String Sing-Along (Sympathetic Vibration) Is Not the Key to Banjo Sound

David Politzer*

(Dated: April 10, 2019)

Among instruments that do not sport explicit sympathetic strings, banjos produce particularly strong sympathetic and other secondary sounds arising from interactions among the melody strings. That certainly contributes to the characteristic timbre and is easily demonstrated and explained. However, a sampling-synthesis experiment suggests that it is not an essential feature of what distinguishes banjo sound from other acoustic, plucked instruments.

* politzer@theory.caltech.edu; http://www.its.caltech.edu/˜politzer; Pasadena CA 91125

String Sing-Along (Sympathetic Vibration) Is Not the Key to Banjo Sound

THE QUESTION

Banjo strings like to "sing along," i.e., resonate with each other, given the chance. Actually, a string disturbance on any acoustic instrument will travel down the string to the bridge, cause the bridge to move, and create disturbances in all the strings. All these motions effect the produced sound — at least to some degree. "Sympathetic resonance" usually refers to the case where the frequency of one of the resonances of the plucked string matches (or is very close to) one of some other string's resonant frequencies. Energy transfers back and forth between the two over many cycles. Less common with other instruments but sometimes discernible on a banjo is when the initial bridge motion from a vigorous pluck is enough to noticeably excite all the other strings, irrespective of frequency.

Compared to other string instruments, the banjo's bridge is relatively light, and the sound board (i.e., the head) is relatively flexible. This makes the plucked banjo relatively loud and of short sustain. But these design features also enhance the "singing along."

Could this singing along be one of the essential aspects that make the sound of all banjos recognizably distinct from other plucked instruments and identifiable as banjos?

The basic phenomenon is easy to demonstrate and understand. I devised a simple experiment to test its relevance to banjo-ness. And the answer seems to be no. With a DIY version of sound-sample synthesis, I compare a short musical phase with and without other strings singing along with the plucked string. The sounds are very slightly different, but neither is more or less like a full banjo.

SINGING ALONG

As a simple example, in double-C tuning (gCGCD), here are three plucks of the low G string:

hear three G's

or go to

http://www.its.caltech.edu/~politzer/turkey/3Gs.mp3.

The first is a pluck with all strings open. The second is the same sort of pluck of the G string, but all the other strings are damped. The third pluck features all strings initially open, but, after about half a second, the plucked G string is damped. What you hear after that is due to the induced vibration of the other four strings.

FIG. 1 is Audacity®'s display of the microphone voltage as a function of time for the three-plucked-G sound sample.

