Design Band Pass FIR Digital Filter for Cut off Frequency Calculation Using Artificial Neural Network

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Abstract - This paper presents a design approach of band pass FIR digital filter for cut-off frequency calculation using artificial neural network (ANN).In this work FDA Tool has been used for design of FIR band pass digital filter with hamming, hanning and Kaiser window because better frequency response has been achieved by these window for design of digital band pass filter than other window and ANN has been used for cut off frequency calculation with two algorithms namely feed forward back propagation and radial basis function.

The cut-off frequencies have been compared by NN Tool and FDA Tool, comparison has been done also for windows and algorithms.

Key Words: **Band pass FIR digital filter, FDA Tool, NNTool, hamming, hanning, Kaiser Window, FFBP, and RBF.**

1. INTRODUCTION

A filter is a device that discriminates of its input according to some attribute of the object. The digital filter can be implemented in both software and Hardware. Digital filter is a linear time invariant system (LTI) which does not vary with time. Digital filter have high accuracy, easy to simulate and design, flexible than analog filter [17]. Based on frequency characteristics digital filter is divided into four types-

Low pass filter (LPF)-Low pass filter only passes the low frequency components ($\leq w_c$).
High pass filter (HPF)-High pass filter only passes the high frequency components ($\geq w_c$).
Band pass filter (BPF)-Band pass filter only passes the frequency components between two frequencies (w_{c1}&w_{c2}).
Stop band filter (SBF)-Stop band filter does not passes the frequency components between two frequency (w_{c1}&w_{c2}).
In this section discussion has been done for the design of band pass FIR digital filter. The band pass filter can also be designed by combining of low and high pass filter.

There are two types of digital filter-
    i.   Finite impulse response filters (FIR).
    ii.   Infinite impulse response (IIR).
The impulse response of FIR filter is finite so this is known as FIR digital filter. They do not use and feedback because they depends on present input and past input so it is also known as non recursive filter.FIR digital filter has linear phase

characteristics and they and inherently stable but IIR filter do not have linear phase characterstics.The impulse response of IIR digital filter is infinite so this is known as IIR digital filter. They requires feedback because they depends on present input, past input and past output so they are also known as recursive filter[10].
The output sequence is given as for FIR filter-
$$Y(n)=\sum_{K=0}^{N} h(k)x(n-k)$$
Y(n)=h(0)x(n)+h(1)x(n-1)+......+h(N)x(n-N)
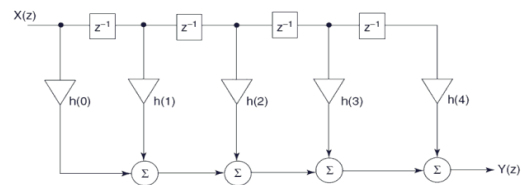This sequence of output is finite so this is known as finite impulse response.

Figure 1. FIR digital filter

2. FIR DIGITAL FILTER DESIGN USING WINDOW METHOD

The window method is one of the simplest methods for design of FIR filter among the two method i.e. fourier series and frequency sampling. In the frequency sampling it only works for particular frequency components and for other it does not works. Window method is easy method and various windows can be used based on our application [5]. The desired unit sample response is given by

$$h_d(n)=\frac{1}{2\pi}\int_{-\pi}^{\pi} Hd(w)e^{iwn}\, dw$$
h(n)=w(n)h$_d$(n)
Where $h_d(w)$ is desired frequency response characteristics.$h_d(n)$ is of infinite duration so $h_d(n)$ is truncated by finite length of window(M-1) which is w(n).so h(n) will be of finite length duration.
In this paper three windows have been used which are-

Hamming window-hamming window is given by

$$w_H(n)=\begin{cases} .54-.46cos\frac{2\pi n}{M-1} & for\ n=0,..M-1 \\ 0 & o.w. \end{cases}$$

Hanning window-hanning window is given by

$$w_{HN}(n)=\begin{cases} .5-.5cos\frac{2\pi n}{M-1} & for\ n=0.....,M-1 \\ 0 & o.w. \end{cases}$$

