

LAB-3

2D FIR DESIGN

INTRODUCTION

In this exercise, we will focus on the design of 2D finite impulse response (FIR) filters. In J-DSP, a 2D finite impulse response can be specified in three ways: First, by the **2D FIR Design1** block that uses a window-based design (Fig. 1(a)), second, by the **2D FIR Design2** block that uses the frequency sampling method (Fig. 1(b)), and third, by the **2D FIR Coeff** block in which you type in the 2D FIR coefficients directly (Fig. 1(c)).



Fig. 1(a) **2D FIR Design1** block



Fig. 1(b) **2D FIR Design2** block.



Fig. 1(c) **2D FIR Coeff** block

Fig. 2 shows the 2D J-DSP editor. In fig. 2, the 2D blocks that are placed in the vertical line on the left hand side are called permanent blocks and are shown in green color. The blocks placed in the horizontal line are shown in yellow color and can be changed by selecting one of the options given in the drop-down menu on the top left corner of the screen. It is always recommended to use any 2D block separately before it is connected with others and to read the [Help] screen of every new block you use.

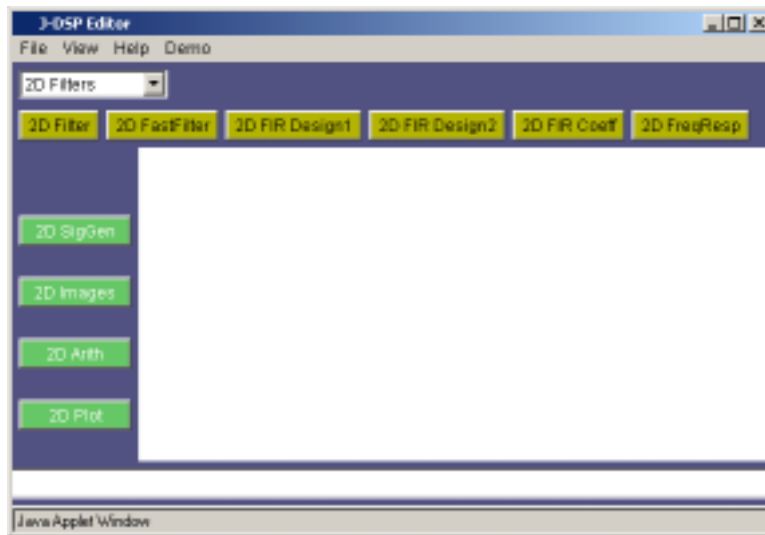


Fig.2 2D J-DSP

In this lab, we will first study the design of 2D FIR filters using the window method. We will consider different windows characteristics and issues associated with separable and non-separable design techniques. Then we will use frequency-sampling method to design 2D FIR filters and will compare the quality measures and complexity issues related with these two design techniques. In FIR filter design, the measure of filter quality is around 3 numbers: maximum error in the pass-band (δ_p), maximum error in the stop-band (δ_s) and transition band $\omega_s - \omega_p = \Delta\omega$. As these parameters become smaller, the quality of the filter improves. The filter order is given by the length of the filter impulse response and is the measure of complexity.

Note: Give reasons for all the answers to the questions, and where necessary, give appropriate J-DSP plots (Time/Frequency-domain) in order to justify your answers. You may need to use other 2D blocks as well.

Remember, the perspective plot provides a quick feel for the quality of the filter and the contour plot is more helpful for measuring the circularity of the pass-band and stop-band.

Design of 2D FIR filters using windows is a spatial domain method; that is, we try to approximate an ideal impulse response by multiplying it with a window function.

Mathematically,

$$h(n_1, n_2) = i(n_1, n_2) * w(n_1, n_2)$$

Where

$w(n_1, n_2)$ is a window function.

$i(n_1, n_2)$ is the impulse response of the ideal filter.

$h(n_1, n_2)$ is the impulse response of the filter designed by the algorithm.

Problem 3.1

Design FIR filters using a non-separable hamming window of orders 11 and 21 to approximate the ideal frequency response.

$$I(\omega_1, \omega_2) = \begin{cases} 1, & (\omega_1^2 + \omega_2^2) \leq (0.6\pi)^2 \\ 0, & \text{otherwise } -\pi \leq (\omega_1, \omega_2) \leq \pi \end{cases}$$

- Does the window-order have any effect on the filter quality?
- Suppose one of the filters is to be implemented in a system and memory is the constraint, which designed filter would you choose (11 or 21)? Why?

Problem 3.2

Design an FIR band-pass filter of order (21×21) with cut-off frequencies of 0.2π and 0.7π . Use rectangular windows of both types; that is, the separable and the non-separable (circularly symmetric) windows. Use **2D Frequency Response** block to see the frequency response of the designed filters.

Note: Use Non-separable filter type in this simulation.

- What is the shape of the region of supports (ROS) of the two designs?
- When implementing the above designed filters, which one is more efficient? Why?
- Which designed filter gives better filter quality? Why?
- In terms of complexity, which one is better, separable or non-separable?

Problem 3.3

Design an FIR band-pass filter with the same cut-off frequencies as in the previous question but with an order of (11×11) using separable:

- o Rectangular window
- o Hamming window
- o Bartlett window

Use **2D Frequency Response** block to answer the questions listed below.

Note: Use Non-separable filter type in this simulation.

- Which designed filter gives sharp cut-off?
- Which designed filter gives better stop-band characteristics?
- When designing any FIR filter with the sharp cut-off, what is the compromise that has to be made?

Problem 3.3.1

If memory resources do not allow using more than (11×11) filter-order, design an FIR low-pass filter using separable Kaiser window with cut-off frequency of 0.5π with the same exact pass-band characteristics as that of the filter designed with the separable rectangular window of the same order.

Problem 3.4

A system-programmable causal FIR low-pass filter is to be designed for a real-time portable device with cut-off frequency of 0.6π . Due to memory constraints and to make the system more efficient, this causal 2D FIR filter cannot hold more than 10 previous (old) samples.

- i) When there is an information signal present at the input of the FIR filter, we want sharp cut-off and in the absence of that signal, better stop-band characteristics of this FIR filter are required. Design a tunable FIR filter that is most suitable to implement on this device. Give reasons for all the specifications you choose to design this filter. Remember this 2D FIR filter is system programmable, which means the values of its certain parameters can be changed at any time.
- ii) If implementation complexity were the major constraint, which window would you use to design this FIR filter? Why?

Note: Part i) and ii) are independent of each other and use non-separable filter type in this simulation.

Problem 3.5

Design an FIR filter of some fixed order using the frequency-sampling method and compare (quality measures and complexity) it with the window-based design. You don't have to submit any results for this problem.

Hint: Use different separable windows.

Problem 3.6

Now answer the following general questions.

Note: No plots are required. State answers clearly.

- a) In what respect does the frequency response of the window-based design differ from the ideal response?
- b) What is the major drawback of the Kaiser window? State the significance of beta (β) in the Kaiser window.
- c) If the impulse response of a 2D FIR filter satisfies the symmetry condition:

1. $h(n_1, n_2) = h(-n_1, -n_2)$

2. $h(n_1, n_2) = -h(-n_1, -n_2)$

what can be inferred about their frequency responses?

- d) What type of window is preferred in the design of an FIR filter to ensure better frequency selectivity?
- e) When designing an FIR filter of some fixed order using Kaiser window, what value of β gives the sharpest cut-off in the designed filter.