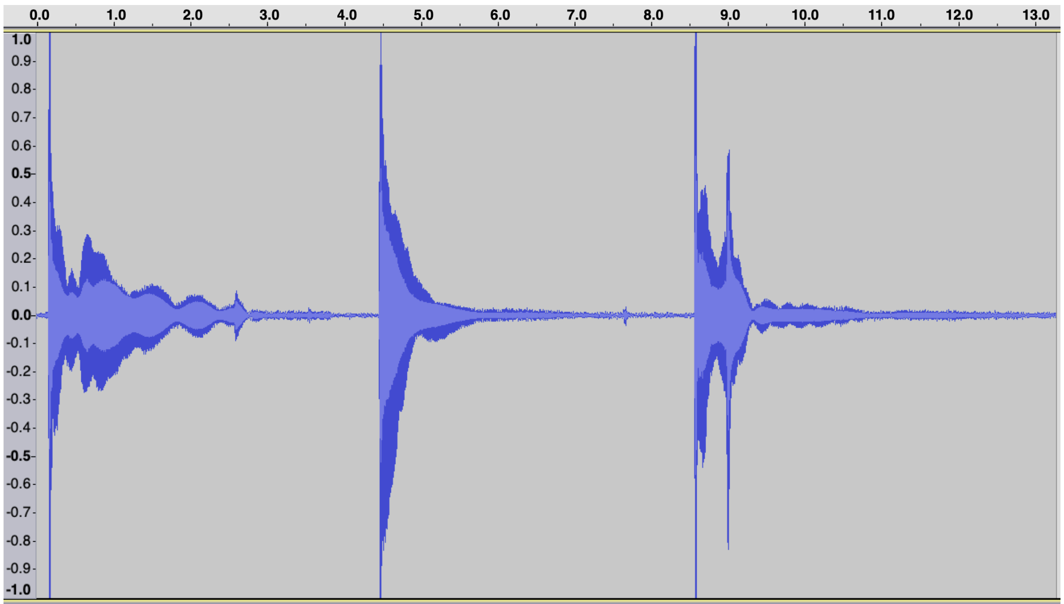

FIG. 1: Three G's: sound amplitude *versus* time (seconds) with all strings open; with all other strings damped; and with the plucked string damped after 0.5 seconds (9 .0 seconds from the start)

THE EXPERIMENT

Here is a very brief musical phrase played on a modified Goodtime banjo[1] and recorded straight to a mic:

normal banjo

or go to

http://www.its.caltech.edu/~politzer/turkey/2-measures-natural.mp3.

I created a library of single, plucked-note sound samples, with all strings damped, except for the plucked one. And I used Audacity® to arrange those samples into the same musical phrase as played above. To make a fair comparison, I also sampled single, plucked notes with all strings open. Rather than simply splicing in the notes at the appropriate time, I did it as a multi-track production, allowing each note to continue ringing after a new note was played. The only exceptions to that were where notes immediately followed a pluck on the same string. In those three cases, I simply stopped the sample sound of the previous pluck when the string was plucked again. The earlier note samples were allowed to continue. Unfortunately, that eliminates the sympathetic sounds of the stopped string in the case of all strings open, but it was by far the simplest approximation to natural playing. The durations of the individual single note samples are 1.5 seconds for all undamped strings and 1.1 seconds for plucks with the other strings damped.

The tempo is set by eighth notes being 0.22 seconds apart or four of them in 0.88 seconds. If you're counting groups of four, that's a leisurely 68 bpm.

The two synthesized sound samples:

The damped-string synth

or go to

http://www.its.caltech.edu/~politzer/turkey/2-measures-damped-synth.mp3.

The undamped-string synth

or go to

http://www.its.caltech.edu/~politzer/turkey/2-measures-synth.mp3.

FIG. 2 shows the synthesized signal using the damped-string samples (above) and the undamped ones (below).

FIG.s 1 & 2 use the same time scales to emphasize what happened — and why the two synth versions sound so similar. At even a leisurely tempo, notes mostly come close enough together that the difference between damped and undamped is overshadowed by the earliest part of the pluck sounds, which are quite similar.

I think I can hear a faint background "glow" in the undamped-string synth, but I wouldn't call it an essential banjo feature.