Kaiser window- Kaiser Window is given as

$$w_k(n) = \begin{cases} I_O(\beta(1 - \left[\frac{n-a}{a}\right]^2)^{.5} & for\ 0 \le n \ge M-1 \\ 0 & o.w. \end{cases}$$

$$\delta = minimum(\delta_1, \delta_2)$$
$$\Delta w = w_s - w_p$$

Where δ_1 and δ_2 is the ripple in pass band and stopband.w_p is pass band frequency and w_s is stop band frequency.β is a shape parameter which is given as

$$\beta = \begin{cases} .1102(A - 8.7) & for\ A > 50 \\ .5842)(A-21)^{.4} + .07886(A-21) & \\ & for\ 21 \le A \ge 50 \\ 0 & for\ A < 21 \end{cases}$$

And filter order is given by

N= $\frac{A-8}{2.285\Delta w}$

Attenuation A= $-20\log_{10}\delta$

The Kaiser window is best among other window because they have less transition band than other.

3. ARTIFICIAL NEURAL NETWORK (ANN)

Artificial neural network is comprised of a network of artificial neurons (node) [15].neural network is an algorithm that based on the human brain works. They can build predicted model by learning the pattern of historical data.ANN made by interconnected processing element, these are known as node or neuron. Each node processes the small part of the task. The most common type of ANN is multi layer perceptron (MLP).in MLP the nodes are organized in layer. It is also known as parallel distributed processing system or connectionist system. The first layer is the input layer, the outer most layer stands for output layer. Between these two comes one or more layer known as hidden layer. The entire node is fully connected with the previous node. Input are multiplied by unique weight and added together by a small value called bias. This total is processed is by the function called the activation function.

f(u)=$w_1u_{1+}w_2u_2+w_3u_3+b$

Where w is weight is an input and b is a bias.

It leaves the node as output, this process proceeds till information reached at the output layer and leaves it as the prediction for the independent variable. The network compares predicted and actual output. If these do not match it adjust all the weight and repeat the process till the network produce an accurate prediction for most of the observation.
There is various algorithms use in ANN this are-
Feed forward back propagation- a feed forward network has feedback paths meaning they can have signals travelling using loops. This system is nonlinear dynamic system because there is a loop which changes until it reaches state of equilibrium. In this the data flows in forward direction and error flows in reverse direction.
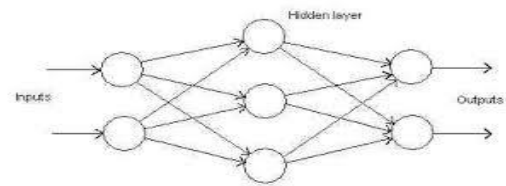
Figure 2. Feed forward network

Feed forward distributed time delay algorithm-In this algorithm whose basic function is to work on sequential data. Time delay represents the time shift usually form part of a larger pattern recognition system. It is mainly use to represent the relation between time and input.
Radial basis function- It is a real value function whose value depends only on the distance from the origin or alternatively on the distance from some other point C, called a center. The norm is usually euclidean distance although other distance function is also possible. Radial basis function has more number of neurons than other algorithm so it gives better result than another algorithm.

4. FORMULATION OF PROBLEM

The objective of this paper is to be estimated the cut-off frequency of proposed filter coefficients of band pass FIR digital filter which is achieved by FDA Tool using hamming, hanning and Kaiser Window. In this the input has been used as filter coefficient and target has been used as cut off frequency for which these filter coefficient have. Some filter coefficients have been chosen which is worked as test input and the cut off frequencies using NN Tool have been estimated for this test input. The comparison has been done between hamming, hanning, Kaiser Window. Feed forward back propagation and radial basis function algorithm of ANN also have been compared.

