

Laboratory 4

(Due date: **005**: March 17th, **006**: March 18th, **007/008**: March 19th)

OBJECTIVES

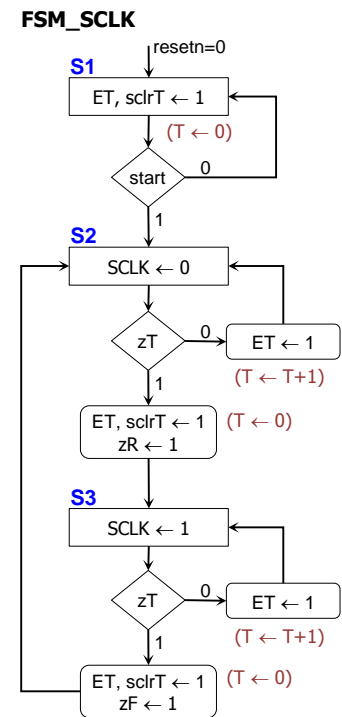
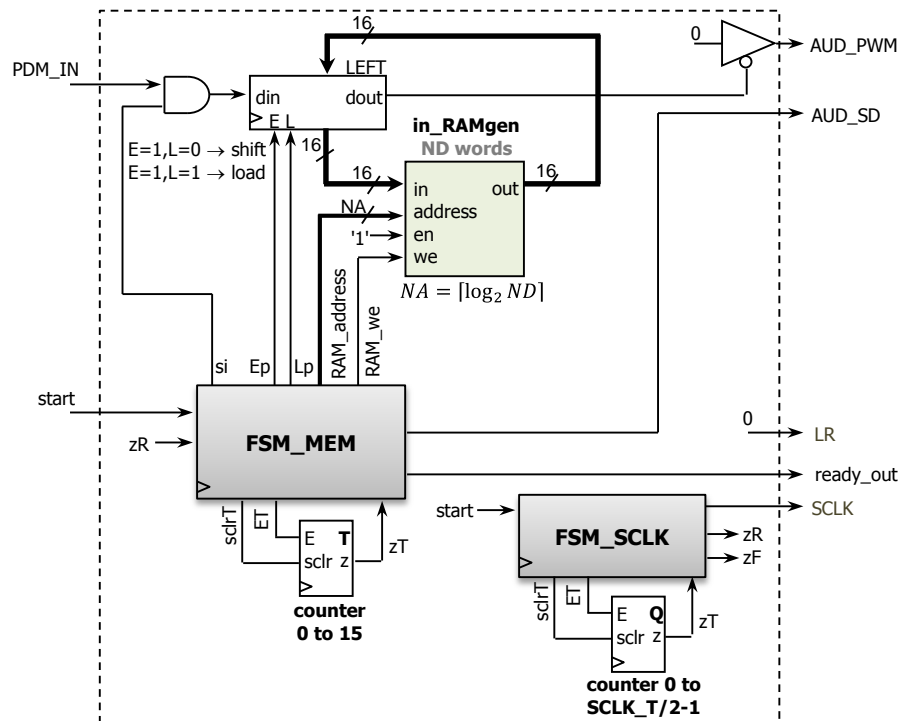
- ✓ Implement a Digital System: Control Unit and Datapath.
- ✓ Learn about reading PDM-coded input audio and playback PDM-coded output audio.
- ✓ Learn interfacing with MEMS microphones (that generate PDM signals) and using BlockRAMs in FPGAs.

VHDL CODING

- ✓ Refer to the [Tutorial: VHDL for FPGAs](#) for a tutorial and a list of examples.