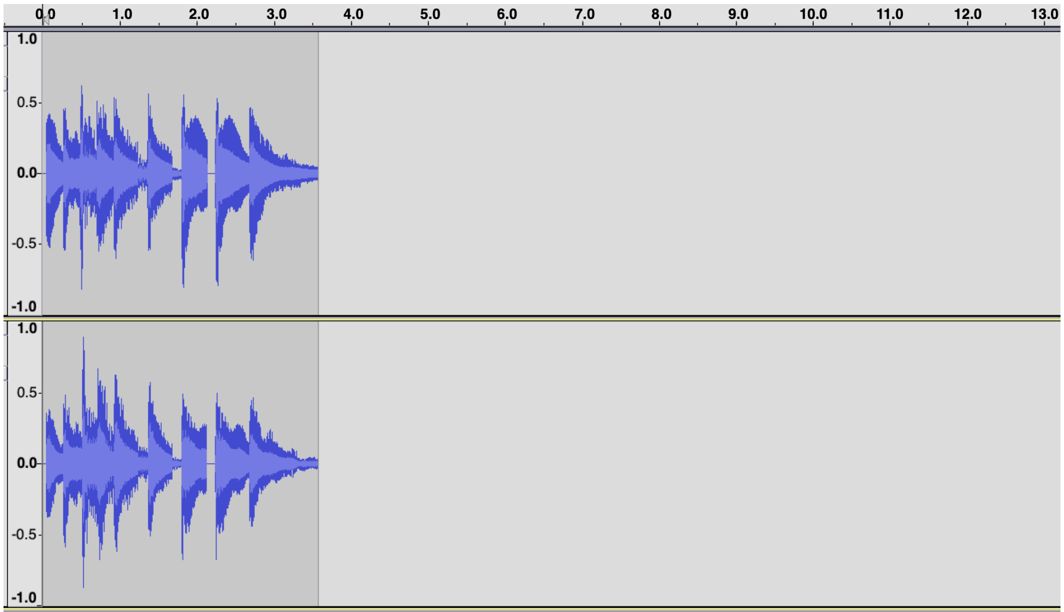

FIG. 2: damped (above) and undamped (below) sampled & synthesized; the time scale is the same as in FIG. 1.

AN EXTREME EXAMPLE

Here is an example that highlights the fact that, for plucked strings, we are listening to transients — as opposed to steady notes. With steady notes, the strongest sympathetic response occurs for matched frequencies of harmonics. In terms of time evolution, the sympathetic response typically builds up to its steady-state level through many vibration cycles; if there is back-and-forth sloshing of energy, it also usually takes place over many cycles. There is no such frequency constraint on what is excited promptly by the initial pluck disturbance.

Again in double-C tuning (gCGCD), here are three plucks of the 1st string, fretted at the 22nd fret — a very high C:

hear the three C's

or go to

http://www.its.caltech.edu/~politzer/turkey/3Cs.mp3.

As with the low G example, the first is a pluck with the 2nd through 5th strings open. The second is the same sort of pluck of the 1st string, 22nd fret, but all the other strings are damped. The third pluck features all strings, but, after about half a second, the plucked 1st string is damped. What you hear after that is the response due to the other four strings.

FIG. 3 is Audacity®'s display of the microphone voltage as a function of time for the three-plucked-high-C sound sample.

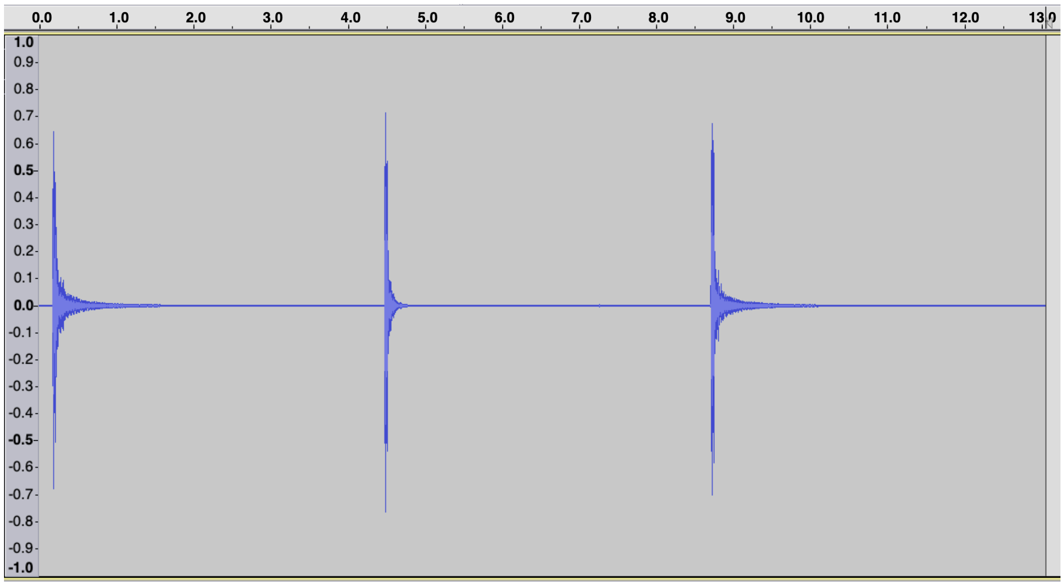

FIG. 3: Three high C's: sound amplitude *versus* time (seconds) with all strings open; with all other strings damped; and with the plucked string damped after 0.5 seconds

