# FPGA Guitar Synthesizer with Karplus-Strong & VGA Visualization

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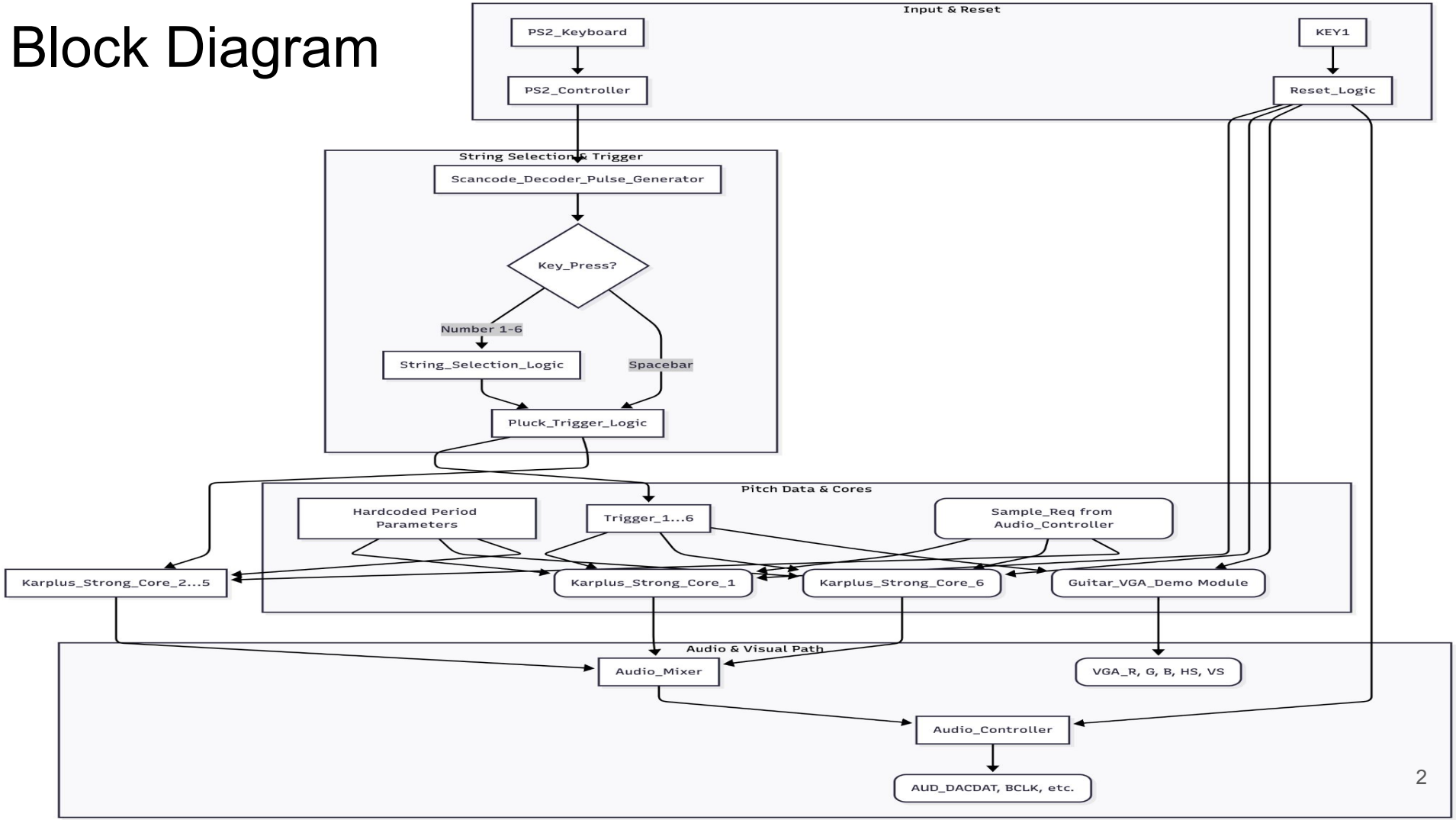
# Project Overview

A digital guitar on the FPGA that:

1. Generates realistic plucked string audio using Karplus Strong algorithm.
2. Displays guitar with 6 vibrating strings on the VGA.
3. Allows user to select strings using PS2 keyboard with keys 1 to 6, and trigger the pluck with Space bar.
4. Outputs Audio on the speakers that is synced with the vibration on the VGA.

