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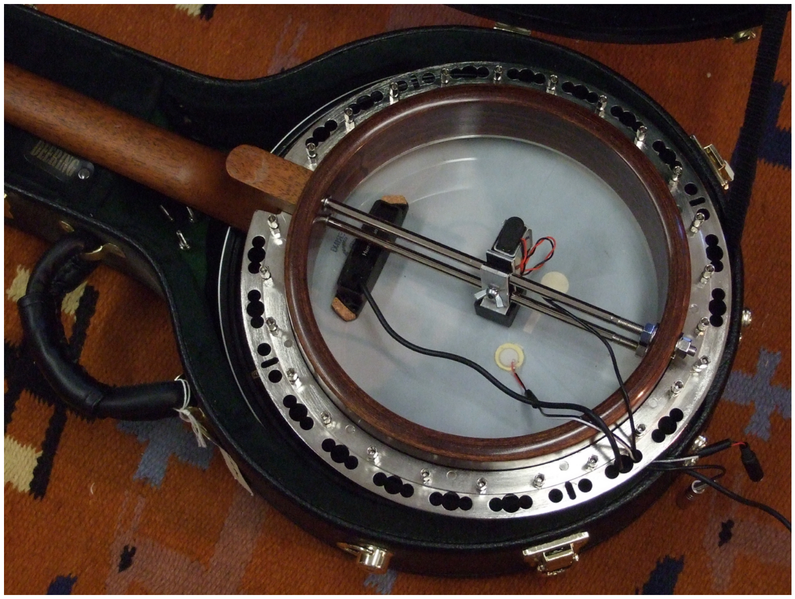

A Banjo Pickup Alternative $\mathcal{AND}$ Trying to Understand Pickup Feedback and Tone — a fool's errand

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(If I were a Lab *with a* Research Group, *this would be an* Internal Report, *just to remind me what I did and learned — perhaps someday to return and do better — or maybe someone else will. Most people who have to deal with this stuff already know a lot more. So it will be more offensive than usual to some but more useful to others.)*

Armed with the rudimentary physics of pickups and feedback, I thought I could make some sense of people's varied experiences and impressions. So I tried a variety of alternatives under controlled but necessarily artificial circumstances. It was frustrating, and the best I can conclude is, "...it depends..." On the other hand, I thought of a novel or at least not routinely mentioned alternative that is relatively inexpensive (i.e., \$30 to \$50 total), is not too feedback-prone, and delivers a vaguely banjo-like sound: a rare-earth guitar sound hole pickup mounted just by the rim used with a very light (e.g., 1.7 gm) bridge.

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FIG. 1. something to try: a rare-earth sound hole pickup double-sticky-taped inside the head, as close to the rim as possible, with a lighter than "normal" bridge (e.g., 1.7 instead of 2.6 gm). Pickups mounted to the bottom of the head show through; paint it white before attaching, if you don't want it to show as much.

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A good microphone, appropriately placed, can capture much of the sound of a banjo. Not surprisingly, intense R&D for over one hundred years, fueled by prospects in one of the world's biggest industries, has produced designs capable of turning sound into an electrical signal which can then be played back with recognizable fidelity. Pickups are a different story, and different designs introduce their own characteristic effects, some linear (as might be described by a frequency-dependent transfer function) and some distinctly non-linear. Not everyone who plays banjo in a band is eager to pay $300 for a pickup, especially when you can buy something that "works" for around $5. This is an exploration of some possibilities in between. I report here the relative resistance to feedback of three different systems and also give a sound sample of each. Knowing the basic physics helped only a tiny bit because (totally understandably) feedback is an inherently non-linear phenomenon. Lots of situation-dependent details determine whether it grows into an undesired howl or stays relatively innocuous. Jimi Hendrix pioneered playing the howl as part of his music. At the other end of the music spectrum, all sustained notes as played on acoustic instruments (i.e., bowed strings, woodwinds, and brass) depend crucially on positive feedback just to make their sound. (You didn't know that?)

FEEDBACK COMPARISON

Susceptibility to feedback howl is certainly a more objective question than quality of tone. I designed a little test that I could do in my living room that might reveal relative merits. I tried many configurations and combinations, and there's really no end to possible variations, e.g., of positioning on the banjo and mounting materials. Here I record just three.

