2024 EE5250 VLSI Design Final Project

Due date: 2024/12/26 (upload to eeclass)

Note

1. The final project is a group assignment for only 2 people per group.
2. Please generate report with pdf format and name report as VLSI_Final_ID1_name1_ID2_name2.pdf. At first page, please add your student IDs and names.
3. Please hand in the SPICE netlist file (.spi) and layout file (.gds).
4. Try to make the information "readable". (Don't use black color in background for your screenshots).
5. Make sure to mark the **titles** and **units** of x-axis and y-axis in all waveforms.
6. Please note that pin names on your layout should be marked on **metal layers**, not on diffusion or poly.
7. Discussion is encouraged, but the results and comments can't be shared.

I. Introduction

The Random Interleaved Sampling (RIS) method [1] is an interleaving scheme designed to spectrally shape the inter-channel mismatch error in time-interleaved analog-to-digital converters (TI ADCs). In this project, you will be asked to design a digital circuit to implement the RIS method and verify the functionality of your design using MATLAB. To facilitate understanding, the core concept of the RIS method will be elucidated through a metaphor.

Imagine that you are a screenwriter of a harem anime (the TI ADC), in which a total of N heroines (the sub-ADC channels), each with their unique personality and charm points (the inter-channel mismatch), take turns being the focus of each episode (the data sample) in the anime series (the output time-series). To make the scenario intriguing, the following four guidelines must be obeyed:

1. **Concentration**: Only one heroine can be the focus of an episode. Each episode should center around a single heroine, highlighting her unique traits and storyline.
2. **Non-repetitive**: In any consecutive M episodes, one heroine can only be the focus once. This ensures that no heroine appears as the central focus too frequently, keeping the narrative fresh and varied.
3. **Balance**: Every heroine should have an equal number of episodes where she is the main focus, ensuring that each character gets a fair share of attention throughout the series.
4. **Randomness**: The order in which the heroines are the focus should be random. The scenario of each episode should be unpredictable, adding an element of surprise and maintaining audience interest.

Please design the RIS logic with **N = 4** under the **0.18 µm** process, and ensure that your circuit and simulation follows the design specifications below.

II. Design specification

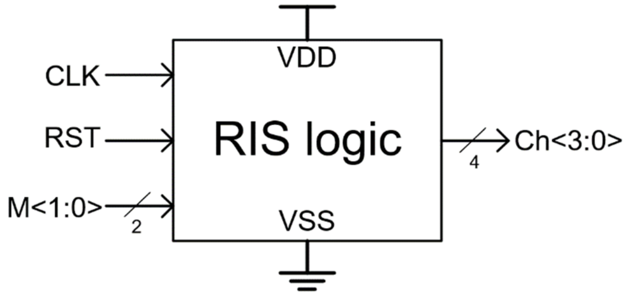


Fig. 1. The pin assignment of the RIS logic with N = 4

Pin order	Pin name	Pin definition
1	CLK	Clock
2	RST	High active synchronous reset
3	VDD	Power
4	VSS	Ground
5 ~ 6	M<1:0>	M-1 for RIS (e.g. M = 2 => M<1:0> = [0, 1])
7 ~ 10	Ch<3:0>	The heroines (high => being the focus)

Table 1. The pin definition of Fig.1

Heroine	Name	Signal	QAM Symbol
	Anna Yanami	Ch<3>	$\frac{1+j}{\sqrt{2}}$
	Lemon Yakishio	Ch<2>	$\frac{-1+j}{\sqrt{2}}$
	Chika Komari	Ch<1>	$\frac{-1-j}{\sqrt{2}}$
	Kaju Nukumizu	Ch<0>	$\frac{1-j}{\sqrt{2}}$

Table 2. The kawaii heroines!!!!!