5. EXPERIMENTATION

Cut-off frequencies of band pass FIR digital filter have been calculated with three steps-

i.   **Step 1**:

Band pass FIR digital filter has been designed by FDA Tool. The order of the filter has been chosen 38 because for low order the frequency response characteristics has not been properly obtained. The cut-off frequencies have been used in the form of normalized, varied from 0 to 1.
Two cut off frequencies have been used say f_{c1} and f_{c2}.The values have been selected as $f_{c1=}0.1$ and $f_{c2}=0.3$ and designed the filter. The value of filter coefficients h(n) have been exported on workspace. The same process have been repeated for f_{c1} from 0.1 to 0 .7 and f_{c2} from 0.3 to 0.9.Total 121 samples have been achieved. Out of these 121 samples, 111 samples have been used

for training and 10 as testing. For Kaiser Window β has been selected as, $\beta = 3.4$.

ii.   Step 2:

The MS excel file has been created for training input, target and testing input. These files have been loaded to MATLAB workspace.

iii.   Step 3:

A neural network has been created by using nntool box. Training algorithms have been selected as feed forward back propagation and radial basis function. After training, the network has been simulated by testing input. Then the cut-off frequencies have been compared by data from FDA Tool.
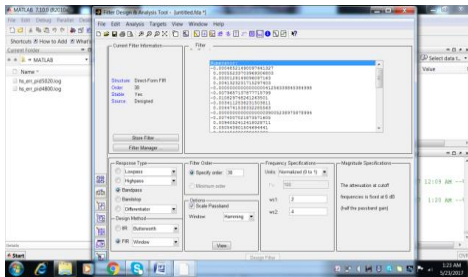
Figure 3. Filter designing by FDA Tool for hamming window

Cut off frequency calculation of Band pass FIR digital filter using hamming window

a) Feed forward back propagation (FFBP)
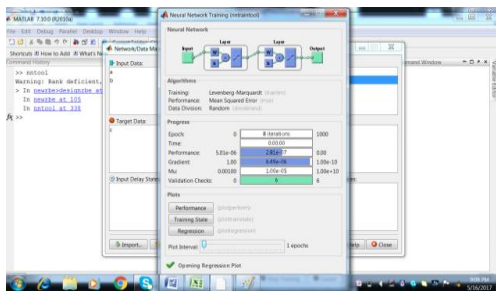
Figure 4. Trained network
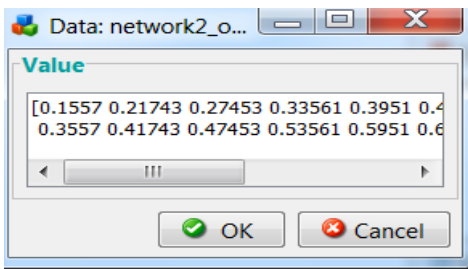
Figure 5.1 Result of FFBP network for hamming window
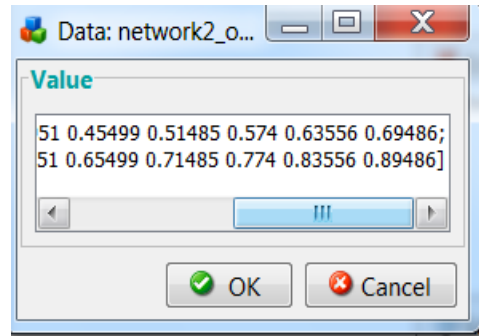
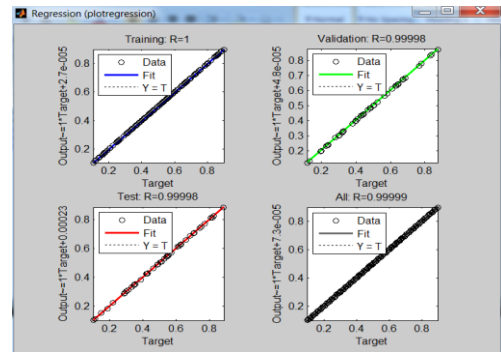Figure 5.2 Result of FFBP network for hamming window
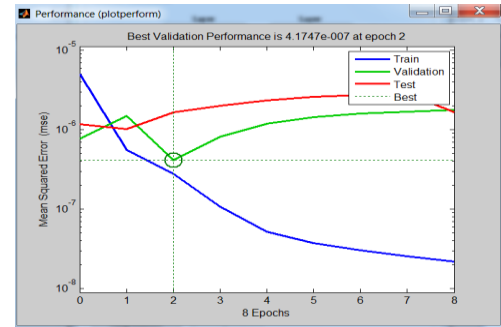

