# Communication Systems Laboratory
# Lab 2: Up/Down-sampling and Filtering

**Report Due: 11:59 pm, Sep. 30, 2025**

The goals of this lab are: (a) perform up-sampling and down-sampling and (b) apply the Square Root Raised Cosine (RRC) filter.

For the submission, please use the MATLAB live script (.mlx).

## [Part 1] Sampling rate adaptation (38.5 points)

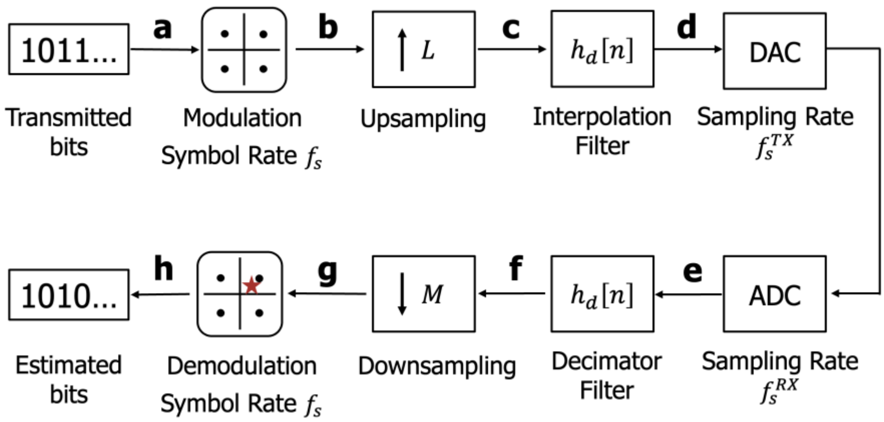


Figure 1. Simulation of transmitter and receiver with different sampling rates.

In this lab, we emulate a transmission in which the transmitter and receiver operate at different sampling frequencies, which typically happens when using equipment of different versions or from different companies. The goal is to transmit and receive symbols successfully. Let's assume the following parameters:

- Symbol rate $f_s = 5$ Hz
- Transmitter's DAC sampling rate $f_s^{TX} = 30$ Hz
- Receiver's ADC sampling rate $f_s^{RX} = 7.5$ Hz

In this lab, please use the provided MATLAB variables (bits, Symbols, tSamp). Here, tSamp is the sample times for the 32 symbols, and the 32 Symbols are generated from bits using the following MATLAB script:

```
Symbols = qammod(bits, 16, 'gray', InputType='bit', UnitAveragePower=true);
```

(1) What is the upsampling factor $L$ from symbols to the DAC? What is the downsampling factor $M$ from the ADC to the symbols?

(2) Perform upsampling to Symbols (**b**) to obtain the upsampled signal (**c**). Plot the real part of (**b**) and (**c**) in the time domain on the same figure. Please provide a clear legend and label the x-

axis with the correct time in seconds.

(3) Following (2), plot the magnitude of the two frequency spectrums, (**b**) and (**c**), on the same figure with 0 Hz in the center, i.e., the range of the frequency in the x-axis should be from -15 Hz to 15 Hz. Please provide a clear legend and label the x-axis with the correct frequency unit.

(4) Apply the interpolation filter in the frequency domain to obtain the interpolated signal (**d**). Please plot the magnitude of the two frequency spectrums, (**c**) and (**d**), on the same figure with 0 Hz in the center, clear legend, and correct frequency unit.

(5) Please plot the real part of (**b**) and (**d**) in the time domain on the same figure, with a clear legend and correct unit.

(6) To obtain signal (**e**), please directly downsample from signal (**d**) without applying any filter. Please plot the real part of (**d**) and (**e**) in the time domain on the same figure, with a clear legend and correct unit.

(7) Since the downsampling factor $M$ is not an integer, to downsample (**e**) back to a symbol rate of 5 Hz, you can first interpolate by a factor of $A$ and decimate by a factor of $B$. What is $A$ and $B$?

(8) Interpolate signal (**e**) by a factor of $A$. Please plot the real part of (**e**) and the interpolated signal in the time domain on the same figure, with a clear legend and correct unit.