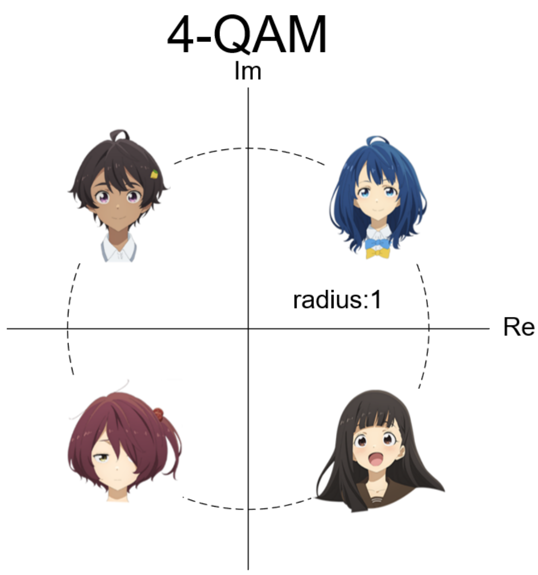
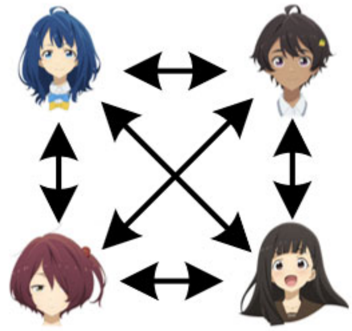
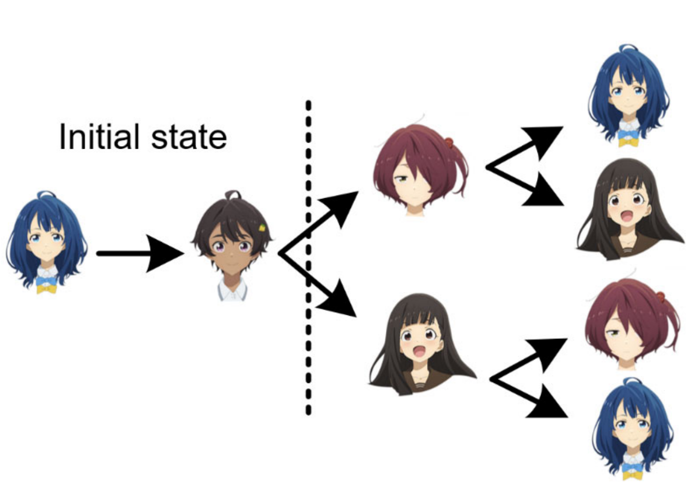


Fig. 2. The QAM constellation

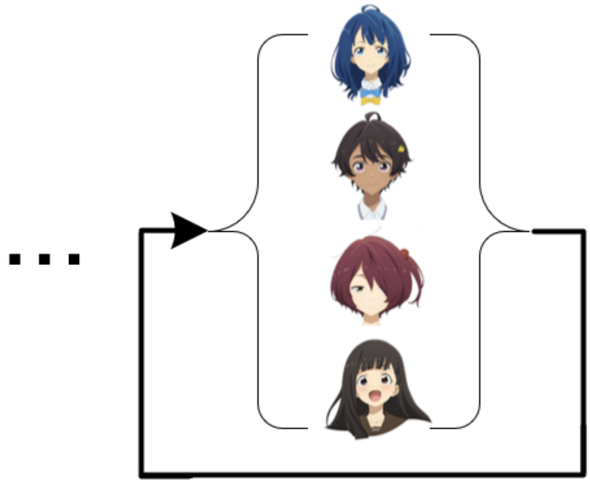
(a) M = 4



(c) M = 2, arrows are with probability $\frac{1}{3}$



(b) M = 3, arrows are with probability $\frac{1}{2}$



(d) M = 1, bracket is with probability $\frac{1}{4}$

Fig. 3. The design example of M = 1 ~ 4 for the N = 4 RIS logic

(a) repetition in consecutive 3 episodes

(b) repetition in consecutive 2 episodes

Fig. 4. The faulty design example: (a) illegal in the M = 3 ~ 4 case (b) illegal in the M = 2 ~ 4 case