Figure 6. Regression plot of FFBP for hamming window

Figure 7. Performance plot for FFBP for hamming window

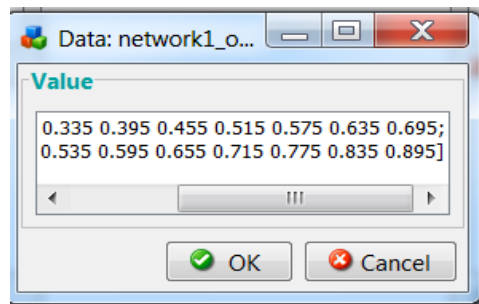### b) Radial basis function (RBF)
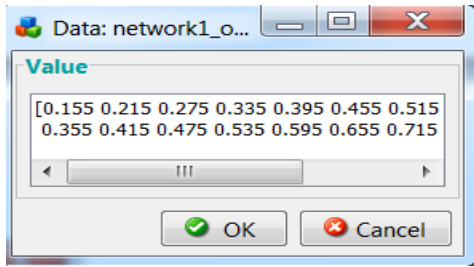

Figure 8.1 result of RBF for hamming window

Figure 8.2 result of RBF for hamming window

Cut off frequency calculation of Band pass FIR digital filter using handing window
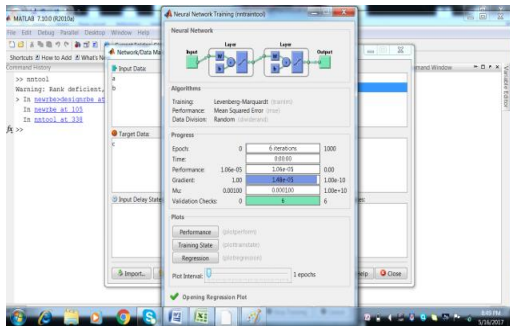
a) Feed forward back propagation (FFBP)

Figure 9. Trained network

Figure 10.1 Result of FFBP network for hanning window

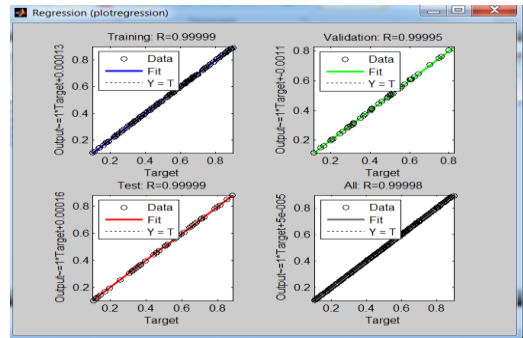Figure 10.2 Result of FFBP network for hanning window

Figure 11. Regression plot of FFBP for hanning window
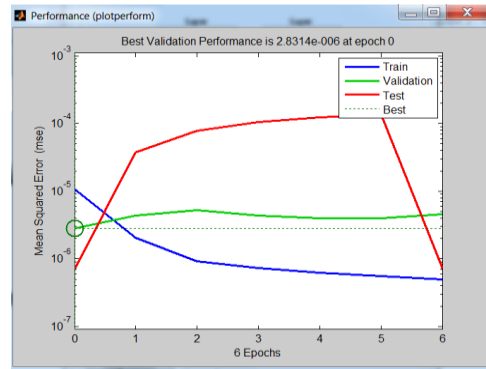