(9) Following (8), to downsample the signal back to a symbol rate of 5 Hz, what is the range of the decimator lowpass filter to avoid aliasing (from x Hz to y Hz)? In this example, is the decimator filter needed?

(10) Following (8), downsample the signal by a factor of $B$ to obtain signal (**g**). Please plot the real part of (**b**) and (**g**) in the time domain on the same figure, with a clear legend and correct unit.

(11) Demodulate signal (**g**) to obtain the estimated bits. How many bit errors do you observe?

## [Part 2] Aliasing in downsampling (42 points)

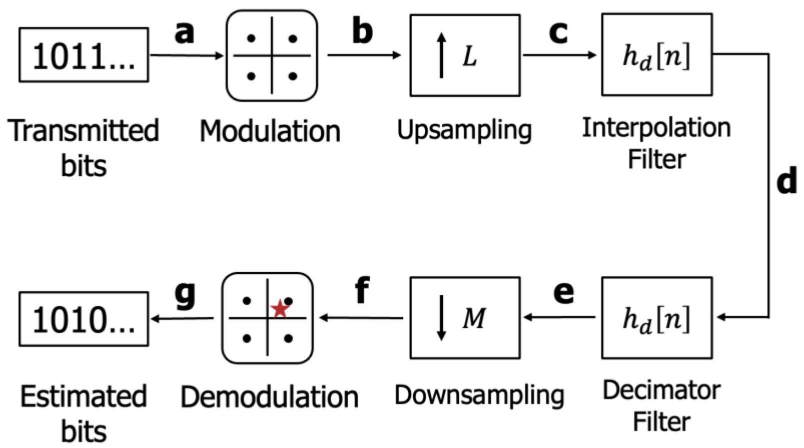


Figure 2. Simulation for aliasing in downsampling.

In this lab, we will observe the effect of aliasing in the downsampling process. The simulation procedure is illustrated in Fig. 2 with parameters as follows:

- Symbol rate = 5 Hz.
- Modulation scheme: BPSK.
- Upsampling factor $L = 6$.

- Downsampling factor $M = 9$.

**Bit pattern alternating between 1 & 0**
Transmitted bits: [1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0];

(1) Modulate the bits with BPSK, upsample it, and apply the interpolation filter to obtain signal (**d**). Please plot the real part of (**b**) and (**d**) in the time domain on the same figure, with a clear legend and correct unit.
(2) Please plot the magnitude of two frequency spectrums, (**b**) and (**d**), on the same figure with 0 Hz in the center, clear legend, and correct frequency unit.
(3) Apply the decimator filter to signal (**d**) to obtain signal (**e**). Please plot the magnitude of the two frequency spectrums, (**d**) and (**e**), on the same figure with 0 Hz in the center, clear legend, and correct frequency unit. What do you observe and why?
(4) Downsample signal (**e**) to obtain signal (**f**). Please plot the real part of (**b**), (**d**), and (**f**) in the time domain on the same figure, with a clear legend and correct unit. What do you observe and why?
(5) Unlike (3), let's assume the decimator filter is omitted in the process. That is, dowsample signal (**d**) directly without applying decimator filter. Please plot the magnitude of the two frequency spectrums, (**d**) and (**f**), on the same figure with 0 Hz in the center, clear legend, and correct frequency unit. What do you observe? How is it different from the result in (3)? Why? (hint: aliasing)
(6) Following (5), please plot the real part of (**b**), (**d**), and (**f**) in the time domain on the same figure, with a clear legend and correct unit. What do you observe? How is it different from the result in (4)? Why?

