ZIPPER NOISE PREVENTION
IN HD AUDIO CODECS

Introduction:

What is zipper noise?
For our purposes, zipper noise is the sound heard when the volume is changed rapidly over a large range. Imagine moving the volume control slider in a typical PC audio system from its lowest gain setting to its highest gain setting and back in the time it took you to read this sentence. A single volume change may produce a slight click or pop sound, but a rapid succession produces a sound reminiscent of a zipper being zipped.

What causes zipper noise?
Zipper noise is caused by large discrete volume changes. Typically people attribute this to digital signal processing, but it can happen in any situation where discrete volume changes are implemented, such as a rotary switch used for changing volume instead of a variable resistor. Another example is a VCA controlled by a DAC. Even a dirty potentiometer or a crude wire-wound potentiometer can cause this effect. However, digital controlled volume stages will not always produce audible noise.

How to prevent zipper noise:

Don't use volume stages with discrete steps?!!
Fortunately, it is not necessary to give up on implementing digital controlled amplifiers and digital signal processing. We are surrounded by many products that exhibit little or no zipper noise. The three most important factors that have allowed us to live with discrete (rather than continuous) volume control are:

1) Implement many small steps instead of a few large steps over the volume control range.
2) Prevent very rapid changes in volume.
3) Change the volume when the signal level is small.

What does this mean?

Implement many small steps:
The ideal volume control element would allow us to continuously change the volume from the current level to the desired level. We can approximate a continuous change by implementing many very small changes. How small? No definitive research exists on this topic; however, a 0.5dB or even a 0.1dB change in volume will be recognized under some conditions, but generally a 1dB change is cited as the minimum perceptible change. Unfortunately, the most common step size for AC'97 and HD Audio CODECs is 1.5dB, although some devices support 1dB or even 0.75dB steps. So, what else can be done?

Prevent rapid volume changes:
A discrete volume change is perceived differently dependent on what is currently happening with the audio, but if the characteristics of the audio program are not changing significantly (low dynamics) then the listener will generally describe a change in volume and a coincident pop or click. The larger the change in volume, the more objectionable the effect. Fortunately, rapid attenuation does not generally cause distress in a listener. For this reason, fade-in and fade-out techniques can often help. Often, though, limiting the rate of change can not overcome implementing too few gain steps. Can we hide it some other way?

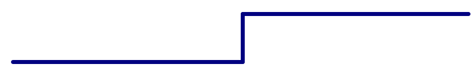
Change volume only during silence:
If you make silence twice as loud, do you still have silence? This may seem like a silly question, but it is an important one. What is silence? That is another good question. A reasonable definition is that silence is the point where the power output is below the threshold of hearing. While this is a vague statement, it leads us to ponder when we can achieve silence. Well, even when we are actively playing music, there are brief periods of 'silence' even in the midst of a very dynamic piece. These moments of silence are where the signal passes through zero. At that time, even though the rate of change may be highest, the amplitude (peak pressure) is lowest. At that time, changing volume will not be noticed.

How well does this work? Extremely well. By changing at the zero crossing point, we prevent a discontinuity in the signal that is the largest component of the click or pop experienced. However, the listener will still notice the volume change and may still object even though the zipper noise is no longer present. Again, implementing many small volume steps and limiting the rate of change of volume helps.

When is silence not silence?

