# PARTICLE SWARM OPTIMIZATION ALGORITHM BASED DESIGN AND ANALYSIS OF DIGITAL FIR FILTER USING KAISER WINDOW FUNCTION

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**Abstract:**

The digital filter hasa major role in signal processing whichismainly employed in applications forthe reduction of noise in various systems.To send and receive the signal unaltered, there is a need to design filters, which are not only able to remove the noise from the signal, but also signal processing itself does not add noise to the signal. It has been a daunting task for researchers to design digital filters for such systems.Also, there are numerous reasons to use the digital filter and it has forced scientists, engineers, and researchers for designing digital filters with improvised, proficient, and intelligent techniques using emerging modern tools and technology. Out of FIR and IIR Filters, the FIR filters are preferred because of their frequency stability and linearity in phase response. The design ofthe FIR filter has multi-modal optimization challenges. Many optimization algorithms are existing and are suggested by the researcher but it has their advantages and limitations. Further, PSO (Particle Swarm Optimization) algorithm has emerged as an adaptable technique based upon Swarm Intelligence (SI) more specifically particles' population in the search space. It has a great option for designing anFIR filter. PSO improves the solution characteristicsby providing a unique approach for updating the velocity and position of the swarm. An optimized set of filter coefficientsaregenerated by Particle Swarm Optimization Techniques which give the optimized results in the pass band and stop band.In this research paper, a digital FIR filter is designed using Kaiser Window Function. The designed filter is applied with the PSO algorithm to optimize the design of the filter in MATLAB. The resultsshow that the designed FIR filteris better than the previously designed FIR filter in the context of the frequency spectrum.

**KEYWORDS:** Particle Swarm Optimization (PSO), Finite Impulse Response Filter (FIR), Swarm Intelligence (SI), Kaiser Window Function.

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## 1. Introduction

Filters are generally used to remove unwanted noise added in the processing of data, images, or video at the source, channel, and destination of communication systems. Unlike analog filters, digital filters are advantageous, proficient, and intelligent for effectively filtering noise from various signals. Moreover, digital Filters are preferred to reduce noise or obtain certain aspects of the given signal. Mathematical operations are applied to the sampled discrete-time signal to obtain the desired results. Digital filters are classified into Finite Impulse Response (FIR) and Infinite Impulse Response (IIR) filters [1-4]. Based onthe dimension of an input signal, filters are classified into one-dimensional (1D) filters and two-dimensional (2D) filters for signal and image processing respectively [5]. Since FIR digital filters are inalienably stable and can have linear phases, they are commonly favored over IIR Filters. These FIR filters have numerous essential applications in digital signal and image processing.

Swarm Intelligence is natural intelligence. This is categorized into two groups of algorithms for solving complex engineering challenges. The first one is Ant Colony Optimization (ACO) and the second one is Particle Swarm Optimization (PSO).

In the PSO algorithm, a group of swarm particles is used and each particle retains its best solution encountered during the optimization process. At the same time, the algorithm has the memory of the global best position for the particle group. With proper choice, the particle swarm algorithm can converge to the global best solution efficiently.

The organization of this research paper is as follows. In section 2, the literature review is discussed. In Section 3,the design of the FIR filter and mathematical representations are discussed. Section 4 of this research paper contains the PSO algorithm in FIR filter design.In Section 5,results and discussions are presented. Conclusions are presented in section 6.

## 2. Literature Review

In paper [6] authors have modified PSO parameters. They have suggested in the paper that Particle swarm optimization (PSO) is one of the most well-regarded optimization tools. It has emerged as a very promising tool for optimization. However, it still suffers from premature convergence. They have also reviewed and presented many recent studies to utilize PSO for various engineering solutions.

In paper [7]authors have presented a two-dimensional filter using PSO and Simulated Annealing (SA). The work is based on integratinga global search of PSO and a local search of SAto overcome the weakness of each of the algorithms. This paper includes Metropolis acceptance criteria to increase the swarm's diversity to accept weaker solutions. The designed filter results improve the performance parameters.

