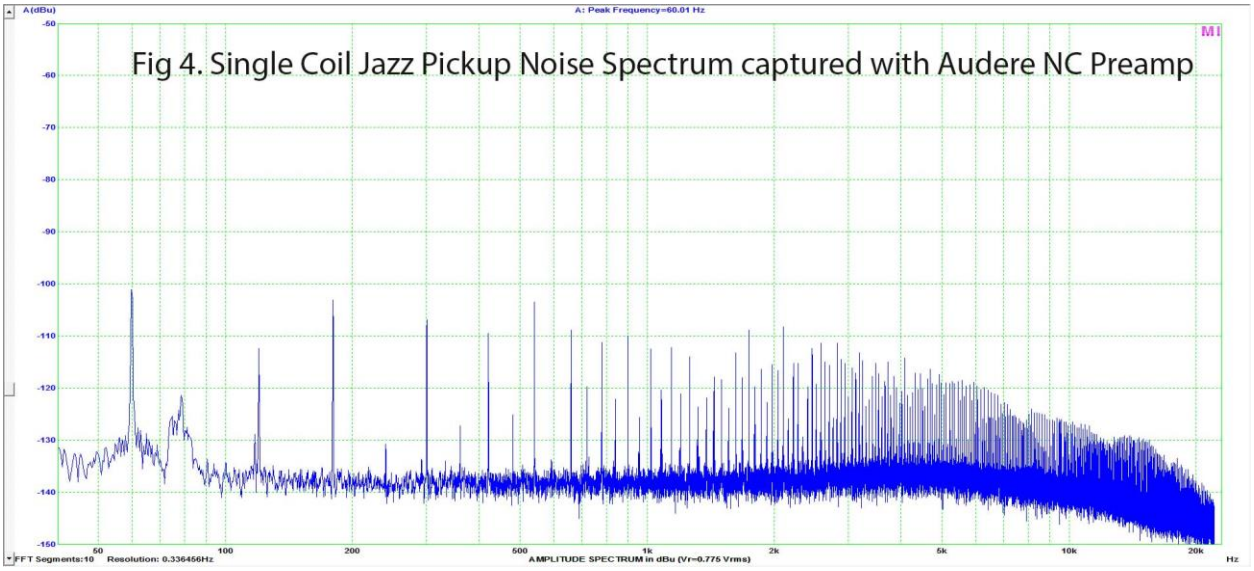
The next problem is that space is very limited and some of it is not ideal. Luckily most current Fender Jazz basses have a routed wire path way in between the electronics cavity and neck pickup under the pickguard.

The goal was to develop a cancelling coil which was much smaller than a normal pickup to fit into this routed wire pathway which could cancel the noise from most types of single coil pickups across a wide range of frequencies and include it with the preamp for a price players could afford – gulp.

Happily it worked but it definitely was not easy!