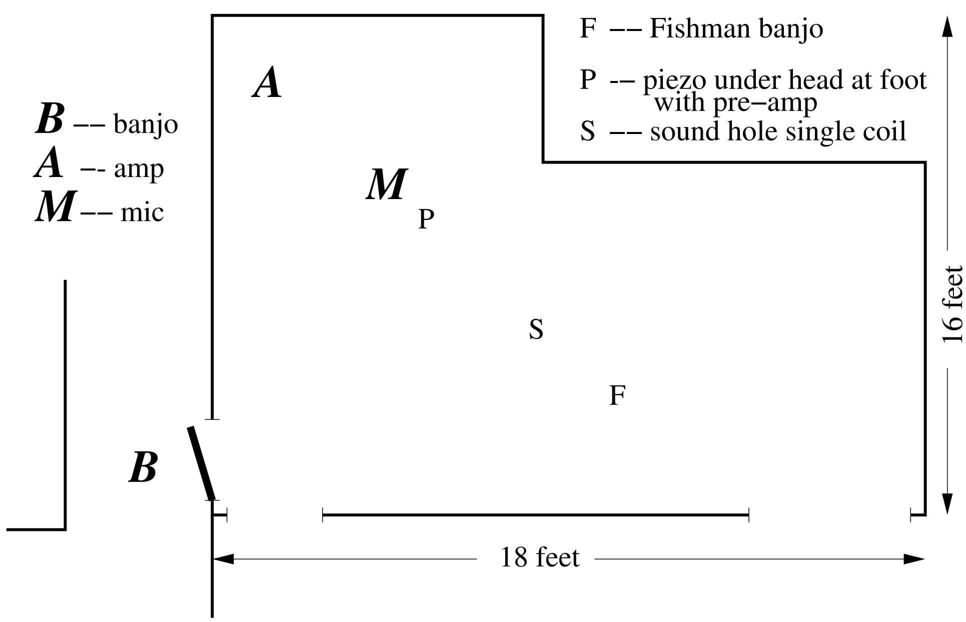

FIG. 2. approximate living room floor plan of banjo, amp, and mic locations and the furthest distance of feedback using the indicated pickup

FIG. 2 gives the floor plan. An small Fender tube amp (c.1995 Blues-Junior, 12″ speaker, 180W input), A, sat in the corner facing a microphone, M, placed 4′ away. The amp master, treble, mid, and bass knobs were all at their middle positions (and no reverb, no FAT). The banjo, B, was

FIG. 3. an inexpensive ($8 if you're patient), op-amp based, commercial guitar pre-amp, with volume control and a four channel equalizer

played in a hallway with the door closed. I adjusted the amp volume control so that the monitored sound level at the mic was the same for each pickup. Sound level was determined by a dB meter on my computer. Of course, that involves choices of time averaging and frequency sensitivity. I just picked something reasonable that gave a reproducible number for gentle, steady strumming.

With the amp volume set for the particular pickup, I brought the banjo into the living room and determined how close I could get to the amp before it would howl. Those places are noted in FIG. 2 for three pickups: the Fishman banjo pickup; a 3/4″ piezo disk attached under the head at one outer foot of the bridge and run through the pre-amp shown in FIG. 3; and a Fishman rare earth, guitar sound hole pickup attached beneath the head at the edge near the neck. Respectively, these are F, P, and S in the figure.

I chose to identify the loud howls as the feedback problem. If one stands still, there can also be much quieter hum, which is feedback that maxes out at a much lower level. The distinction is only qualitative, but I thought it relevant to make. The quieter hums also built up at a much slower rate. So it's not clear that they'd be very noticeable in a realistic setting with music and motion.

The amp-to-banjo distance determinations can be converted to loudness differences at the banjo using the measurements in FIG. 4. I played white noise through the amp at a fixed volume. I recorded the loudness in dB at the mic as I moved it diagonally across the room. That allows