Authors in paper [8] have proposed designing of Low Pass FIR filter using Kaiser Window Function. They use parameter value beta (β) between 0 and 4. They have also carried out a comparative study for a different order of filters thatare used to control the transition bandwidth.This paper exhibits that Kaiser Window (β) parameter can be controlled and it controls the main lone width and stopband attenuation of the filter.



In the research paper [9]authors have presented the design of an LP FIR filter using Particle Swarm Optimization (PSO). The design of the filter is done based onthe best solution obtained from PSO for the co-efficieints of the filter. The velocity vector is modified and hence the particle vectors are improved solutions. This improves the quality of the solution obtained using PSO algorithms.

The paper [10] describes the development of an adaptive equalizer using Quantum behaved Particle Swarm Optimization (QPSO). Authors have compared the performance of PSO with Least Mean Square (LMS), Constant Weight Intertia PSO, and Linear Decay Inertia PSO algorithms to determine the efficiency of PSO. It is claimed by the authors that QPSO improves performance.

Authors in paper [11] have presented the analysis of linear phase low pass FIR filter. They have used PSO algorithms and modified the inertia weight of PSO to improvethe searching ability of swarms. This has given the best global and optimal solution. It is claimed in the paper that the PSO simulation compared with other techniques performs better. The faster convergence and accurate co-efficient are obtained by using PSO algorithms.

In paper [12]Particle Swarm Optimization algorithm is applied for designing the LP FIR filter. The best filter co-efficient is obtained using PSO. Authors suggest that PSO is a simple swarm optimization technique applied for the optimization of multi-dimensional complex engineering challenges.

In the paper [13] authors have designed filters and compared optimal filter co-efficient and other parameters of the designed filter. To optimize the performance of the filter authors have applied Grasshopper Optimization algorithms (GOA). The LP linear phase FIR filter is designed using GOA. The paper describes the design of LP, HP, BP, and BS filters. The GOA models the grasshopper behavior in search of food sources. This behavior of grasshopper is applied for optimization of problem. GOA is used to obtain the optimal filter co-efficient. Authors claim to have reduced the ripples using GOA.

In the paper [14], the FIR filter is designed using PSO. The authors have compared the performance of ARPSO and CRPSO in MATLAB for designing of FIR filter. The performance is also compared with PM. The results obtained in the experiments show that the PSO-based algorithm performs better in terms of the frequency spectrum and RMS error while designing linear phase FIR filters.

In the paper [15], a comprehensive review of the designing of FIR and IIR filters using various optimization techniques is presented. Authors have more specifically presented the nature-inspired techniques for optimization of complex engineering issues. The Swarm Intelligence (SI), Cuckoo Search (CS), Grasshopper Optimization Algorithms, Particle Swarm Optimization, (PSO), Ant Colony Optimization (ACO Bat Algorithms (BA), Genetic Algorithms (GA), Artificial Bee Colony (ABC), Bacterial foraging optimization (BFO, Biogeography-based optimization (BBO), Harmony search (HS), Krill herd (KH), Social spider optimization (SSO), Symbiotic organisms search (SOS), Firefly algorithm (FA), Gravitational search algorithm (GSA), Grey wolf algorithm (GWO), Teaching-learning-based optimization (TLBO), Whale optimization algorithm (WOA)" techniques are well explained in this paper. This can be applied to designing digital filters and optimization of filter co-efficient.

In the paper [16], the evaluation of Hankel integration is used for the interpretation of electromagnetic data. The digital linear filter method is applied. The paper describes the application of Particle Swarm Optimization for the optimization of spacing and shift. The paper claims that the results show an improvement over previous techniques by use of PSO.

The review of the literature confirms that Particle Swarm Optimization techniques are one of the best emerging techniques for finding optimal filter co-efficient while designing FIR filters.