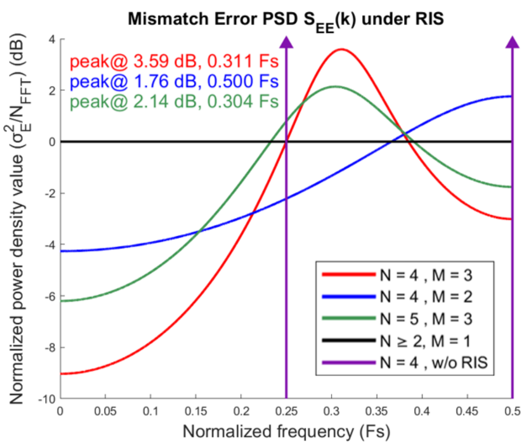


Fig. 5. The ideal spectrum of M = 1 ~ 4 for the N = 4 RIS logic

(M = 4 case has no randomness, hence labeled as w/o RIS)

1. Your design is only allowed to use the pins listed in Fig. 1 and Table 1.
2. Table 2 defines the heroines [2] in this project.
3. The RIS guideline **Concentration** indicates that the signal Ch<3:0> should be one-hot, which means there is one and only one bit of it that is high.
4. Fig. 3 and 4 show the correct and faulty design examples for the RIS guideline **Non-repetitive**. Notice that, the heroine series in the M = 4 case is not random, and there is no faulty design in the M = 1 case.
5. To test the RIS guidelines **Balance** and **Randomness**, the fastest way is to perform 4-QAM modulation of the heroine series and analyze it in the frequency domain using FFT. The constellation diagram and the symbol definition are shown in Fig. 2 and Table 2.
6. Mathematically, the RIS guideline **Balance** means that the DC component of the spectrum is 0.
7. Mathematically, the RIS guideline **Randomness** means that the spectrum will be as shown in Fig. 5, which guarantees that the transition probability from one heroine to each other in your design is equal.
8. In real case, 6 & 7 will suffer from the statistical errors. Therefore, we will check **Balance** and **Randomness** by observing the spectrum. (However, the DC power and the SNDR boost under 4x oversampling ratio will still be calculated to help you verifying the functionality of your design.) In contrast, **Concentration** and **Non-repetitive** will be directly checked by MATLAB.
9. Your subcircuit name and pin order can only be defined as follows:

   .subckt RIS CLK RST VDD VSS M<1> M<0> Ch<3> Ch<2> Ch<1> Ch<0>
10. Name your .spi file as **RIS.spi** (for pre-sim) and **RIS.pex.spi** (for post-sim).
11. You can only modify the file **Data.txt** in HSPICE simulation.
12. The maximum allowable VDD in this project is 1.8V.
13. Test your .spi files with **RIS.sp**, and check the power of your design in the file **RIS.lis**.
14. Dump **4 (M = 1 ~ 4 cases) x 1024 (FFT points) = 4096 samples** of the signal **Ch<3:0>** into the file **RIS.csv**, and check the functional correctness of your design with **RIS.m**, under the operating frequency and voltage you set in **Data.txt**.
15. Before joining the FoM ranking, your design should be functional work in all 5 corners (TT, FF, SS, FS, and SF), with an aspect ratio (long side / short side) ≤ 3, VDD ≤ 1.8V, and be DRC & LVS clean.
16. The FoM is defined as $\sqrt{\mathrm{Area}(\mathrm{um}^2)} \times \frac{\mathrm{Power}(\mathrm{uW})}{F_{CLK}{}^2(\mathrm{MHz}^2)}$ (post-sim, TT).