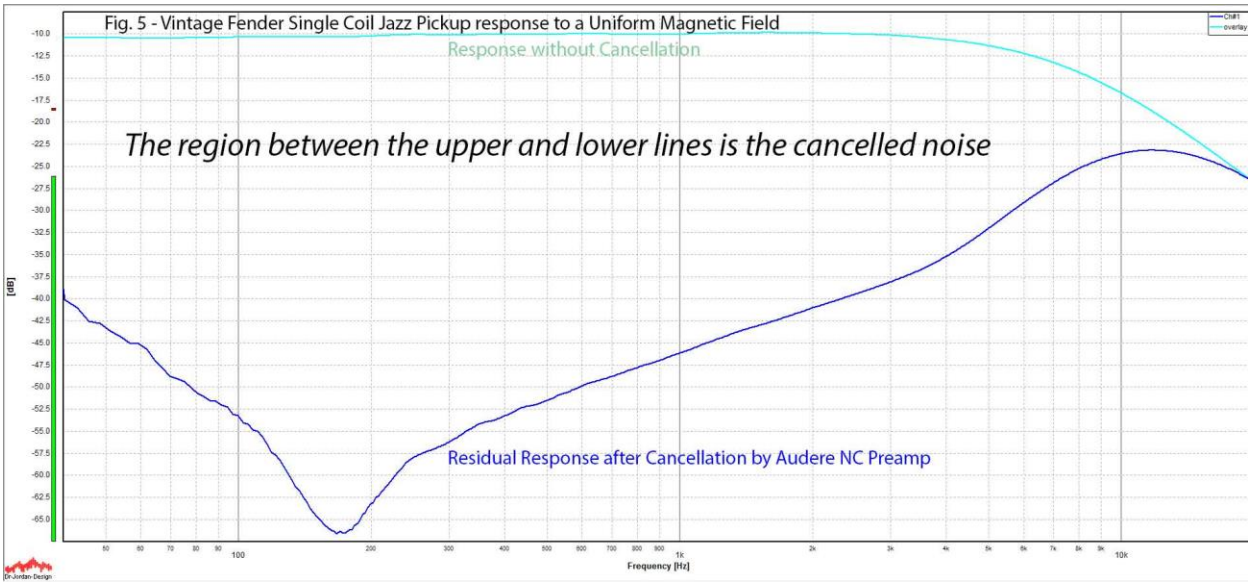
The graphs below are from our new preamp using the same bass and acquired in the same real world setup as figures #1 and #2.





As you can see the reduction in noise is large and this is not just "hum" cancelling. At **www.audereaudio.com/Audio/Audere_NC_Pre_Intro.mp3** is a sound clip as opposed to an engineering graph – ideally listen to the clip using closed ear head phones.

In the real world the noise you get at any location, orientation and point in time varies which makes development and testing hard so we created a uniform magnetic field test bed. The graph below shows the noise reduction for a vintage Fender Jazz pickup assuming you had a noise source creating a uniform magnetic field (i.e. a magnetic field which passed though the pickup and cancelling coil equally).



Remember that 10 dB is 10 times the power – so each 4 horizontal graph lines are 10x the power level. The top teal line is the amplitude of noise collected vs. frequency for this Jazz Pickup. The Blue line is the residual response after the cancellation by our preamp. Lower on the graph is better for the blue line but what is important is the difference in between the 2 lines.

This pickup is getting close to 100,000 to 1 power reduction at the 2nd and 3rd overtones of the power line which are more obnoxious to your mind than the fundamental. At 1 KHz the cancellation is falling but you are still getting better than 10,000 to 1 power reduction. You can work out the rest of the numbers at any frequency but the system is reducing the noise very effectively!

Again this graph was for an ideal condition which only exits in our engineering test bed – so how does it perform in the real world where you might record your bass performance?

If you take the noise peaks in Fig 2 and calculate the differences in between theses peaks and corresponding peaks in Fig 4 then you can calculate the level of noise reduction – for example:

Frequency	Harmonic of the power line	Cancellation in dB
60	1 or fundamental	38
180	3	26
300	5	28
540	9	26
1020	17	24
2100	35	15
3900	65	13

As would be expected, the real world performance is reduced by the multiple noise sources which are located at different amplitudes, distances and directions. There are no 40+ dB reductions in the table and above about 4 KHz the passive pickup can no longer drive the cable plus preamp input used to capture the data with full response so it's hard to calculate the noise reduction.