I find two features particularly interesting. Nearly all the sound after 0.11 seconds comes from the unplucked and unfretted strings. Also, the sound, particularly for the undamped cases, right from the start includes frequencies much lower than the fundamental of the plucked string — a clear example of the initial bridge disturbance exciting other strings, irrespective of frequencies.

SECONDARY VIBRATIONS: SYMPATHETIC & OTHERWISE

As mentioned at the top of Banjo Physics 411 [2], you'll have to look elsewhere for explanations of the physics that is common to all string instruments. The standard discussions of sympathetic string vibrations treat the subject in terms of steady-state behavior. However, the transient behavior when damping is on the same scale as the coupling between resonances is rarely discussed and generally misunderstood — and it is typically very relevant to the behavior of plucked strings. A simple but very common case that can analyzed completely using pencil and paper is what happens when there are only two resonances with equal or nearly equal frequencies, e.g., [3]. In general, there are slight shifts in frequencies due to the coupling and damping, and energy can slosh back and forth between modes.

(The sloshing is quite evident in FIG. 1. When the plucked string is allowed to interact with the others, there is a richer variety of sound amplitude variation. [Note: even a single ideal string has two resonant modes for each resonant frequency — e.g., up-and-down and side-to-side. These typically couple while they die away.])

With a limited number of strings besides the plucked one, there may not be a close frequency match to the resonances of the plucked string — particularly if it's fretted. That is why instruments with intentional sympathetic strings typically have a great many. Many instruments of India and its neighbors have one, two, and even three dozen sympathetic strings, to better cover the played notes.

Where along the string the plucked string is plucked also impacts the sympathetic response — because that determines the relative strengths of its own various resonant excitations.

The "extreme" example of the plucked high C reveals another corner of the space of possible behaviors. As mentioned above, this is presumably due to the large initial motion of the bridge (following the pluck) exciting all of the strings. A model of this behavior, with some appropriate idealizations and approximations, would certainly help in understanding how much of which sounds are produced when. But that will not be attempted here.

COMPARE INSTRUMENTS

Here is a quick sampler of singing along for the instruments pictured in the cover page photo. The modified Goodtime is again in double-C and plucked on the G. To get a fair comparison, the steel-string flat-top guitar is tuned to XXCGCD (CGCGCD with strings 6 and 5 damped because the octave of the low C chimed in very audibly, and it's the four high strings that match the banjo). The 3$^{\text{rd}}$ string G is plucked. The ukulele is tuned FCFG, with the two F's in unison. To parallel the banjo case, the C is the plucked string on the uke. The 13″ fretless (built by Eric Prust[4]) is tuned to bEBEF$^{\#}$ (which is just an ultra-mellow version of double-C), and the B is the plucked string. I left the mandolin in standard GDAE and plucked the D. Tuned all in 5$^{\text{th}}$'s, it's about as sympathetic as it can be. Of course, much of its character comes from the doubled strings.

Here are the sounds of those instruments with all strings open and the plucked string damped after about half a second. The order is Goodtime, guitar, ukulele, 13″ fretless, and mandolin:

hear the five instruments

or go to

http://www.its.caltech.edu/~politzer/turkey/5-instruments.mp3.

The recorded sound amplitudes are shown in FIG. 4.