## 3. Design of FIR Filter

The Finite Impulse response (FIR) digital filter [17] is one whose impulse response is of finite duration. The impulse response is "finite" because there is no feedback in the filter. One dimensional FIR filter: a typical one-dimensional FIR digital filter can be characterized by the transfer function H(z) is,

$$H(z) = \sum_{n=0}^{N-1} h(n)z^{-1} \text{------------------------------------} (1)$$

$$H(z) = h(0) + h(1)z^{-1} + -- + h(n)z^{-(N-1)} \text{----------------} (2)$$

WhereNisthefilterlengthoftheimpulseresponseh(n).
Here,the output in time domain y(n)is

$$y(n)= x(n)*h(n) \text{ --------(3)}$$

andtheoutputinfrequencydomainY(z)is,

$$Y(z)= X(z)H(z) \text{ ------(4)}$$

Wherex(n)andX(z)aretheinputsignalsinthe timeandfrequency domain receptively. The frequency response of a one-dimensional FIR filteris;

$$H(w_k) = \sum_{n=0}^{N} h(n)e^{-jw_k n} \text{ ----- (5)}$$

Where k = 2πk/n; $H(w_k)$ is the Fourier transform complex vector. This is the FIR filter frequency response. The frequency in [0, π] is sampled with N points.

Kaiser window: It approximates the prolate spheroidal window. This is the ratio of the main-lobe energy to the sidelobe energy.The parameter β controls the relative sidelobe attenuation. For a given β, the relative sidelobe attenuation is fixed with respect to window length.
The statement kaiser(n,beta) computes a length n Kaiser window with parameter beta.The coefficients of a Kaiser window are computed with:

$$w(n) = \frac{I0\left(\beta\sqrt{1-\left(\frac{n-N/2}{N/2}\right).^2}\right)}{I0(\beta)} \quad \text{for } 0 \le n \le N \quad \text{------------- (6)}$$

where I0 is zeroorder modified Bessel function.

$$\text{Thelength } L = N + 1 \quad \text{----------------------------- (7)}$$

besseli(0,beta*sqrt(1-(((0:L-1)-(L-1)/2)/((L-1)/2)).^2))/besseli(0,beta)---(8)

Kaiser Windows is used in FIR filter Design. To get the desired filter design two equations for the calculation of β and n as mentioned in equations (9) to (12). To achieve a relative sidelobe attenuation of –α dB, the β (beta) parameter was used.

$$\beta = (0.1102(\alpha - 8.7)) \text{ for } \alpha > 50 \text{ ------------------------------------- (9)}$$

$$\beta = 0.5842(\alpha - 21)^{0\cdot 4} + 0.07886(\alpha - 21) \text{ for } 50 \ge \alpha \ge 21 \text{ ------- (10)}$$

$$\beta = 0 \text{ for } \alpha < 21 \text{ --------(11)}$$

$$n = \frac{\alpha - 8}{2.285\Delta w} + 1 \text{ ----------(12)}$$

## 4. PSO Algorithm in FIR Filter Design

The first PSO was presented by Kennedy and Eberhart as a continuous real-valued algorithm [18]. A swarm of particles flies in a D-dimensional search space searching foran optimal solution. The particle i storesthe current velocity vector

$$V_i = [v_{i1}, v_{i2}, . . . ,v_{iD}] \text{ --------- } (13)$$

A current position vector is stored as

$$X_i = [x_{i1}, x_{i2}, . . . ,x_{iD}] \text{ --------- } (14)$$

Where D is the number of dimensions.