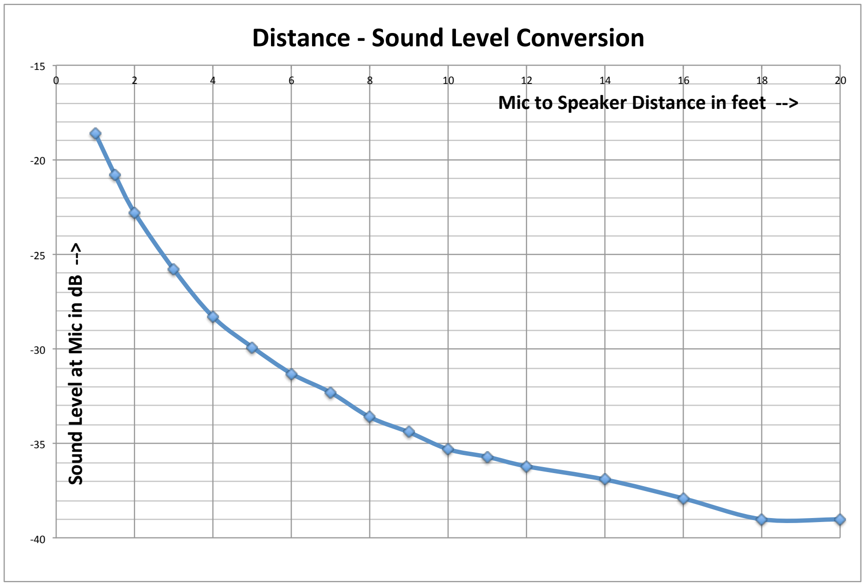

FIG. 4. The mic sound level of fixed speaker white noise as a function of separation, progressing diagonally across the room in FIG. 2. 18′ is getting close to the walls of a corner.

a comparison of the pickups of how loud it can get at the banjo before it feeds back a howl. In particular, relative to howl onset with the Fishman banjo pickup (a somewhat pricey [$200] but quality product), the piezo pickup with the pre-amp began to howl at about 5 dB lower ambient sound level, but the sound hole pickup howled at only about 1 dB lower. For the record, the same piezo straight to the amp, without the pre-amp howled at 11 dB lower than the Fishman banjo pickup. (I also tried wedging a piezo between a bridge foot and the head. Not surprisingly, the feedback was similar to placing the piezo under the head. The sound was a bit different (there's squeezing from both sides and not just the piezo's ineria), but the connecting wire was awkward. Touching it produced piezo noise.

PICKUP COMMENTS AND DETAILS

Note that a piezo attached anywhere but right at the bridge produced a howl just as I brought the banjo into the room. The head, itself, gladly sings along with any ambient sound. The combination of strings and head keep the bridge from moving nearly as much. So somehow that's a quieter place.

The Fishman steel shim is about 0.2 gm but is not directly under the bridge. The shim mass is likely of no consequence. However, its magnetic attraction to the pickup's permanent magnet depends on distance. So there is some distortion of string motion due to that position-dependent magnetic force — in addition to the non-linear relation of the induced voltage to the string vibration amplitude. My 3/4″ piezo disk is about 0.7 gm, installed directly under a bridge foot. That may well count as adding to the inertia of the bridge. Likely, an equal amount should be removed from the bridge feet to prevent effects associated with extra bridge weight, i.e., increased sustain, decreased volume, and weakened high frequencies. The sound hole pickup is substantially heavier, but it is installed far from the bridge and as near to the head edge as possible. The impact of its inertia on the total sound is expected to be negligible.

Useful types of 3M double-sided tape are"permanent," "mounting," and "indoor poster." "Removable" come off too easily. "Permanent" is the thinnest, and the one I used. "Indoor poster" is the thickest and provides a little cushion, though far less than a layer of hot gun or silicone glue. All are not that hard to remove from the surfaces in question but are reliable enough for long-term use.

Regarding sound hole pickups, the (passive) Fishman humbucker runs about $80; the Fishman single is some $40 or $50; other rare earth singles start around $30. The Fishman's come with a permanently attached 7′ cable. The humbucker is heavier than the single by 12 gm. On the other hand, more inertia means less feedback. The ad copy reads: "Warm & Full Humbucking Sound" *vs.* "Brilliant & Articulate Single Coil Sound." I went for brilliant and articulate but upgraded (for $10 more) to a "single coil humbucker." (I imagine that means that the coil has a humbucking configuration, but there is only a single set of magnet poles.) A further possible modification on the Fishman sound hole pickups: one can shave off about 3 gm by removing the mounting ears and, more significantly, about 1/16" off the "top" so that the magnets and coil are that much closer to the strings to give a stronger signal. (Caution: that top plate is bonded to the body, but it is not uniformly thick; you can only remove a bit less than half before exposing and ruining the guts.)

