Apple II
Technical Notes

Developer Technical Support

Apple IIGS
#11: Ensoniq DOC Swap-Mode Anomaly

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Under certain conditions, the IIGS Ensoniq Digital Oscillator Chip (DOC) inserts a spurious zero-crossing byte into the output sample stream. The output sample waveform may mask the anomaly, but if it does not, the user may hear intermittent clicks or even a more pervasive "static." This Technical Note discusses the situations in which the DOC produces this spurious zero crossing, as well as strategies to avoid or mask this undesirable behavior.

Background

The Ensoniq DOC in the Apple IIGS is actually a microprocessor dedicated to producing sound. Like a time-sharing computer, the DOC continually scans through its array of sound oscillators, proceeding from lower-numbered oscillators to higher-numbered ones, and updates the signal output level of each active one to match that indicated by the oscillator's current sample byte.

An oscillator can operate in any one of several functional modes, as described in the *Apple IIGS Hardware Reference*. Here, however, we are concerned only with swap mode, where two consecutive oscillators are considered as a single generator. The low-numbered oscillator in the pair is always even. For example, the pairs of oscillators 0 & 1, 2 & 3, … , 12 & 13, and 14 & 15 constitute generators. The IIGS Sound Tool Set – the `FFStartSound` call in particular – configures the oscillators it uses to operate in swap mode. In swap mode, the even-numbered oscillator plays its waveform first, halts its own playback, then starts its partner which also plays its waveform, halts its own playback upon exhausting its waveform, and restarts the even-numbered oscillator. At any time between the start of any particular `FFStartSound` call and the time the oscillator finishes playing a wave, the Sound Tool Set interrupt handler may be busy transferring waveform information from the IIGS main RAM to the dormant oscillator's buffer in DOC RAM. Since one oscillator is producing sound while the Sound Tool Set interrupt handler is transferring waveform information to the other oscillator, you can use a generator pair to produce continuous sound of arbitrary length, and you are limited only by the amount of memory you can devote to the waveform in the main RAM.

Each oscillator draws its output samples from a dedicated buffer in DOC RAM, the size and location of which are specified by parameters to the `FFStartSound` call. The maximum size for an oscillator buffer is 32K, but since buffers may neither coincide nor overlap, the practical maximum may be lower when more than one generator is active. For instance, if four generators (eight paired oscillators) are active simultaneously, the maximum buffer size is 8K, since eight non-overlapping buffers of 8K each would occupy the entire 64K available in the DOC RAM.

The Problem

Whenever a swap occurs from a higher-numbered oscillator to a lower-numbered one, the output signal from the corresponding generator temporarily falls to the zero-crossing level (silence); this anomaly does not occur during swaps from lower-numbered oscillators to higher-numbered ones. The spurious level change lasts no longer than a single sample period, at which time the interrupted waveform resumes. However, even this tiny glitch in the output can be audible as a pop or click; the further away the waveform is from the zero crossing when the swap interrupts it, the louder the ear will perceive the pop or click. When high-to-low swaps occur with great frequency, the pops and clicks happen so often that they are perceived as gentle, but pervasive, static.

Several Workarounds

There is no ideal solution to the problem of signal interruption in swap mode. This problem is an anomaly of the DOC design, which may or may not be addressed in later versions of the chip. However, we have found three general strategies for mitigating the audible damage to the output waveform caused by the chip's undesirable behavior.

Minimize Oscillator Swaps per Unit Time

The more often swaps from high-numbered oscillators to low-numbered ones occur, the more obtrusive the brief signal interruptions will seem. To minimize the interruptions, you must make the oscillators play for a longer period of time before swapping to their partners. This means that they must play at slower output sample rates, use larger buffers in DOC RAM, or use the two in tandem. Commensurate with the number of active generators you wish to use and the level of output signal fidelity that you desire, always specify the largest DOC buffer size and the lowest output sample rate that you possibly can. Remember that a large number of active generators implies a very small maximum buffer size for any particular oscillator, so you should always try to minimize the number of generators that are active at any one time. As a rough benchmark, the clicks of signal interruption begin to blend into highly audible static when you specify buffers smaller than 8K for use at the maximum-fidelity output sample rate of about 26 kHz. (Note: The DOC supports greater sample rates, but these rates are limited by the output filtering on the IIGS which permits no greater signal fidelity than that possible using the 26 kHz rate.) Our figures suggest that output fidelity must suffer, or signal noise must increase, when more than four generators (eight oscillators in swap mode) are operating simultaneously.

Avoid Silent or Quiet Passages

The signal content of your waveform can hide the additional noise caused by the "swap-mode anomaly." The more complex and louder a waveform, the less your ear will perceive the brief interruption that occurs whenever a higher-numbered oscillator swaps to a lower-numbered one; pop and rock music is far less susceptible to this problem than classical, folk, or jazz pieces, which typically include many quiet passages. In addition, a signal that naturally contains a large amount of "pink noise," such as recordings of rainstorms or the surf at the beach, can mask the anomalous noise altogether.

Arrange for Swaps to Occur at or Near Zero Crossings

If the high-to-low swap occurs at a time when the normal output signal level sits at or near the zero crossing, the swap will cause little or no audible damage to the waveform. When reproducing arbitrary sampled sound, it is almost impossible to insure that the output signal level is near the zero crossing. However, when constructing long waveforms for playback, you may be able to sidestep the chip's anomalous behavior by ensuring that the waveform values lie at or near $80 at the end of every waveform segment, where a waveform segment spans twice the length of one oscillator buffer. For example, if you specify a buffer size of 4K, make sure that your constructed waveform crosses the baseline after every 8,192 samples, and for 16K buffers, make sure that the waveform makes a zero crossing after every 32K.

The length of the waveform segment should be twice the buffer length only if you are going to reproduce the waveform exactly once per `FFStartSound` call. It may be necessary to shorten the length of the waveform segment to exactly the specified DOC buffer length if you use the `nextwave_start` parameter in the `FFStartSound` parameter block to invoke automatic looping of the waveform. In other words, you may need to arrange for twice as many zero crossings in your constructed waveform in the looping case as you would under normal circumstances since subsequent repetitions of the waveform during the single `FFStartSound` call may begin with either the even or odd oscillator, depending upon which member of the pair was active when the previous repetition ended. If the playback of a waveform starts with the odd oscillator, then the odd-to-even swaps will occur at different points in the waveform than they would when the playback starts with the even oscillator.

Also note that the use of larger buffers causes a progressively longer disabling of interrupts while the Sound Tool Set moves the waveform into the DOC RAM.

Further Reference

- *Apple IIGS Toolbox Reference*, Volume 2
- *Apple IIGS Hardware Reference*