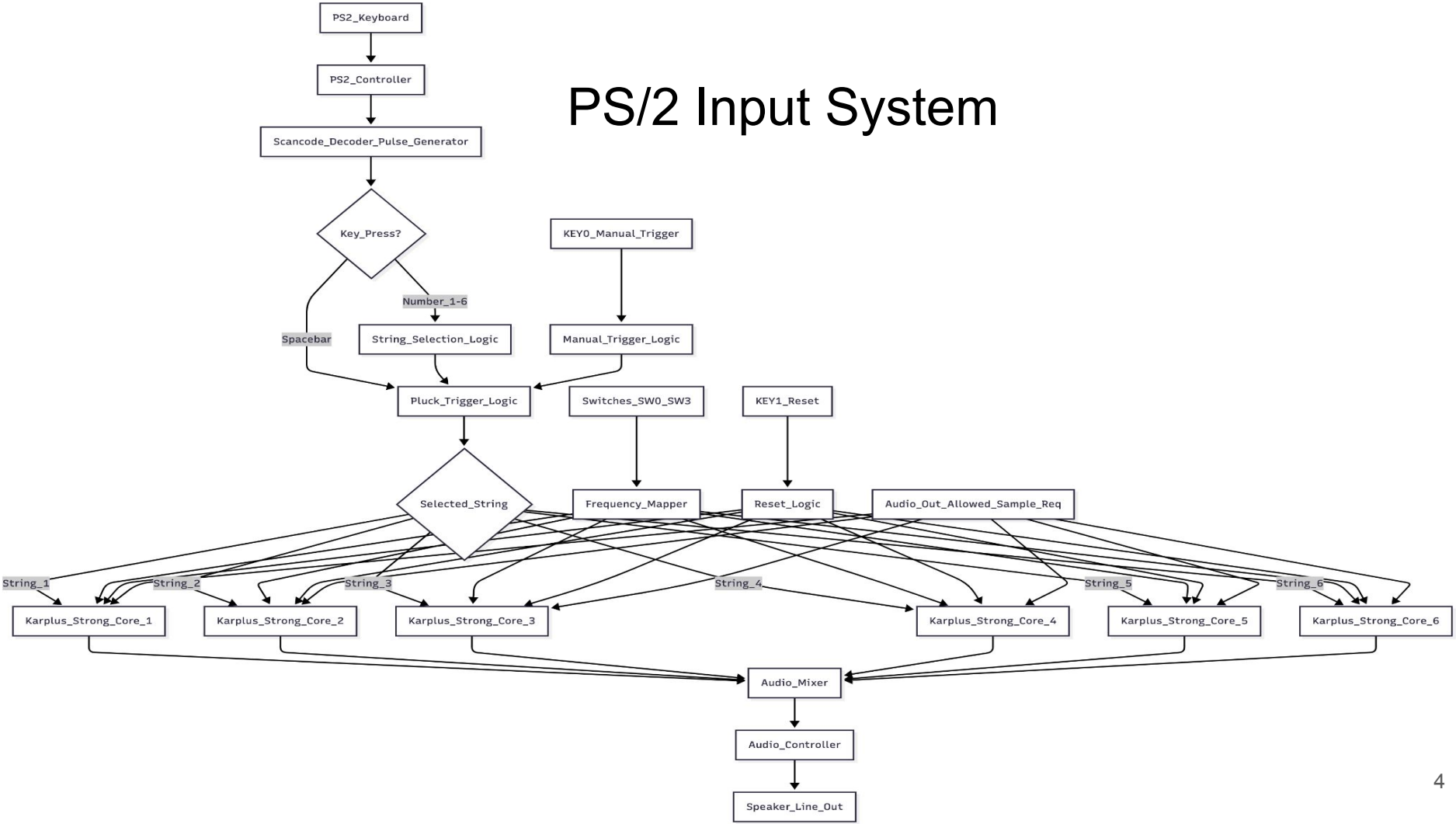
# Block Diagram



# PS/2 Input System

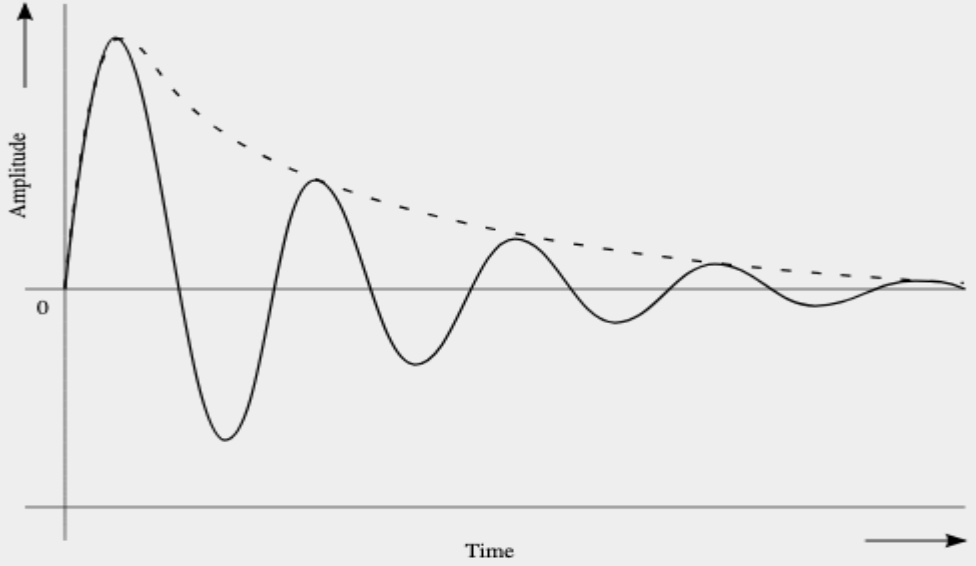
- PS/2 Keyboard Module:
- Reads scancodes from the keyboard
- Maps keys 1-6 to string_trigger 0 to 5
- When spacebar is pressed, the selected string vibrates on VGA while its audio is played on the speakers.
- Prevents multiple strings from being triggered and played at once.

# PS/2 Input System

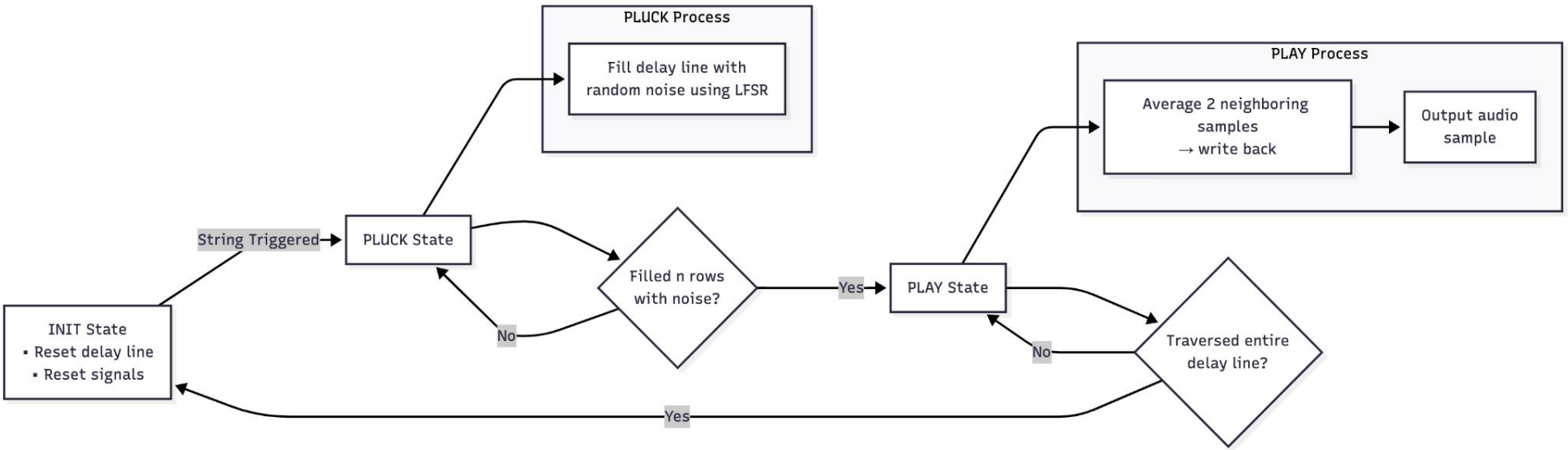


# Karplus Strong Core

The Karplus-Strong Core is the digital audio engine that implements physical modeling synthesis to generate real-time guitar-like sounds. It simulates a vibrating string by creating an initial noise burst (the "pluck"), then processing it through a circular delay line buffer. The buffer is continuously traversed, averaging each pair of neighboring samples and storing the result back—this filtering process produces the characteristic decaying string vibration sound while outputting audio samples to the audio system.