SOUND SAMPLES

For the following brief sound samples, I plucked with bare fingers. Again, the banjo was in the hallway, behind a closed door. The mic was 4′ from the amp. The amp settings were neutral, as before, except for the attempt to equalize the overall volume.

I've read some people's complaints that guitar-style magnetic pickups produce too much of an electric guitar-like sound. I didn't imagine how that could be because banjo string motion is majorly effected by the bridge and the head. The overall sustain is comparatively short, and the various harmonics far off in their individual banjo-like fashion. But the proof is in the pudding, and I could hear what those folks mean. I thought of a modification that goes in the right direction: a lighter bridge. I just grabbed the closest thing at hand: a S. S. Stewart-style 1.7 gm bridge, as appears in FIG. 1.

The sound samples are: 1) the Fishman banjo pickup; 2) the piezo under the head at an outer bridge foot with a quick guess at a reasonable pre-amp setting; 3) the Fishman sound hole pickup with a 1.7 gm bridge; 4) the Fishman sound hole pickup with a 2.6 gm bridge; and 5) the same piezo without the pre-amp.

1) Click or go to http://www.its.caltech.edu/~politzer/pickups/fish.mp3

2) Click or go to http://www.its.caltech.edu/~politzer/pickups/peizo-pre-amp.mp3

3) Click or go to http://www.its.caltech.edu/~politzer/pickups/soundhole-SSS.mp3

4) Click or go to http://www.its.caltech.edu/~politzer/pickups/soundhole-std.mp3

5) Click or go to http://www.its.caltech.edu/~politzer/pickups/piezo.mp3

TONE

When playing with other instruments, an essential requirement is that your banjo be heard. That's not just a matter of volume. The banjo sound has to cut through and distinguish itself from the rest. It's key characteristic is its sharp, high frequency attack. So I believe that preserving that characteristic is essential. Other aspects of tone — perhaps not so much.

You can buy a new violin for $100 and another for $50,000. Both can be played in tune, but most people can discern a difference in tone. Where's *your* price point? (You can get a piezo disk for as little as $1; a 1/4″ guitar female jack (jill?) or socket for about $1.)

The Fishman banjo pickup is not simply a passive magnet-and-coil inductive device. It runs on a 9 volt battery. Presumably, at $200, packed into its small body is balancing circuitry that contributes to its fairly convincing sound.

A magnetic pickup on a guitar doesn't sound like an acoustic through a microphone. Nevertheless, solid body electrics became the sound of rock 'n' roll.

In Jim Mills' 2014 interview with J.D. Crowe (https://www.youtube.com/watch?v=g4fxjdjYwwA) a discussion of heads begins at 21:35 and specifically plastic heads (introduced in 1959) at 23:10. Mills says, "You were one of the earliest guys to change over," to which Crowe adds, "and I hated to." He said he put it on and thought,"Oh, no... I don't know whether I'm gonna like this or not..." He didn't, but practical considerations won out over tone. Within a decade, mylar became the sound of bluegrass banjo. Few amateurs today would consider anything else in their quest to sound like their heroes.

People do not all hear the same way. This became obvious to me when sufficient high frequency hearing loss prompted getting some high-end hearing aids, which are programmable and adjustable. Furthermore, anything that you "hear" is a mental construct, albeit based on sensory inputs. For example, pitch is not frequency, and volume is not acoustic power. They certainly have some relation, but it depends on the individual, the situation, and many, many other details. The details of tone perception and distinctions are particularly sensitive to individual neurobiology. If this is not obvious, read Dan Levitin's fine book *This Is Your Brain on Music.*

Most banjo players care *a lot* about the tone of their banjo. It is not so clear that their audiences share that obsession. I'm pretty sure that musicianship (intangible but real) trumps tone and even virtuosity in terms of making connection with listeners.

RUDIMENTS OF PICKUP PHYSICS

Piezo electric materials produce a voltage if distorted and *vice versa.* (They make dandy motors, e.g., for scanning-tunneling microscopes, atomic force microscopes and for bending telescope mirrors for adaptive optics.) The voltage is produced literally by the slight rearrangement of the atoms. The materials are typically insulators; they do not conduct electricity. Distortion of the piezo material clearly occurs when a piezo disk is placed between a foot of the bridge and the head and a string is plucked. Piezo distortion and voltage also arise if the piezo is attached to a vibrating surface. (That's a contact microphone.) The piezo is an elastic medium, and it has inertia. Think of a piece of jello on a plate. Accelerate the plate upward, and the jello gets a bit squished in the vertical direction.