The PSO starts by randomly initializing $V_i$ and $X_i$.Then, in each iteration, the best position that has been found by the particle as

$$iPbest_i = [Pbest_{i1}, Pbest_{i2}, . . . ,Pbest_{iD}] \text{ ----------------- } (15)$$

The best position is determined by swarms

$$Gbest = [Gbest_1, Gbest_2, . . . ,Gbest_D] \text{ -------------------- } (16)$$

The particle i updates velocity and position as mentioned in equations (17) and (18):

$$v_{id} (t + 1) = v_{id} (t) + c_1r_1 (Pbest_{id} (t) − x_{id}(t)) + c_2r_2 (Gbest_d (t) − x_{id}(t)) \text{ -------------}(17)$$

$$x_{id} (t + 1) = x_{id}(t) + v_{id} (t + 1) \text{ ----------------------------------}(18)$$

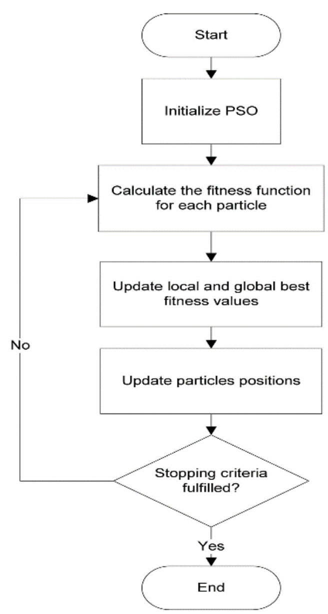



Fig. 1: Flowchart of PSO algorithm

Steps of PSOAlgorithm:

Step I. Define specification of filter, error fitness function, and swarm size and set the boundaries in terms of maximum and minimum value of the coefficient.

Step II. Initialize particles' population array to random positions and their certain velocities in search space.



Step III. Calculate fitness function value

Step IV. Update local and global best fitness value

Step V. Reevaluate the fitness function value and compare it with its pbest and gbest.

Step VI. Iterate continuously from step II to V until the maximum no of iterations or minimum error criteria condition is reached.

Step VII. The result is a set of the optimized coefficients of the desired filter.

## 5. Results and Discussions

FIR filter using Kaiser Window function is designed for with parameters mentioned in Table.1 in MATLAB and outputs are obtained in terms of coefficients and RMS error. Further, coefficients are optimized by designing the FIR filter using the PSO algorithm.

Kaiser window is generated for different ß values. Kaiser windows with length (n)20 and beta (β)parameters of 1, 4, and 8 are shown in Fig.2.

Kaiser(n,beta) is used to compute a length n Kaiser window with parameter beta.

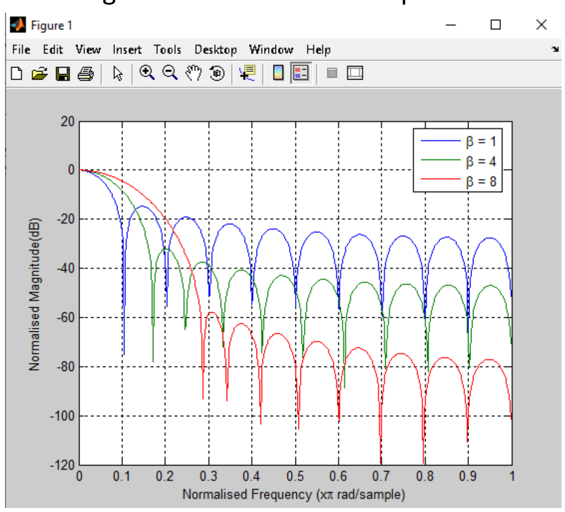



Fig.2: Kaiser Window with length 20 and beta parameters 1, 4, and 8.

With widow length 20, as the value of beta has increased the width of the main lobes increases as β is increased. Also, the side lobe attenuation decreases with an increase in parameter beta as shown in Fig.2.

Further, the Kaiser window is generated for different window lengths (n). Kaiser windows with lengths n= 20 (Kaiser1), n=40 (Kaiser2),and n=80 (Kaiser3) with a beta (β)parameter of 8 are shown in Fig.3.

