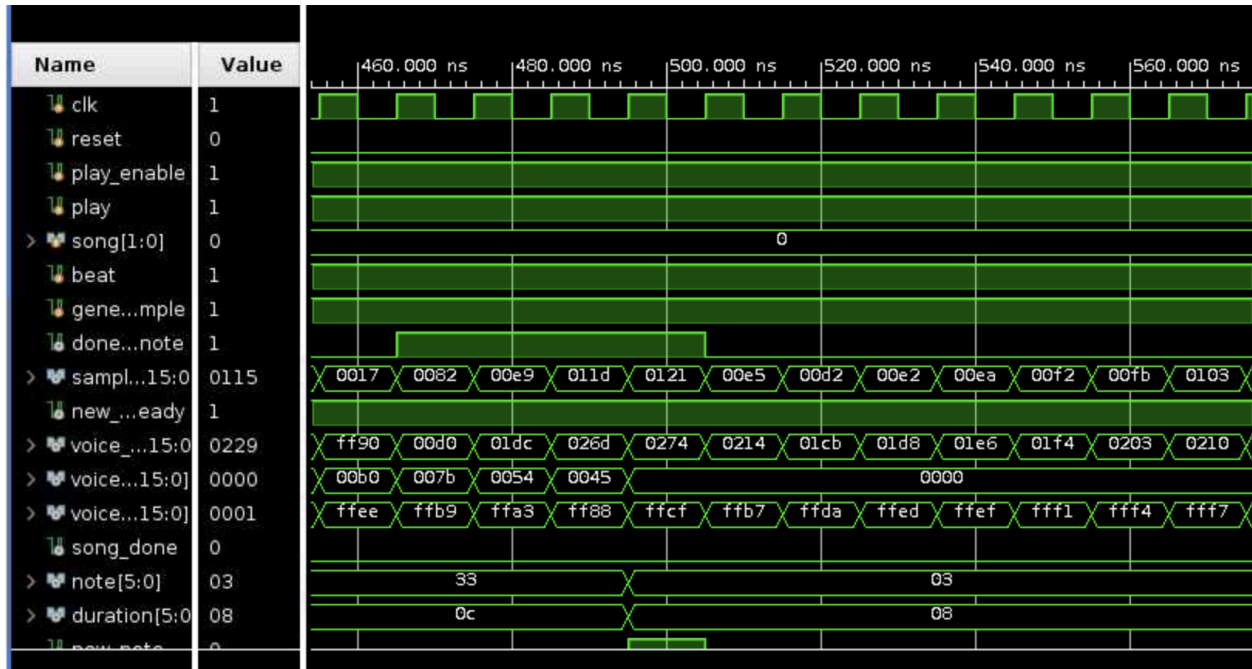


Chords:



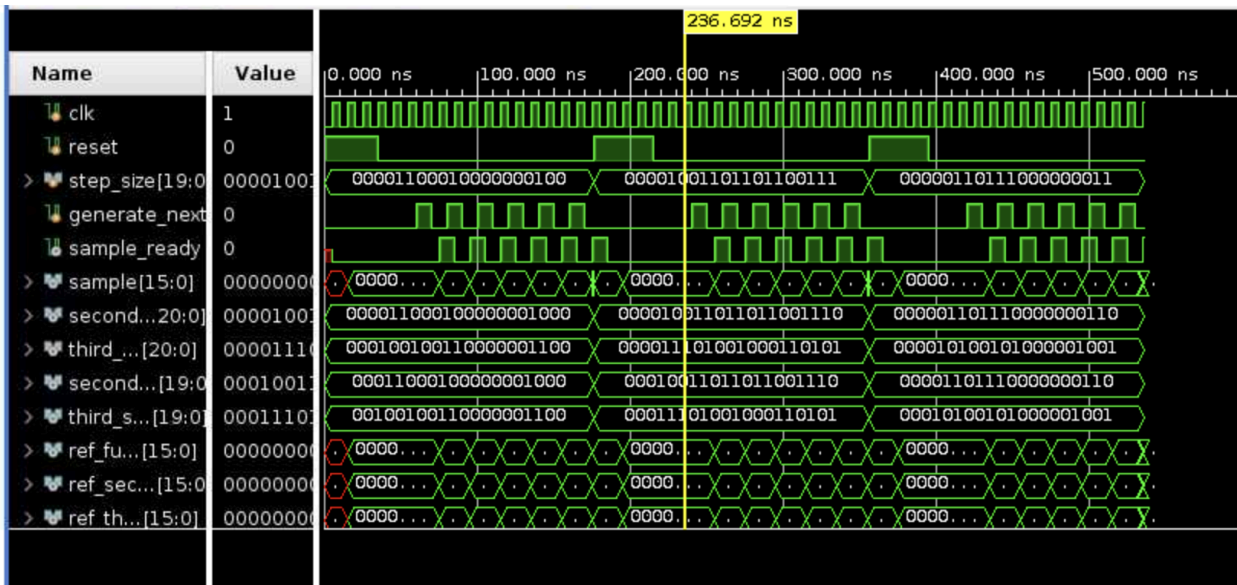
460 ns: initial chord state, root and fifth voice outputs active while third voice present
 480 ns: first note (0x21 / decimal 33) active, root, third, and fifth voices all generating samples
 500 ns: note transition begins, done_note asserted and next note scheduled
 510 ns: second note (0x03) loaded with duration 0x08, root and fifth voices remain active
 520 ns: third voice output drops to 0, low-note rule suppresses third voice
 540 ns: chord generation stable for second note, root and fifth continue producing samples
 560 ns: pipeline steady, new samples continue updating with only root and fifth active