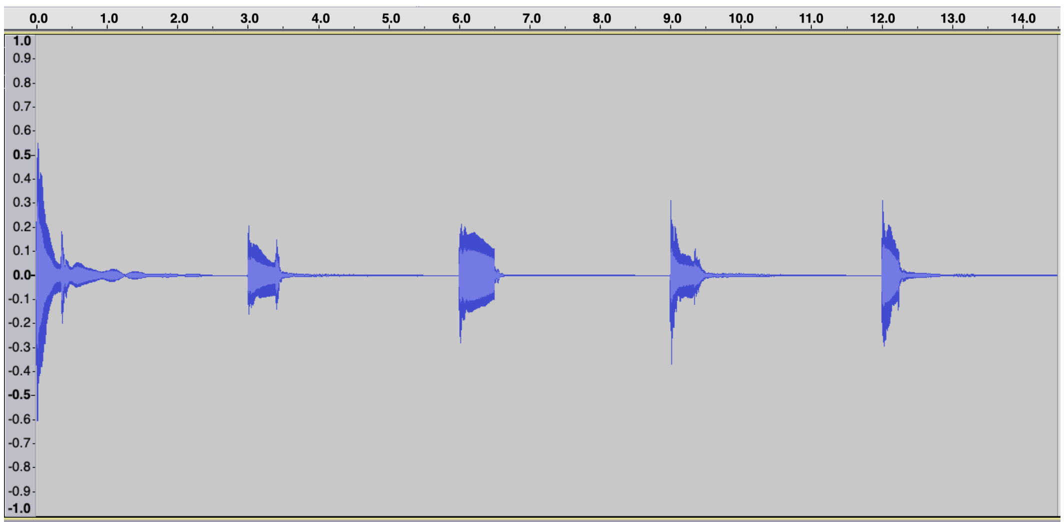

FIG. 4: Sound amplitude *versus* time (seconds) with strings open and the plucked string damped after 0.5 seconds. The instruments, in order, are a modified Goodtime banjo, a flat-top steel-string guitar, a soprano ukulele, a 13″ fretless banjo, and a mandolin.

The sample above may not represent a well-controlled experiment, but it does reflect the notion that banjo strings generally sing along more than what occurs with other instruments. However, the sampled-note synthesis demonstration suggests that the singing along is not an essential, identifying characteristic of banjo sound.

CONCLUSION

Here is a reminder that banjos sound like banjos; case in point: the 13″ loose, thick skin head; $27\frac{3}{4}''$ scale; thick synthetic strings (Aquila "Minstrel"s); Prust fretless. (The playing isn't particularly good enough to entertain anyone but myself, but it's unmistakably a banjo. It rings.)

the sound of the Prust 13″ fretless

or go to

http://www.its.caltech.edu/~politzer/turkey/ark.mp3.

A reasonable question for the world of acoustics of musical instruments is: Why do banjos ring? I have previously suggested one possibility which is certainly at least part of the answer: the frequency modulation produced by a floating bridge on a drum head — see [5].

---

[1] The banjo, simply plucked with bare fingers, started its life on the Deering Goodtime assembly line. However, the pot was turned to get a Stu-Mac Bacon repro tone ring. And further modifications were an internal resonator, a skin head, and a no-knot tailpiece.

[2] http://www.its.caltech.edu/~politzer/

[3] *Zany strings and finicky banjo bridges* (HDP: 14-05) and *The plucked string: an example of non-normal dynamics* (HDP: 14-04) are two versions of my explication of the transients of coupled, damped oscillators. Both are linked on http://www.its.caltech.edu/~politzer/; scroll down to JULY 2014.

[4] Eric Prust makes amazing, simple 13″ banjos and sells them at an incredibly low price; see http://www.chloesgarden.com/Banjos%20on%20Web/Banjos.htm.

[5] D. Politzer, *Banjo timbre from string stretching and frequency modulation*, Acta Acoustica (united with Acoustica), AAuA 101(1) 1, January 2015. That's a brief, formal published version. Far easier to access and replete with sound samples and more complete explanations is the APRIL 2014 entry at http://www.its.caltech.edu/~politzer — or directly as *String Stretching, Frequency Modulation, and Banjo Clang*. An even more dramatic and convincing demonstration than those offered in 2014 is featured in *Banjo Ring from Stretching String: A Zero Break Angle Demo*, the MARCH 2019 entry at Banjo Physics 411.