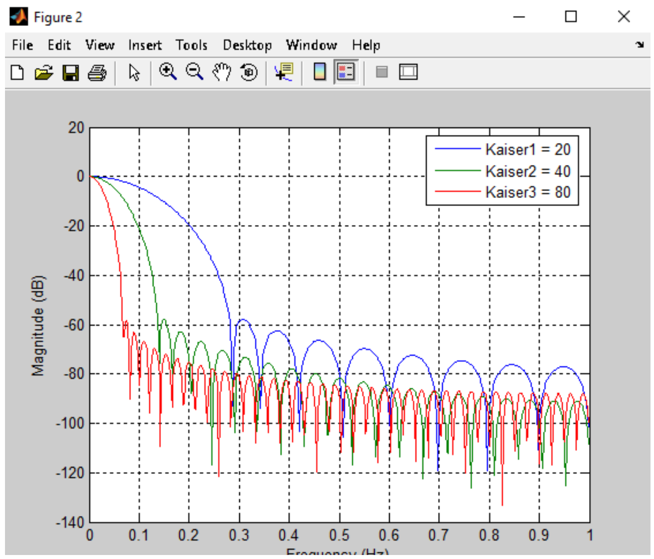



Fig.3: Kaiser Window with length n=20, n=40, and n=80 with beta parameter 8.

The Kaiser windows obtained Kaiser1, Kaiser2 and Kaiser3 show that with a fixed value of a beta parameter and an increase in window length the main lobe width decreases. Also, the side lobe attenuation decreases with an increase in window length as shown in Fig.3.

Also, the PSO algorithm is applied on designed FIR filters using the Kaiser window function with window lengths n=20, n=40, and n=80, and beta parameter 8 are named Kaiser1, Kaiser2, and Kaiser3 respectively.The PSO design parameters are shown in Table.1.

| Parameters | PSO Values | | |
|---|---|---|---|
| Filter Order | 20 | 40 | 80 |
| Swarm Size | 22 | 22 | 22 |
| Acceleration Coefficient (c1) | 2 | 2 | 2 |
| Acceleration Coefficient (c2) | 2 | 2 | 2 |
| Inertia Coefficient (w) | 0.3 | 0.3 | 0.3 |
| Damping Ratio of Inertia Coefficient (wdamp) | 0.999 | 0.999 | 0.999 |
| Max no. of Iteration | 100 | 100 | 100 |

Table.1: Parameters for PSO

After executing the PSO algorithm code on FIR filter Kaiser1 (n=20, β =8) based on input parameters as given in table1, the output obtained is shown in Fig.4.

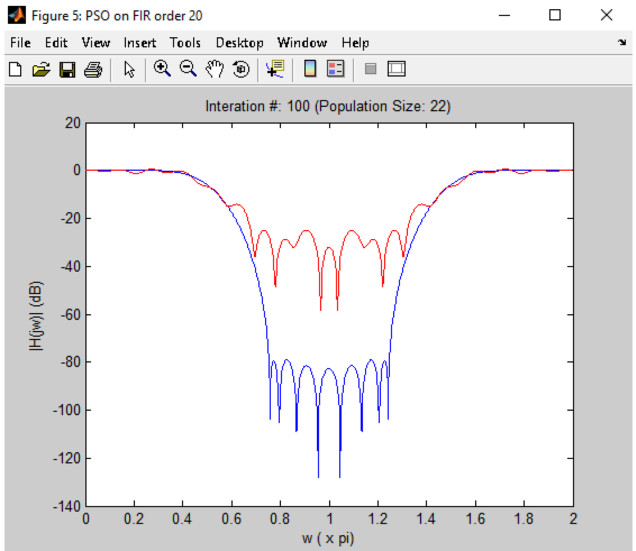



Fig. 4: Output of PSO applied on FIR filter of order 20.

After executing the PSO algorithm code on FIR filter Kaiser2 (n=40, β =8) based on input parameters as given in table 1, the output obtained is shown in Fig.5.