III. Report (75%)

Please write the report according to the following format:

1. Top-level design (15%)

(a) Please draw the block diagram of your top-level circuit, discuss on your design. (5%)

(b) Please draw the block diagram of your pseudo-random generator (PRG) circuit, which generates the desired probabilities for RIS method implementation, discuss on your design. (5%)

(c) Please discuss on how you optimize your design in detail. which block is the speed bottleneck? (5%)

2. M = 4 case (5%)

(a) Please draw the block diagram of your logic in this case, discuss on your design. (5%)

3. M = 3 case (10%)

(a) Please draw the block diagram of your logic in this case, discuss on your design. (5%)

(b) Please discuss on how you generate the probability $\frac{1}{2}$ using the PRG. (5%)

4. M = 2 case (10%)

(a) Please draw the block diagram of your logic in this case, discuss on your design. (5%)

(b) Please discuss on how you generate the probability $\frac{1}{3}$ using the PRG. (5%)

5. M = 1 case (10%)

(a) Please draw the block diagram of your logic in this case, discuss on your design. (5%)

(b) Please discuss on how you generate the probability $\frac{1}{4}$ using the PRG. (5%)

6. Simulation Result (25%)

(a) Please take a screenshot of your layout (with area and aspect ratio labeled), and the DRC/LVS result. (5%)

(b) Please take a screenshot of the waveform of Ch<3:0> in Waveview, the verification result of functional correctness, and the spectrum in MATLAB, for all 4 cases, 5 corners, as well as pre/post-sim. Additionally, fill the SPEC table, and provide a discussion on the results. (4 x 5 x 1% = 20%)

SPEC Table					
Power Supply (≤ 1.8) (V)					
Layout Area (um^2)					
Layout aspect ratio (≤ 3)					
FoM = $\sqrt{\mathrm{Area}(\mathrm{um}^2)} \times \frac{\mathrm{Power}(\mathrm{uW})}{F_{CLK}{}^2(\mathrm{MHz}^2)}$ (post-sim, TT)					
Pre-sim	TT	FF	SS	FS	SF
Max. freq. (MHz)					
Power (uW)					
Functional Work? (pass / M = X failed)					
Post-sim	TT	FF	SS	FS	SF
Max. freq. (MHz)					
Power (uW)					
Functional Work? (pass / M = X failed)					

IV. FoM Ranking (10%)

1. The top-performing student receives all the points in this part, the lowest-performing student receives 0 points in this part, and the remaining students are graded proportionally.
2. Before joining the FoM ranking, your design should be functional work in all 5 corners (TT, FF, SS, FS, and SF), with an aspect ratio (long side / short side) ≤ 3, VDD ≤ 1.8V, and be DRC & LVS clean.

V. Demo (15%)

1. The time and location of the demo session will be announced on eeclass.
2. In the demo session, you will have to describe your design to TAs and explain your design considerations. In additions, TAs might ask you some questions about your design.
3. The simulation/DRC/LVS/PEX results will be shown to the TAs, and the TAs will record your FoM.
4. It's necessary to **bring your laptop** to show the MATLAB verification results.
5. The grading of your FoM ranking depends on the result you provide in the demo session, and the SPEC Table in your report should be matched to the result.

VI. Reference

[1] M. Tamba, A. Shimizu, H. Munakata, and T. Komuro, "A method to improve SFDR with random interleaved sampling method," in Proc. IEEE Int. Test Conf., pp. 512–520, Nov. 2001

[2] "https://ani.gamer.com.tw/animeVideo.php?sn=38881", the link of the anime "Too Many Losing Heroines", which is **strongly recommended to watch** by the TAs