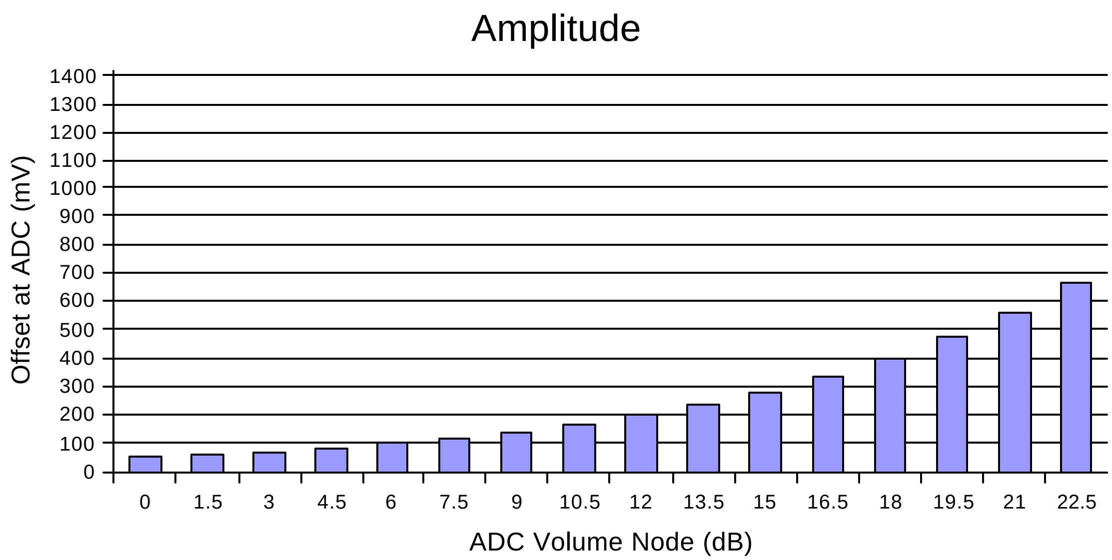
Noise is everywhere. But small amounts of noise don't usually present a problem. However, even a perfectly quiet system with a small DC offset will produce zipper noise. Why? Let's take a look.

What happens when we change the volume when a DC offset is present? We get a change in offset that looks like a step:

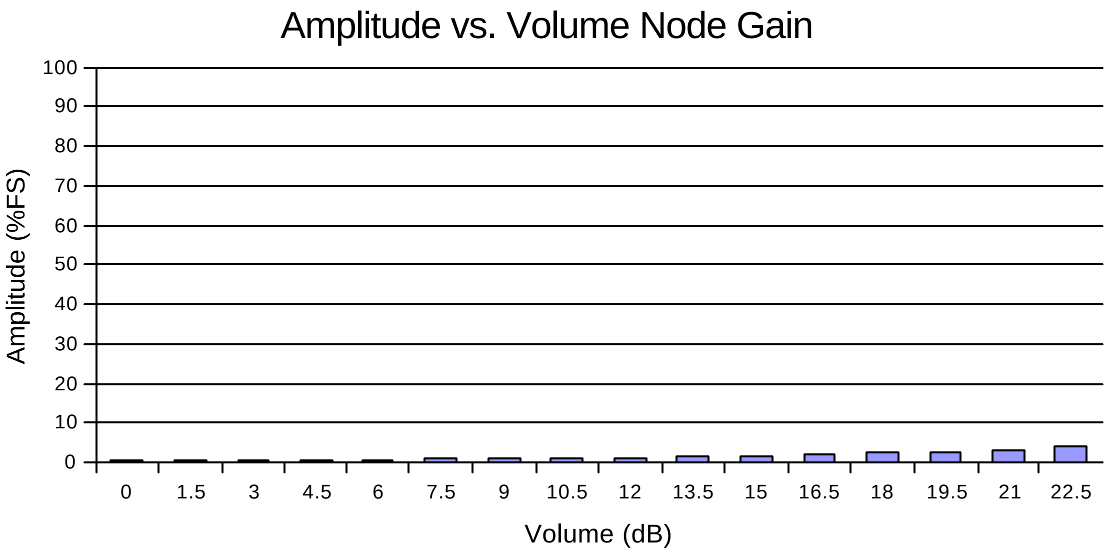


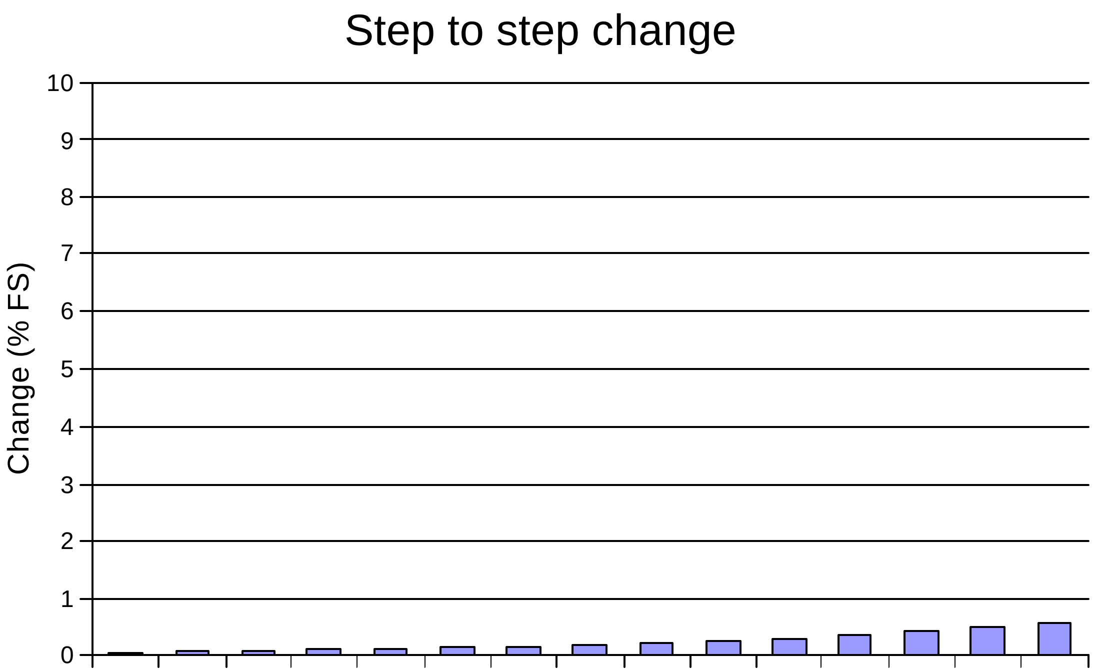
If we make a series of volume changes, we get something like this:

We should note that it is under these circumstances that less than 1dB of change can be heard. In fact, it is common to hear complaints from listeners if there is greater than a 1% change in amplitude compared to full scale, which is about 0.1dB.