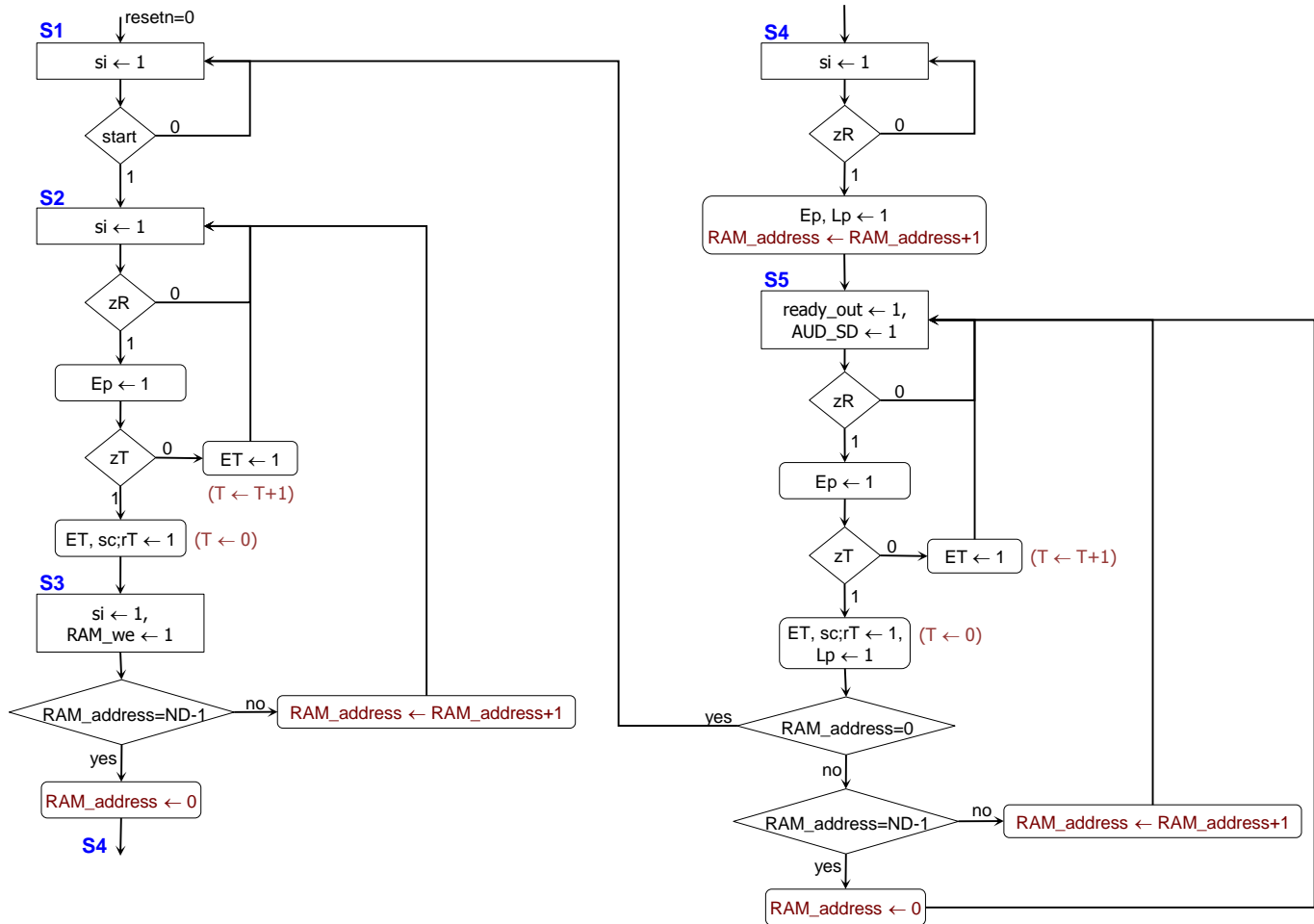
FIRST ACTIVITY: AUDIO RETRIEVAL AND PLAYBACK CIRCUIT (100/100)

- **MICROPHONE AND MONO AUDIO OUTPUT:** Implement the following circuit that reads data from the ADMP421 MEMS microphone, stores data in memory and plays data back on a mono audio output.



- **MEMS MICROPHONE (ADMP421):**
 - ✓ SCLK: 1 – 3 MHz. We use 1.2 MHz.
 - ✓ PDM_IN: PDM signal generated by the ADMP421.
 - ✓ LR: Left right control for stereo mode. We use LR = 0 (Data is captured on CLK rising edge).
- **MONO AUDIO OUTPUT:**
 - ✓ The on-board audio jack of the board (Nexys-A7-50T/A7-100T, Nexys 4-DDR) does not support stereo output. Thus, we only retrieve a mono audio input from the ADMP42 microphone (e.g. L/R = 0). Keep this in mind when testing (as only one speaker or earphone side will work).
 - ✓ The on-board audio jack is driven by a low-pass filter with 12 KHz cut-off frequency. We need to feed a PDM signal (AUD_PWM: open-drain output) into the low-pass filter. Note that AUD_PWM is the output of a tri-state buffer:
 - If we want to transmit a '0', AUD_PWM = '0'.
 - If we want to transmit a '1', AUD_PWM = 'Z'.
- **FSM_SCLK:**
 - ✓ This circuit generates a free running clock (SCLK). It also generates a pulse on zR when a rising edge on SCLK occurs, and a pulse on zF when a falling edge on SCLK occurs. We want to use a frequency of 1.2 MHz. This requires SCLK_T=84.
 - You can use the VHDL code fsm_sclk.vhd (along with my_genpulse_sclr.vhd) with the parameter COUNT_SCKLHP = SCLK_T/2=42.