Logs:

```
# run 1000ns
PASS: root and fifth voices active
PASS: third voice active for mid note
PASS: root and fifth voices active
PASS: third voice suppressed for very low note
chord_tb complete.
```

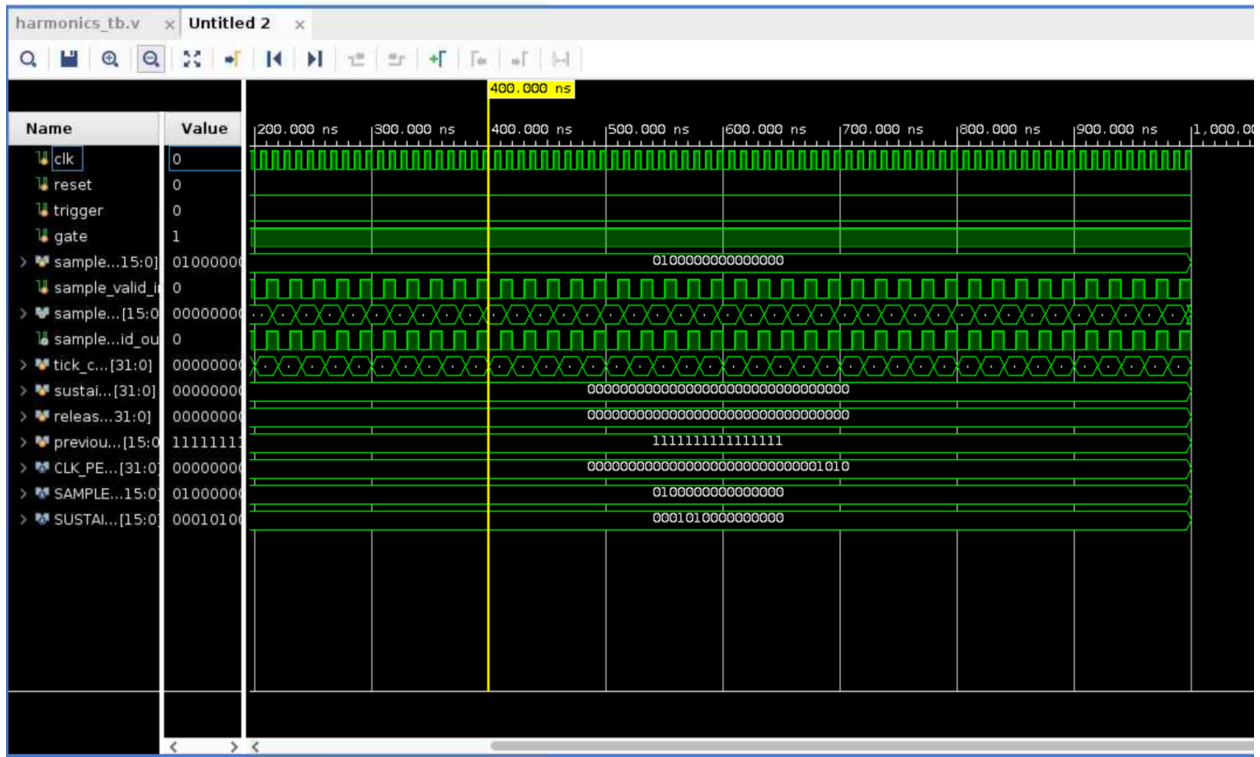
Dynamics & Harmonics

Harmonics: We check functionality by varying modes and computing the expected mixed sample (using same weighted sum and right shift) and compare values.



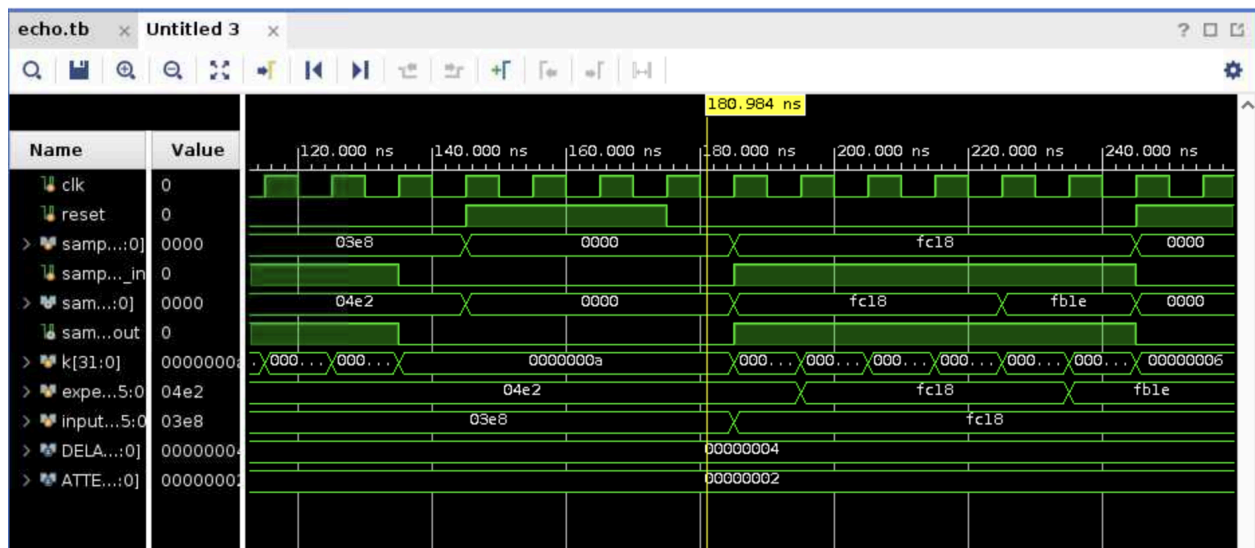
- 0 ns: reset asserted, harmonics DUT and reference sine readers cleared; sample starts at 0/unknown until the first sample request propagates
- 20 ns: reset deasserted, step_size set to 50180 (normal-note region); second_step_size and third_step_size update to 2x and 3x the fundamental step size
- 50 ns: first burst of generate_next pulses begins, requesting successive harmonic samples from the fundamental, second, and third sine readers
- 70 ns: sample_ready begins asserting after the expected reader latency; DUT output sample now matches the expected weighted mix of fundamental + second harmonic + third harmonic
- 180 ns: reset pulsed again and step_size changes to 39783 (low-note region); this switches the harmonic logic into the low-note case
- 200 ns: new generate_next burst starts for the low-note case; the second harmonic is still used but more heavily attenuated, while the third harmonic contribution is removed
- 236 ns: sample_ready asserted in the low-note region; sample matches the expected low-note mix computed from ref_fundamental_sample and the reduced ref_second_sample term
- 360 ns: reset pulsed again and step_size changes to 28163 (very-low-note region); this activates the very-low-note case where upper harmonics are suppressed
- 400 ns: final generate_next burst begins for the very-low-note case; reference readers still advance, but the expected output now keeps only the fundamental contribution
- 430 ns: sample_ready asserted in the very-low-note region; DUT sample continues matching the expected weighted result, confirming correct behavior across all three harmonic regions

Dynamics: We explicitly check values that match ASDR behavior, follow sample_tick timing, and release properly once note_done is pulsed.