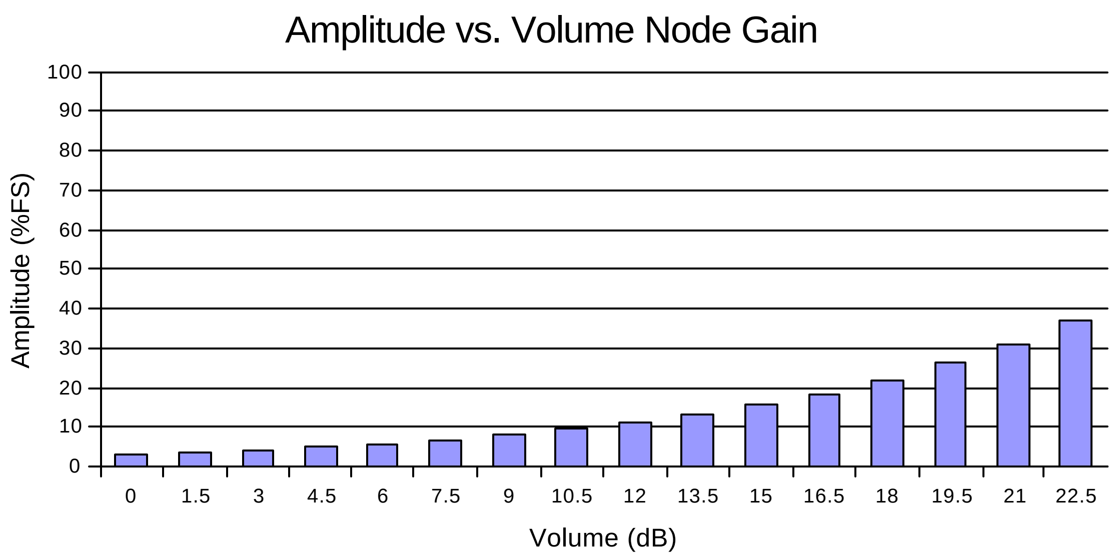


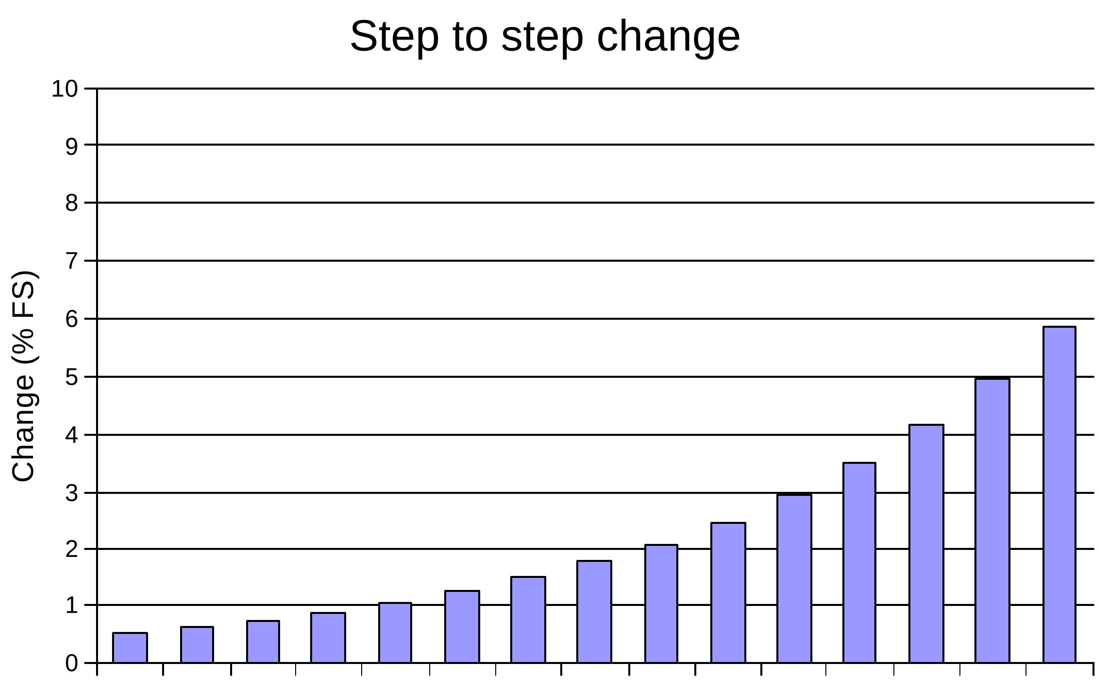
It is fairly common to see offsets in record and playback paths in the range of 5mV, which is good and generally does not generate complaints from listeners. If implementing 32 gain steps of 1.5dB, the absolute offset and step-to-step change in offset relative to full scale will be:





However, if the path were used for recording microphone input and an additional 20dB of gain were applied, then the following would be observed:





Certainly this level of change will generate complaints. It is important to point out that as the record slider is increased from 0dB to 22.5dB (20dB to 42.5dB total gain), the first few steps likely wouldn't be objectionable, but the last several will be quite loud.

In addition, if there is an audio signal superimposed on the DC offset, then high levels of gain may also cause clipping of the audio signal, which makes the zipper noise even more pronounced.

Where do DC offsets come from?
DC offsets can come from internal and external sources. Internal offsets are often due to device mismatches in amplifiers, although other sources can create offsets. In devices that implement analog signal processing stages, offsets are unavoidable, and limiting offset is often expensive in terms of die area and power consumption. External offsets are generally due to leakage currents caused by the physical structure of the components and the presence of surface contaminants from the board assembly process. To provide an understanding of the level of sensitivity an audio circuit has, let us take a look at a common situation:

A designer has chosen a rather typical 4.7uF 6.3V X5R ceramic capacitor with a stated insulation resistance of (100/C) M ohm. We calculate that the minimum equivalent parallel resistance is about 20M ohm. This appears satisfactory at first, but some calculation reveals a problem.

This capacitor is used in a circuit that has 4V of microphone bias on one side and 2.25V of CODEC bias on the other side for 1.75V tension on the cap. At 20M ohm insulation resistance, we would experience 87.5 nA of leakage current. The CODEC has a nominal input impedance of 50K ohms. Therefore the leakage current would create an offset of 4.375 mV at the input of the CODEC.

Summary and conclusions

Zipper noise is related to implementing large gain steps in the volume control stages. It does not matter if the volume control is implemented in analog circuitry, digital circuitry, or software. DC offsets are very problematic but are inherent to analog circuitry present inside the CODEC and are created by external components and contamination.

There are techniques to help control zipper noise, but only careful attention to design and component choice will prevent objectionable levels of noise.

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