- **MEMORY:** Implemented with the on-chip memory (BlockRAMs) inside the Artix-7 FPGA.
 - ✓ Data requested or to be written is available on the next clock cycle. Use the given VHDL code `in_RAMgen.vhd`. This is a 2D memory of `nrows×ncols`. Word length: 16 bits. We can use it as a 1D memory by making `ncols=1`. Use the following parameters `nrows=(this depends on the board)`, `ncols=1`, `INIT_VALUES="NO"`, `FILE_IMG="myinival.txt"`.
 - For Nexys A7-100T/Nexys-4 DDR, use: `nrows=512*512`
 - For Nexys A7-50T, use `nrows=512*256` (there is less memory in the FPGA inside this board)
- **FSM_MEM:** This is the main controller. This FSM embeds the counter `RAM_address`. Make sure to use the correct ND:
 - ✓ $ND = 512 \times 512 = 2^{18}$ for Nexys A7-100T/Nexys-4 DDR. Sequence duration: $2^{18} \times 16 \times 84 \times 10ns = 3.52$ seconds.
 - ✓ $ND = 512 \times 256 = 2^{17}$ for Nexys A7-50T.



PROCEDURE

- **Vivado: Complete the following steps:**
 - ✓ Create a new Vivado Project. Select the corresponding Artix-7 FPGA device (e.g.: the XC7A100T-1CSG324 FPGA device for the Nexys A7-100T board).
 - ✓ Write the VHDL for the given circuit. Synthesize your circuit. (Run Synthesis).
 - Use the **Structural description**: Create (or re-use) a separate `.vhd` file for i) parallel access shift register, ii) `inRAM_gen`, iii) `FSM_MEM`, iv) `FSM_SCLK`, and v) top file (where you will interconnect them all).
 - Use the proper parameters and I/O connections. Note that `FSM_SCLK` is made out of two `.vhd` files.
 - ✓ Write the VHDL testbench (generate a 100 MHz input clock for your simulations).
 - To avoid long simulation times, use `nrows=4x4`, `ncols=1` and `COUNT_SCLKHP = SCLK_T/2 = 2` for simulation purposes (resynthesize your circuit).
 - `PDM_IN`: Generate the following serial input stream (4x4 16-bit words), where each bit is to be captured at the rising edge of `SCLK`: 1110 1100 1110 1011 0100 0111 0001 0000 1010 1100 1110 1101 1110 1010 1010 0001 and then just 1's. These bits are stored in memory (`inRAM_gen`) as 16-bit values: ECEB 4710 ACED EA51 FFFF ... FFFF.

- ✓ Perform Behavioral Simulation (Run Simulation → Run Behavioral Simulation). **Demonstrate this to your TA.**
 - To help debug your circuit, add internal signals to the waveform (e.g.: FSM_MEM/state, RAM_address, SCLK, inRAM_gen/in, inRAM_gen/out, etc).
 - Run the simulation for 21 us (remember to use `nrows=4x4, ncols=1, COUNT_SCLKHP = SCLK_T/2 = 2`).
 - Verify that the hexadecimal values (see testbench directions) appear on inRAM_gen/out (memory output) during state S5 in FSM_MEM.
 - Verify that the serial stream (see testbench directions) appears on dout (parallel access left shift register output)

- ✓ I/O Assignment: Create the XDC file associated with your board.

- Suggestion (Nexys A7-50T/A7-100T, Nexys 4/DDR):

Board pin names	CLK100MHZ	CPU_RESET	BTNC	M_DATA	M_CLK	M_LRSEL	AUD_PWM	AUD_SD	LED0
Signal names in code	<i>clock</i>	<i>resetn</i>	<i>start</i>	PDM_IN	SCLK	LR	AUD_PWM	AUD_SD	ready_out

- ✓ Implement your design (Run Implementation).

- ✓ Generate and download the bitstream on the FPGA. Test the circuit. **Demonstrate this to your TA.**

- Press start and record an audio sequence for 3.52 seconds (this is for the Nexys A7-100T/Nexys-4 DDR). After that, the audio sequence is played back (use a headphone/speaker).

- Submit (as a .zip file) the generated files: VHDL code, and VHDL testbench, and XDC file to Moodle (an assignment will be created). DO NOT submit the whole Vivado Project.

TA signature: _____

Date: _____