# Working of Karplus Strong Core:



# VGA DISPLAY

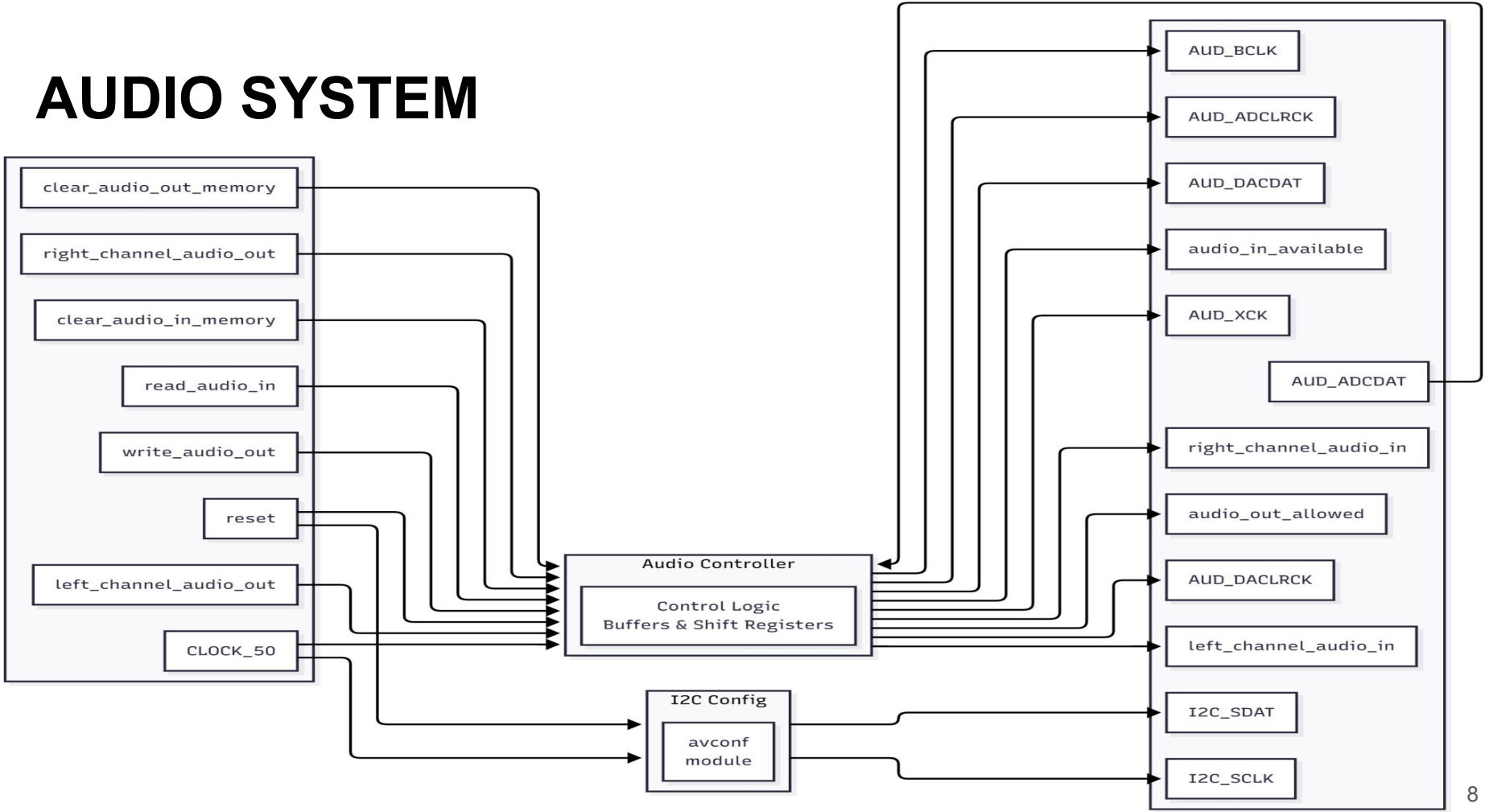
The VGA module displays a static 640x480 guitar image (MIF file) as the background.

Using animate logic, it displays 6 horizontal strings.

When a string is plucked, it erases and redraws it, resulting in a vibrating type animation.

After a certain number of cycles, the animation stops.