- 0 ns: reset asserted, dynamics module held in IDLE; trigger=0, gate=0, sample_valid_in=0, and sample_out=0
- 40 ns: reset deasserted, DUT ready for a new note event; sample_in is fixed at 0x4000 for all checks
- 60 ns: trigger pulse asserted and gate goes high, starting the ADSR envelope for the new note
- 100 ns: first sample_valid_in pulse arrives; this acts as the sample tick, so the envelope logic advances only here, not on every clock cycle
- 120 ns: sample_valid_out follows the tick, confirming the DUT only updates output on valid sample events
- 140 ns: first non-zero sample_out value appears, showing the beginning of the ATTACK phase after the trigger/sample-tick delay
- 200 ns: repeated sample_valid_in pulses continue, and tick_count increments each time; sample_out rises in small steps, confirming the envelope is increasing only on sample ticks
- 400 ns: gate remains high, so the TB is still in the attack/early envelope region; sustain_hits and release_ticks remain zero because sustain and release have not started yet
- 600 ns: sample_out continues increasing monotonically with each sample tick, showing correct ADSR progression while the note is held
- 1000 ns: waveform still shows clock-driven sample ticks with stable behavior between ticks, confirming the module does not change output asynchronously between valid sample events

Echo

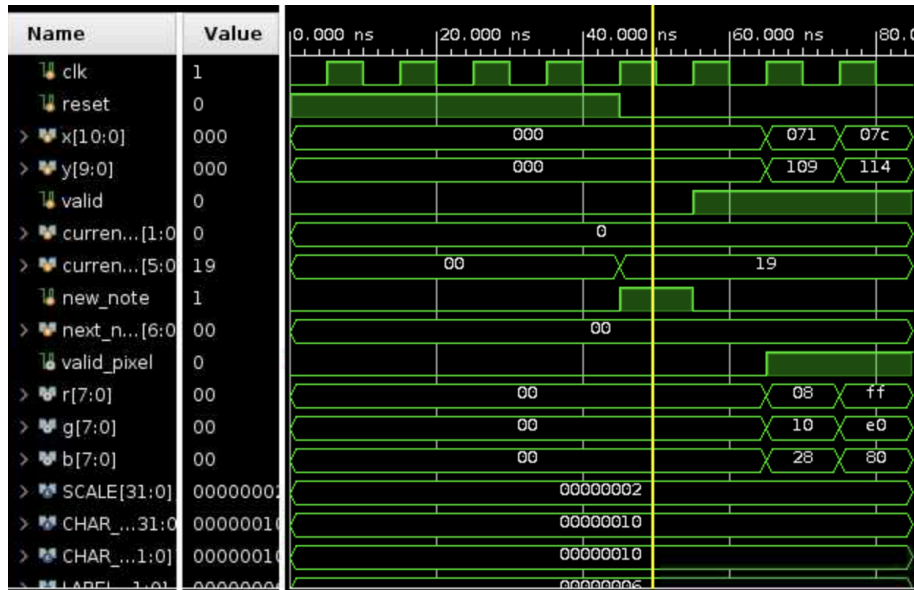


- 135 ns: valid sample (03e8), delay buffer filling
- 145 ns: echoed output appears (04e2)
- 170 ns: reset deasserted, DUT is ready for next test
- 180 ns: new input sample (fc18 = -1000) begins the negative echo test
- 220 ns: echoed negative sample appears (fb1e)
- 240 ns: reset asserted to begin next test

Logs:

- PASS: basic echo response
- PASS: sample_valid_out deasserts with input invalid
- PASS: negative echo response
- PASS: positive saturation
- PASS: negative saturation
- echo_tb complete.