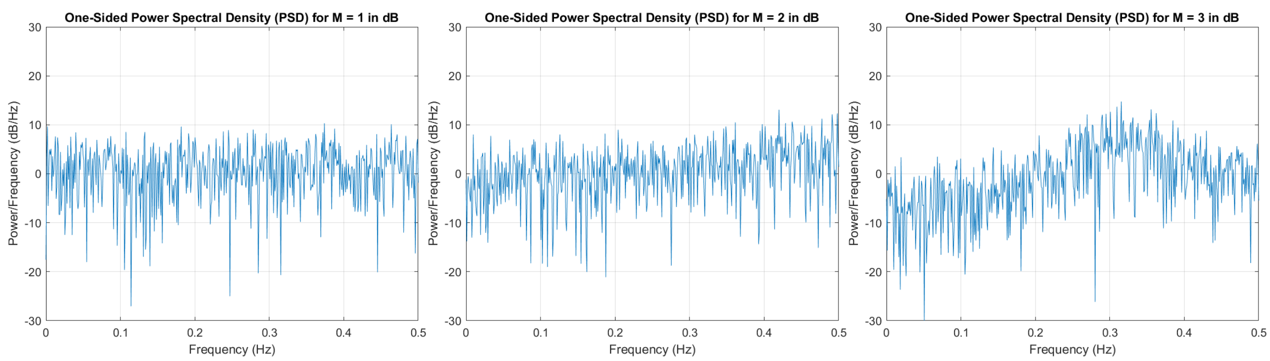
VII. Appendix: MATLAB behavior model simulation example

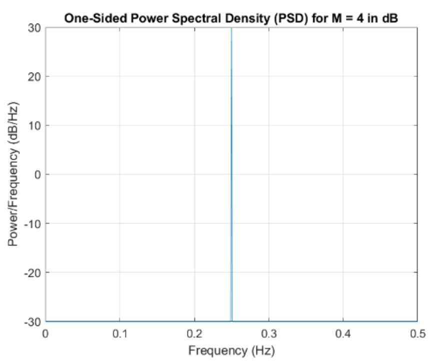
- Before enabling the behavior model simulation, please comment the block `test mode` and uncomment the block `behavior model` in RIS.m.

- If the RIS functionality is correct, the comment window in MATLAB will display:

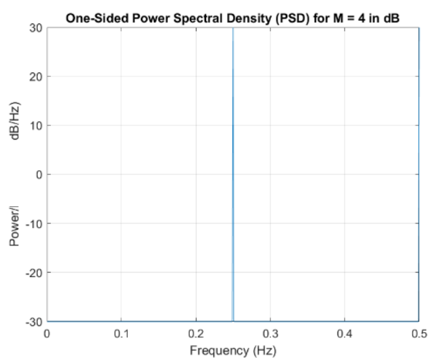
```
Concentration test
Congratulation!!!!! Your design passed the test of Concentration rule.

Non-repetitive test
Congratulation!!!!! Your design passed the test of Non-repetitive rule.

Balance test
Check whether the DC power of the PSD is small enough for cases M = 1 ~ 3
If the DC power is larger than 10dB, your design might be failed in the Balance test.
DC Power in dB for case M = 1: -1.5782dB
DC Power in dB for case M = 2: -4.5885dB
DC Power in dB for case M = 3: -12.4687dB

Randomness test
Check whether the SNDR boost is close enough to the ideal one for cases M = 1 ~ 3
If the gap is larger than 2dB, your design might be failed in the Randomness test.
Measured SNDR boost for case M = 1: 6.103dB
Ideal SNDR boost for case M = 1:    6.0000dB

Measured SNDR boost for case M = 2: 8.9726dB
Ideal SNDR boost for case M = 2:    8.8628dB

Measured SNDR boost for case M = 3: 13.5142dB
Ideal SNDR boost for case M = 3:    13.1330dB

Balance and Randomness test
Compare the PSD with Fig.5 in the PDF for cases M = 1 ~ 4
If the PSD looks different, your design might be failed in the Balance or Randomness test.
```

- And the PSD will be like:





OR



- Notice that there is a slope in the M = 2 case, in contrast with the M = 1 case.

- In the M = 4 case, it's acceptable whether there is a tone @ 0.5 Fs or not.