# AUDIO SYSTEM



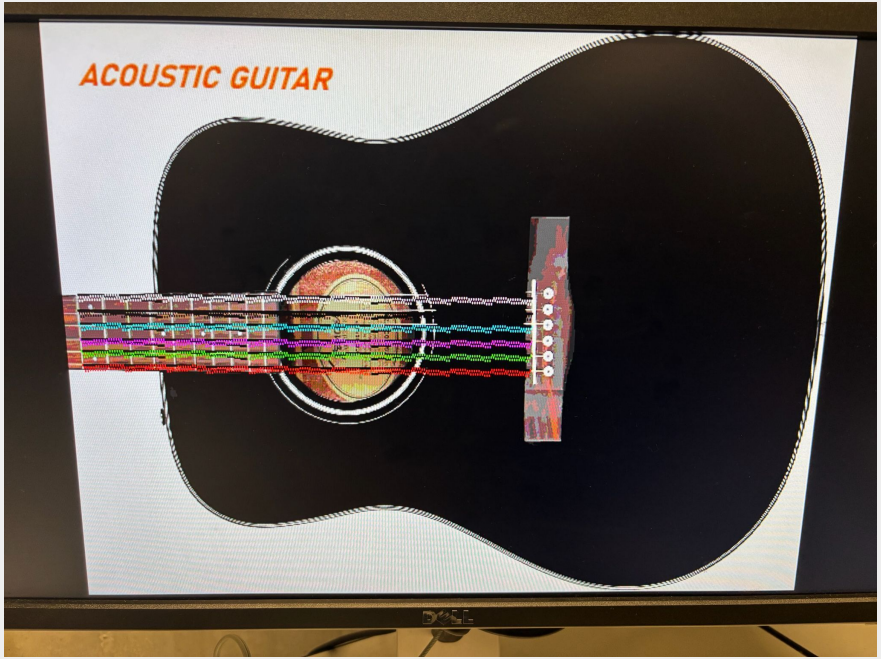
# Implementation challenges

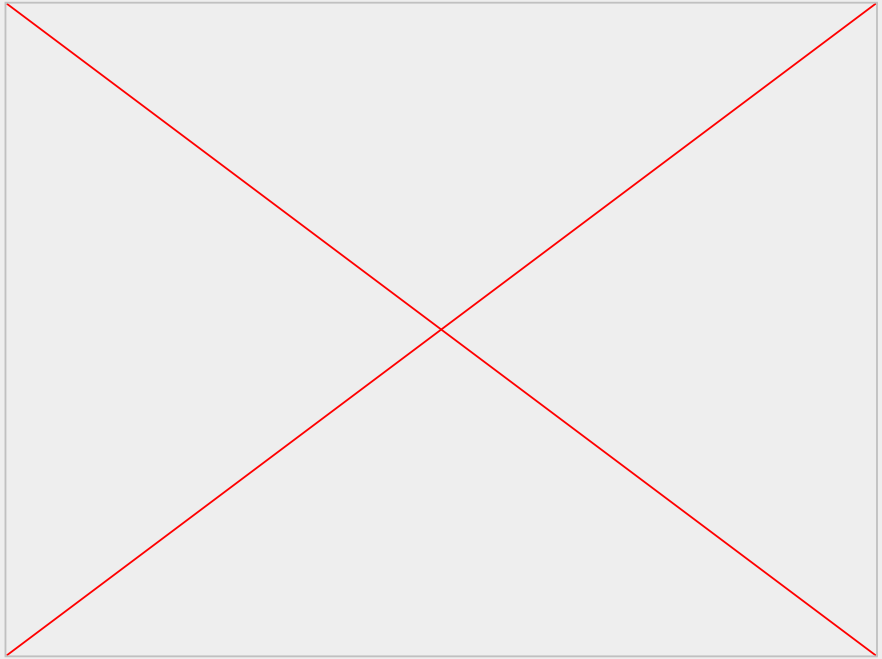
- Switching strings during decay phase caused the new note to auto-trigger

  Fix: New string selection requires a manual trigger (Spacebar).

- Positioning of strings on the guitar body was tricky, requiring precision.
- Choosing the right frequencies to sound as close to guitar strings as possible through trial and error.
- Bringing string animation to human comprehensible speeds through adjusting timings.

# Project pictures



# Future work:

- Upgrade the system to support dynamic pitch control, allowing selection of any note across the fretboard

- Integrate the PS/2 Mouse scroll wheel to initiate the pluck and measure the scroll speed to control the note's volume and intensity

# Final Work Distribution

**Mohammad Azlan**

Implemented the Karplus-Strong audio pipeline, integrated the Audio Controller, and verified timing/behavior on the FPGA.

Developed PS/2 keyboard input handling (keys 1-6 for string selection, spacebar trigger), and connected it to multi-string pluck logic.

Created the VGA background layout and positioned the guitar strings; contributed to the string-animation FSM design.

Performed simulation and debugging in ModelSim for both the audio and VGA modules.

**Kabir Jain**

Designed the FSM for Karplus Strong Core from scratch. (INIT/PLUCK/PLAY).

Developed the PS/2 keyboard interaction logic to capture user input and integrated comprehensive per-string control into the audio path, enabling dynamic parameter adjustment for individual strings

Developed the VGA string vibration animation and co-designed the animation FSMs.

Contributed to system testing, debugging, and ModelSim simulations of the audio + VGA subsystems.

# THANK YOU