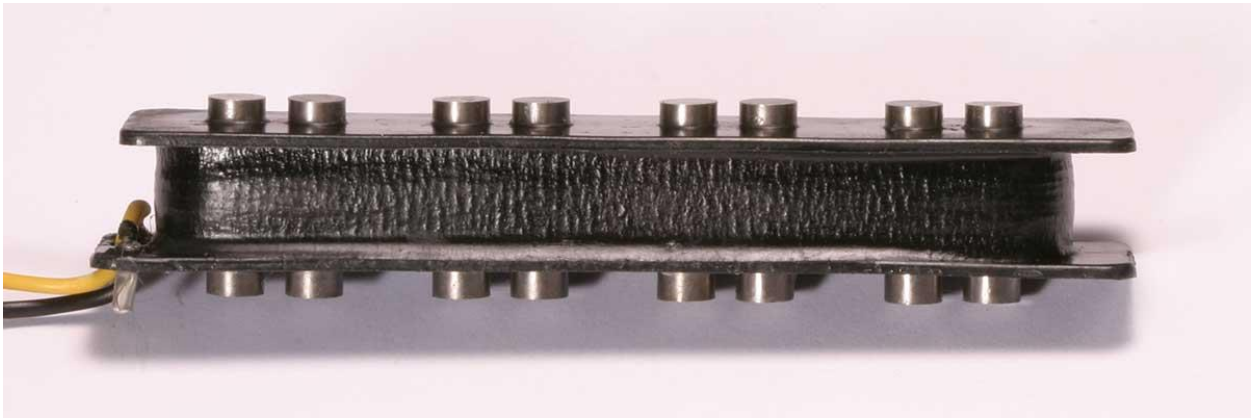
But the real world performance is still amazing which is what you heard in the sound clip which in case you missed it is at **www.audereaudio.com/Audio/Audere_NC_Pre_Intro.mp3**

So our noise cancelling theory is that the same magnetic field passes through your jazz pickups and our small noise sensing coil and we can make the small coil respond exactly like the much larger pickups in both amplitude and phase response.

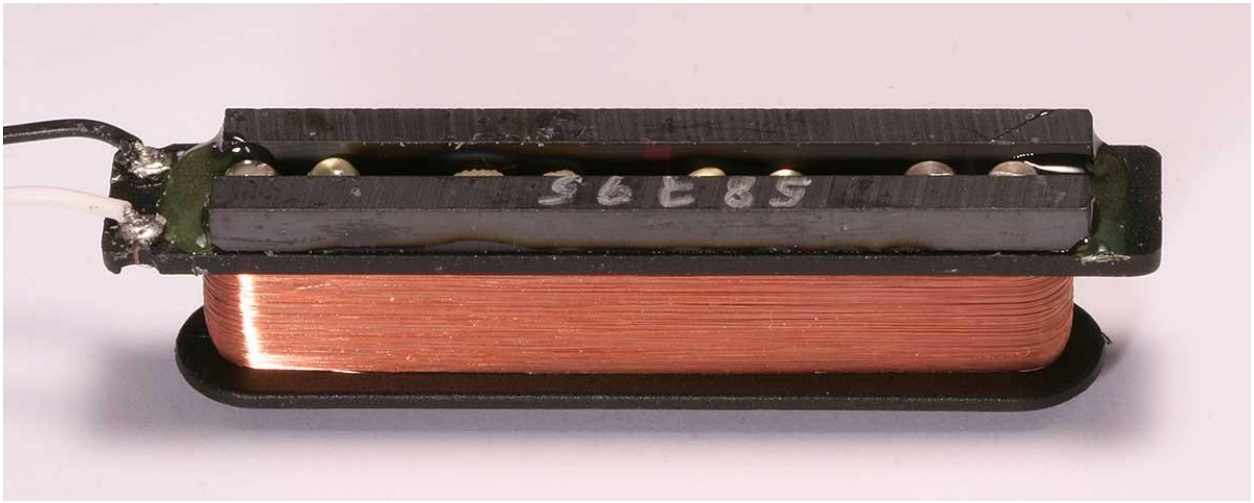
Does it work with most pickups?

As you would expect, pickup makers optimize their designs to sound as good as is possible. They all have different ideas as to what makes the best sounding pickups.

Some pickups are designed with a very short coil while others employ a very tall coil:



These 2 Fender pickups share a lot of the same parts but the top one has AlNiCo magnets while the bottom employed ceramic magnets with steel pole pieces:



Most ceramic pickups and the pickups containing the rare earth magnets (samarium cobalt or neodymium) use steel pole pieces, sheets or bars to control the shape of the magnetic field. In the common configurations this steel also causes the pickups to collect more noise than AlNiCo pickups.

Some types of variations are not easy to see in a picture. For example, Pickup type A will use a winding pattern where the wire is placed down very uniformly while Pickup B will be scatter wound. Pickup C will have the hot on the outside of the coil while D will have the hot on the inside. Or a pickup might include various configurations of copper shielding wrapped around the coil, or change how the pickup is potted, etc.