The voltage produced by the piezo is somewhat analogous to water pressure in a pipe when there is no flow. If it's just a short section of garden hose, when you open one end, it shoots out, but there's not much water in total, and the pressure quickly drops. The analog statement is that the piezo cannot source a significant amount of current. Connect it to something that can absorb current, and the voltage quickly drops. Just what actually happens depends on a lot of things.

A pre-amp can handle this, i.e., take the piezo voltage and produce substantial current at that voltage, i.e., to drive a regular guitar amp. The cheapest, crudest pre-amps just have a single op-amp (operational amplifier). Hooked up appropriately (in a circuit that relies on *negative* feedback), op-amp pre-amps are ideal — at least to a theoretical physicist. They let essentially no current in at the input and can put out current at that input voltage (or very simply amplified), limited in power (volts times amps) only by the power also supplied to the pre-amp.

Magnetic pickups work curtesy of Michael Faraday (1831). A permanent magnet in the pickup magnetizes some vibrating material. With a guitar pickup, that material is a portion of the string; in the Fishman banjo pickup, it's mostly the steel shim attached to the head but also, to a lesser extent, the strings themselves. When that magnetized material moves in the vicinity of a coil of wire, a voltage is generated between the ends of the wire. The power required to source current at that voltage comes from the vibrating magnetized material. Guitar pickup coils typically have 8000 to 10,000 turns because the end-to-end voltage is proportional to the number of turns, and that's what's needed to get a passive magnetic pickup (i.e., with no energy source of its own) to produce something like 0.1 to 1.0 volts.

The magnetic pickup induced electrical signal comes from the *relative* motion of the coil and the vibrating magnetized material. With a sound hole pickup stuck to the under side of the head, head vibration also contributes to the signal. It averages over separate string motions and is insensitive to head motion wavelengths shorter than its own size. Nevertheless, there's something there, in principle.

FEEDBACK

Positive feedback allows energy to be pumped in at a frequency that is initially innocuously small. The rate of increase of the signal is proportional to the signal's strength. That's a recipe for exponential growth. It can't continue to grow indefinitely. Some other consideration always limits it. Typically there is a final balance at some amplitude. How large that actually is depends on... lots of stuff. Getting started in a substantial way also depends... Roughly speaking, then, there are three phases of feedback evolution. With lots of other things going on, the amplitude of the particular, dangerous resonance may or may not ever get above the level needed to really get going. Other influences might intervene. The real context is a live performance, with people, hands, and sounds on the move. A given feedback possibility will have a characteristic doubling time. In a realistic situation, a howl results only if that time is relatively short. Otherwise, again, other factors may intervene. And the saturation level, which is determined by a great many competing factors, may or may not be objectionable.

In the specific case of an amplifier feeding back to a banjo, positive feedback requires that the amplifier's sound arrive at the head in phase with the head motion at that frequency. Move half a wavelength associated with that frequency and the feedback becomes negative and gives cancellation instead of growth.

BANJO SOUND

Banjo sound, i.e., the thing that gets to your ears, does not come from the strings. They do not really vibrate any air; they force the bridge which, in turn, moves the head. What you hear is not the vibration of the head either but, rather, the sound that the head vibrations produce. Frequencies and regions of the head are not equals in this process. For example, the highest frequencies come preferentially from near the edge of the head. The physics origin is that those regions have fewer counter-vibrating neighbors than regions in the interior of the head. And adjoining counter-vibrating regions radiate sounds that tend to cancel one another. That's why pot-stuffers tuck their sponges or socks where they do. I wrote previously how damping that region can reduce much of the ping of a taut mylar head (http://www.its.caltech.edu/ politzer/ — see MARCH 2017: DYI Mylar Flange for a More Mellow Banjo Head).

A microphone can pick up the sound radiated from near the edge. A magnetic pickup, which is only sensitive to the string motion, does not get the balance of frequencies characteristic of the total radiated sound. A pickup that is sensitive only to the motion of the bridge likewise misses the unamplified acoustic balance. But a surface contact mic mounted near the edge of the head courts serious feedback. I guess you take your pick and steer a path between Scylla and Charybdis.