Note Display:

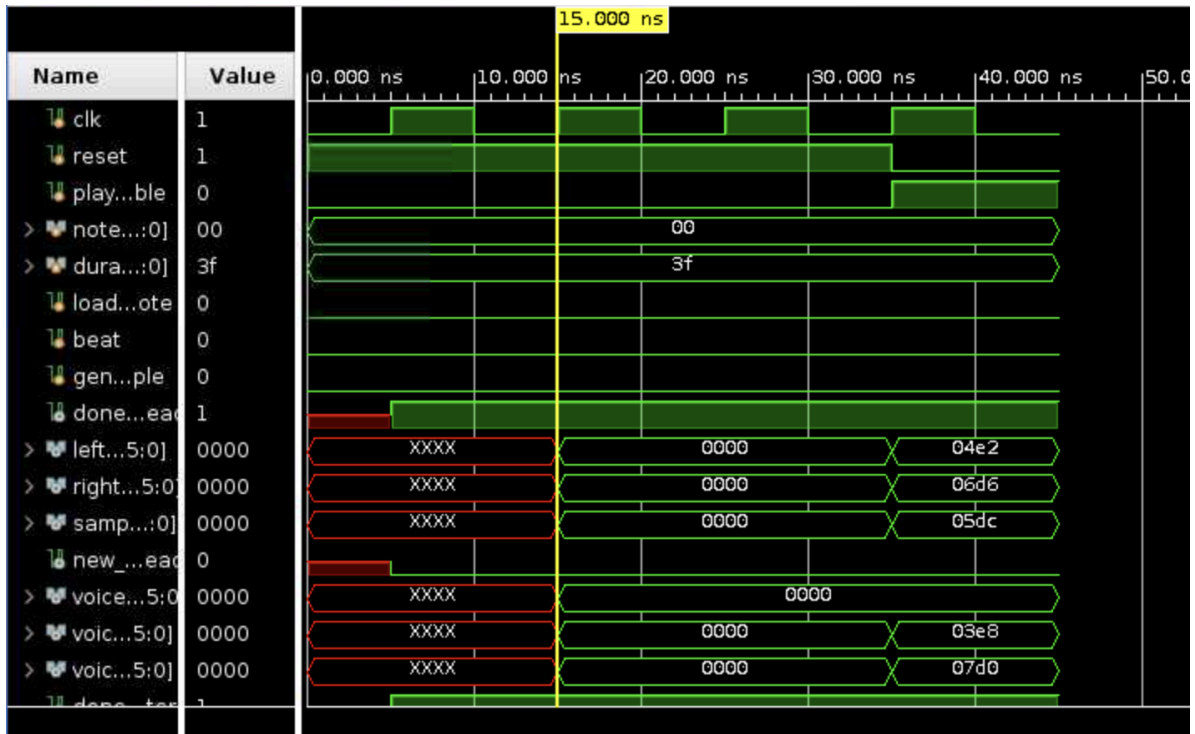


0 ns: reset low, display pipeline idle, x=0, y=0, valid=0, RGB outputs 00 (background)
20 ns: scan coordinates begin updating, display logic starts advancing x/y counters
40 ns: new_note pulse asserted, current note register updates (00 to 19) and note display pipeline triggered
50 ns: note display logic loads ASCII glyph data, CHAR registers populated from font ROM
60 ns: valid_pixel asserted, display enters active drawing region for note display box
65 ns: border region detected, RGB remains 00 for background outside box
70 ns: text region active, RGB values become non-zero (r=08 to ff, g=10 to e0, b=28 to 80) showing the pixels are drawn
80 ns: pixel scanning continues across text region, ASCII characters for past/present/future notes rendered on screen

Logs:

PASS: outside box valid_pixel
PASS: outside box RGB black
PASS: box border valid_pixel
PASS: box border RGB background
PASS: text region RGB nonzero

Stereo Effects:



0 ns: reset, system held in idle; all outputs undefined, play_enable=0, and no note activity

10 ns: duration (0x3f) and note (0x00) visible but not yet latched

15 ns: reset to 0, DUT becomes active, all datapath signals go from undefined to 0000

30 ns: play_enable goes high, start of playback sequence, note and duration now actively used by datapath

40 ns: shifted outputs, left = 0x04e2 (1250), right = 0x0606 (1542), sample = 0x05dc (1500)

45 ns: multi-voice contribution to the final sample

Logs:

stereo_effects_tb starting

PASS: spread panning L/R differ for samples

PASS: centered panning L/R match for samples

stereo_effects_tb complete.