All these construction details and more affect how the pickup collects the external noise.

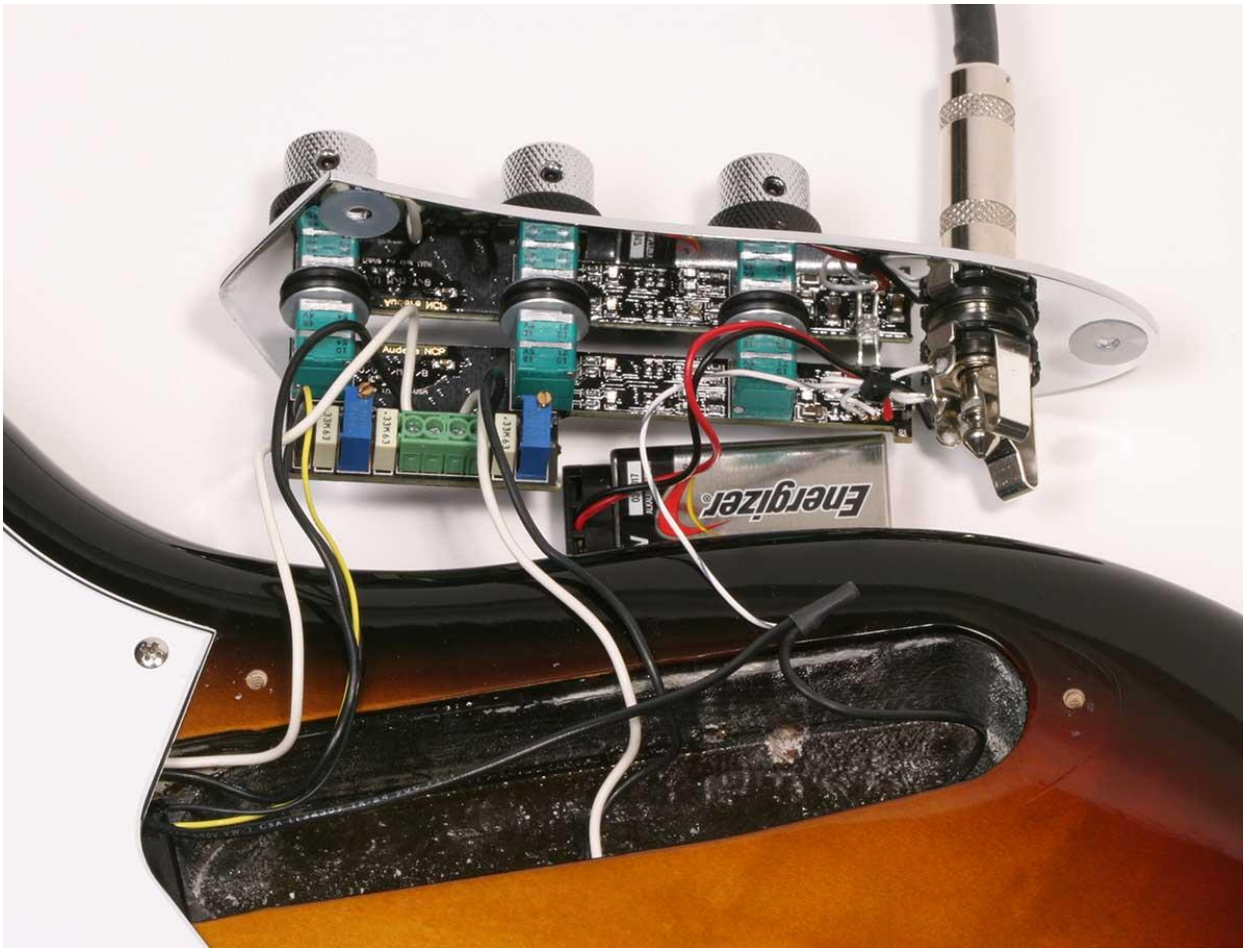
To account for the different pickup types we designed many different types of noise sensors (almost every pickup type required a unique sensor) – 32 versions of the noise sensors have been developed as I write this. We support 20 Fender pickup types, 9 Nordstrand types, 7 Seymour Duncan types and selected other single coil types.