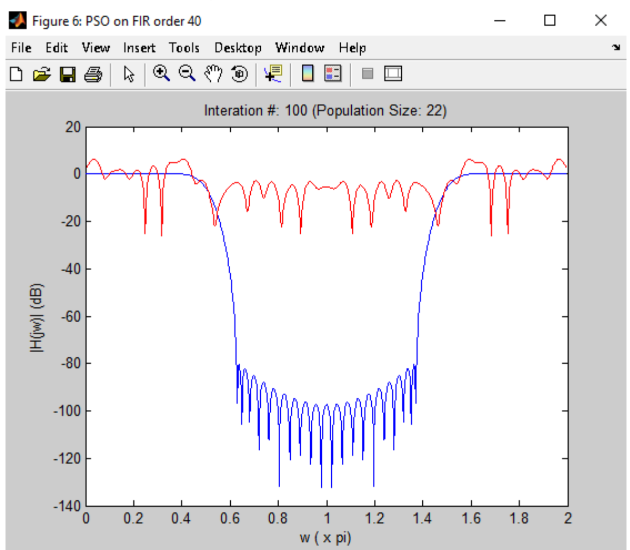



Fig.5:Output of PSO applied on FIR filter of order 40

Similarly, after executing the PSO algorithm code on FIR filter Kaiser3 (n=80, β =8) based on input parameters as given in table 1, the output obtained is shown in Fig.6.

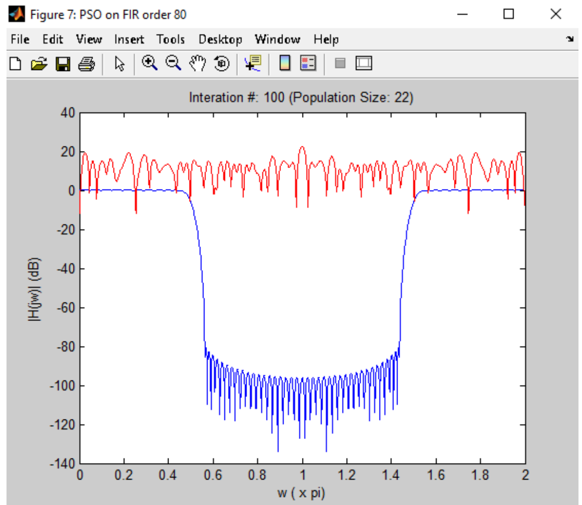
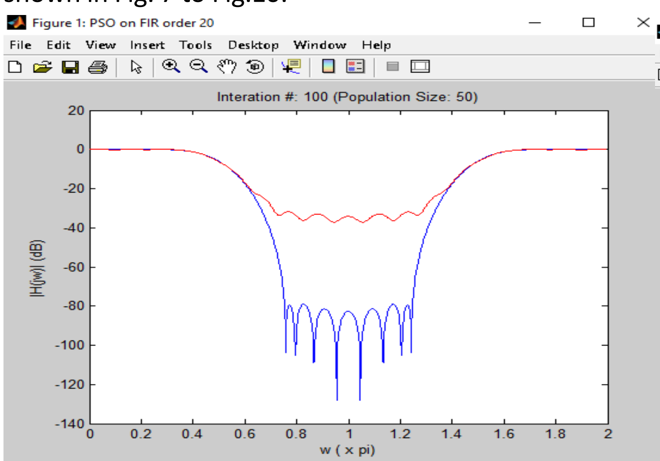



Fig.6: Output of PSO applied on FIR filter of order 80

Further, we have increased the no. of iteration and swarm population size then the output obtained is as shown in Fig. 7 to Fig.10.