**Bit pattern alternating between 111 & 000**
Transmitted bits: [1,1,1,0,0,0,1,1,1,0,0,0,1,1,1,0,0,0];

(7) As in (1), modulate the bits with BPSK, upsample it, and apply the interpolation filter to obtain signal (**d**). Please plot the real part of (**b**) and (**d**) in the time domain on the same figure, with a clear legend and correct unit.
(8) As in (2), please plot the magnitude of two frequency spectrums, (**b**) and (**d**), on the same figure with 0 Hz in the center, clear legend, and correct frequency unit.
(9) As in (3), apply the decimator filter to signal (**d**) to obtain signal (**e**). Please plot the magnitude of the two frequency spectrums, (**d**) and (**e**), on the same figure with 0 Hz in the center, clear legend, and correct frequency unit. What do you observe and why?
(10) As in (4), downsample signal (**e**) to obtain signal (**f**). Please plot the real part of (**b**), (**d**), and (**f**) in the time domain on the same figure, with a clear legend and correct unit. What do you observe and why?
(11) As in (5) and (6), let's assume the decimator filter is omitted in the process. That is, dowsample signal (**d**) directly without applying decimator filter. Please plot the real part of (**b**), (**d**), and (**f**) in the time domain on the same figure, with a clear legend and correct unit. What do you observe? How is it different from the result in (10)? Why?
(12) Compare the results you obtain in (6) and (11) for different bit patterns, what do you observe?

## [Part 3] Square Root Raised Cosine (RRC) filter (17.5 points)

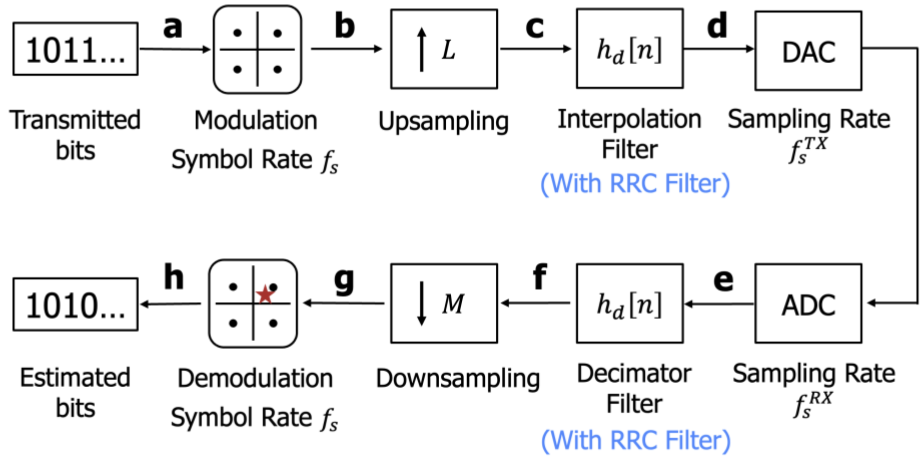


Figure 3. Simulation of transmitter and receiver with different sampling rates.

In Part 3, we continue the simulation in Part 1 to observe the effect of RRC filtering. All parameters follow Part 1 except:

- The receiver's ADC sampling rate $f_s^{RX} = 10$ Hz (instead of 7.5 Hz).

This selection of sampling rate ensures an integer number of samples per symbol at the receiver side for simplicity. As illustrated in Fig. 3, for the interpolation and decimator filters, use RRC filters with a roll-off factor $\alpha = 0.5$. You may use MATLAB built-in functions like rcosdesign.

(1) Consider the RRC filters to have a span of 6 symbols. Note that the DAC and ADC have different sampling rates, and the RRC filters need to be designed according to their sampling rates. Plot the RRC filter in the time domain for both the transmitter and receiver sides on the same figure, with a clear legend and correct unit.

(2) Following (1), plot the magnitude of the frequency spectrums of the RRC filters on the same figure with 0 Hz in the center, with a clear legend and correct unit.

(3) Apply the RRC filter to signal (**c**) to obtain signal (**d**). Plot the real part of signal (**b**) and (**d**) in the time domain on the same figure, with a clear legend and correct unit. Do you observe inter-symbol interference?

(4) As in Part 1, to obtain signal (**e**), directly downconvert from signal (**d**). Then, apply the RRC filter to obtain signal (**f**). Plot the real part of signal (**b**), (**d**), and (**f**) in the time domain on the same figure, with a clear legend and correct unit. Do you observe inter-symbol interference?

(5) Continue to downsample and demodulate as in Part 1. Plot the transmit and constellations on the same figure. Are the constellations identical?

Grading:

- 3.5 points for each problem. 98 points in total for 28 questions.
- 2 points for submitting the assignment.