We also needed gain adjustments to allow for the inconsistency in the pickup manufacturing and other effects like the angles of the pickups and noise cancelling coil to obtain the high levels of cancellation we desired.

While we cannot reasonably support all single coil pickup designs, our system is flexible enough to cancel the noise for the most of the popular styles of single coil pickups without decreasing their touch response or changing their tone.

A lot of development effort went into making this work, for example, we had to design unique custom measurement equipment and acquire an amazing number of measurements on different pickups. The noise sensors use different sensing coils created on a computer controlled winding machine to match, by pickup type, the amplitude and phase response across the frequency range.

Quick overview of the design:



The preamp front end signal path is a stereo design. Each pickup input has a dedicated signal path. The noise sensor signal is processed as a 3rd input and does not compromise the sound of the pickups. The noise sensor's gain is adjusted independently for each pickup by 2 trim pots. These trim pots are each 20 turns going from the max positive gain through 0 to the max negative gain (i.e. inverting the phase). Adjusting these pots for noise cancellation is easy:

1. Set the preamp tone controls flat (for active controls this is in the center detents)
2. Configure the preamp with the dual volumes or the balance control so that only the neck pickup is active
3. Rotate the neck pot to the right
4. When the hum gets louder then reverse direction
5. Stop at the minimum level
6. Next configure the preamp controls so that only the bridge pickup input is active
7. Rotate the bridge pot right, left and stop at the minimum level.

   Note - during the adjustment procedure you may have to increase the gain of your power amp to offset the drop off that occurs during the pot adjustment.

After the noise is cancelled for each pickup – their signals are mixed together by the volume / volume controls or the balance control – this mixing system is active. Active pickup mixing allows many more additional usable sounds from your pickups than the traditional neck pickup, both pickups, and bridge only settings. We suggest that you experiment with this feature to understand it's potential. We also recommend that you try moving just slightly off center for your "center" setting as this sounds better with many of the pickups we have tested and there is now no longer a noise penalty for doing this.

Next the signal path flows into the tone control subsystem which can be 2, 3 or 4 bands of active tone controls. The tone controls are flat in the center detents and offer a slow modification during their initial rotation to give you more control. The frequency points and ranges of the tone controls have been optimized for each control configuration separately using unique circuit board designs.

After the tone controls the signal path flows through a master volume (in the volume balance configurations) and into the cable driving system which drives your external power amp. The output will drive any type of cable and most types of power amps with the full range of frequencies from the pickup from 5 Hz to 20 KHz.

For the passive players who do not want a preamp we offer designs featuring Volume, Volume, Tone or Volume, Balance, Tone control sets. The Tone cap is located in gold sockets and can be changed as desired. The tone cap is located after the noise cancellation system but is designed to be a very good emulation of the effects of a tone pot in a passive plate. The output cable drive has been designed to make these units sensitive to the loading effects of cables and what you plug into next, like occurs in a traditional passive plate. In other words these units have been specifically designed to behave as close as possible to a passive plate but with noise cancelling.

All versions include a simple battery power LED meter. If the LED lights for more than 0.1 second you are good to go and a longer length of initial LED flash indicates a stronger battery.

If you change your pickups then you can replace the noise sensor assuming we have developed a matching noise sensor for your new pickup type and that you can solder the wires to the terminal posts. The system also works well for a bass with only 1 non cancelling pickup – like a PJ configuration where the P is humbucking but the J is noisy.

If you want to hear an audio sample of the preamp's performance (short version of previous sound clip) **www.audereaudio.com/Audio/Audere_NC_Pre_Short.mp3**

As a player all this technical stuff maybe interesting but the bottom line is you are getting the real touch and frequency response of single coil pickups but you lose the vast majority of the noise and get all the flexibility of a superior quality system at an unbeatable price.

Choose your favorite type of single coil pickups and enjoy…