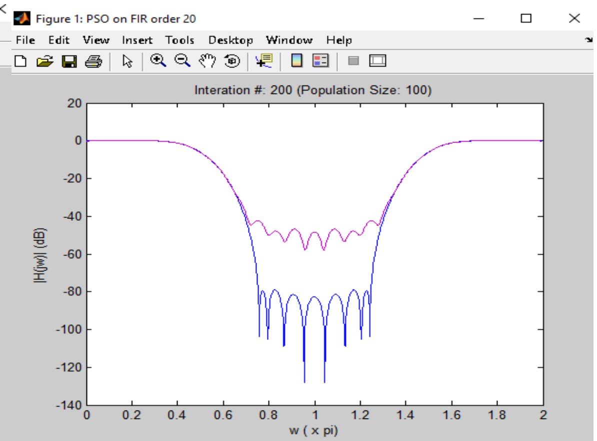
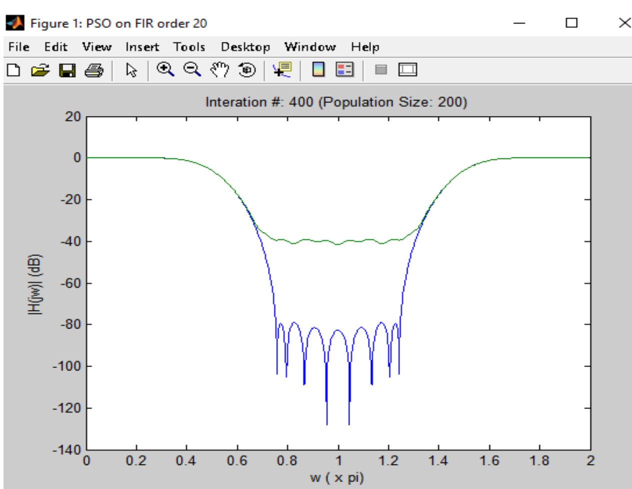




Fig.7: Output for Population=50, Iterations = 100 Fig.8: Output for Population=100, Iterations = 200



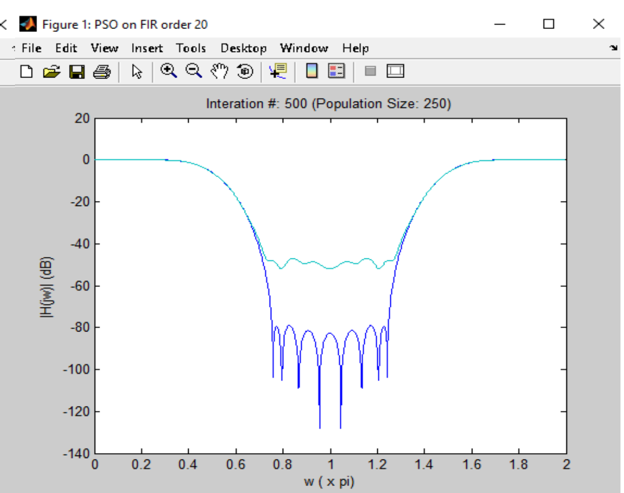




Fig.9: Output for Population=200, Iterations = 400Fig.10: Output for Population=250, Iterations = 500

It is found that with an increase in the population size to 50, 100, 200, and 250 and an increase in no. of iterations to 100,200,400,500 respectively the output of PSO applied FIR filter performs better in terms of stop band ripples and cutoff response.The stop band ripples decrease to a great extent. Also, by an increase in the number of iterations, a desirable sharp cutoff response is observed.

## 6. Conclusions

The Particle Swarm Optimization technique is applied for designing of FIR filter. The FIR filter is designed using Kaiser Window Function. PSO improves the solution characteristics by providing a unique approach for updating the velocity and position of the swarm. An optimized set of filter coefficients are obtained by Particle Swarm Optimization Techniques which give the optimized results in passband and stopband. We have effectively and efficiently designed a digital FIR filter using Kaiser Window Function in MATLAB. The PSO code is applied to the design. The results show that the designed FIR filter is better than the previously designed FIR filters in the context of the frequency spectrum. The stop band ripples decrease to a great extent. Also, it is observed that with an increase in the number of iterations a desirable sharp cutoff response is obtained.

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