Figure 12. Performance plot for FFBP for hanning window
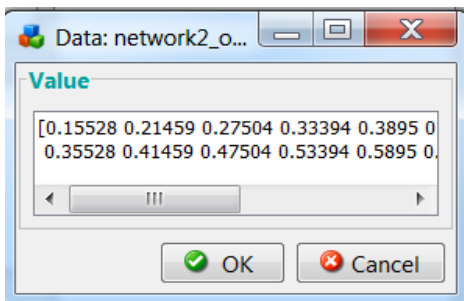
b) Radial basis function (RBF)

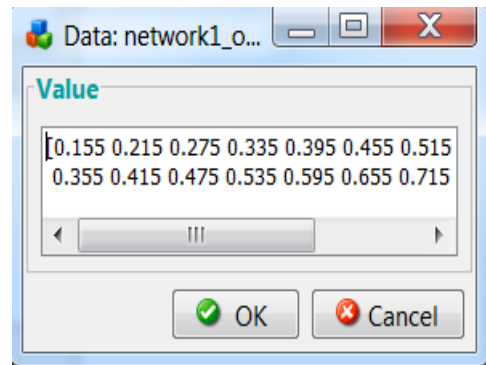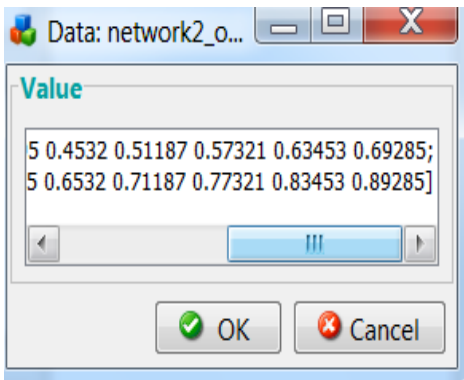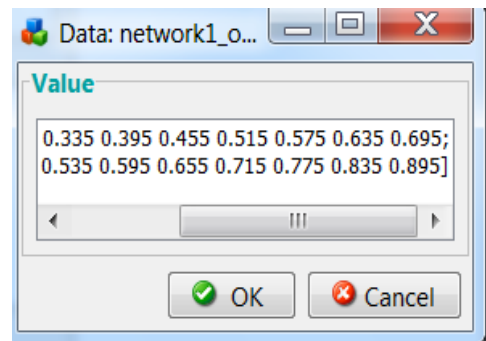Figure 13.1 Result of RBF network for hanning window

Figure 13.2 Result of RBF network for hanning window

Cut off frequency calculation of Band pass FIR digital filter using Kaiser Window

a) feed forward back propagation (FFBP)

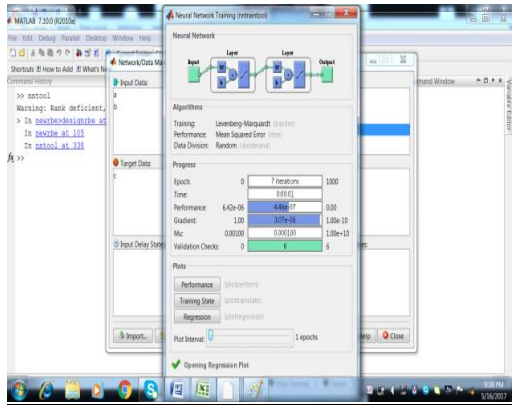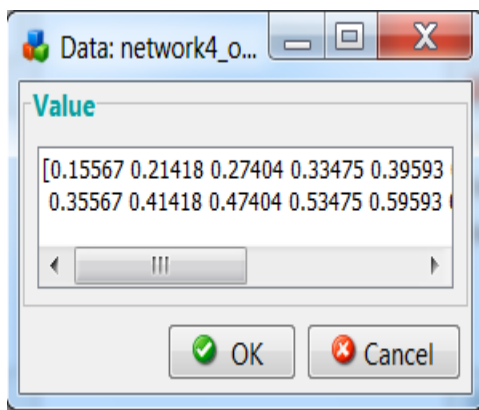Figure 14. Trained network

Figure 15.1 Result of FFBP network for Kaiser Window
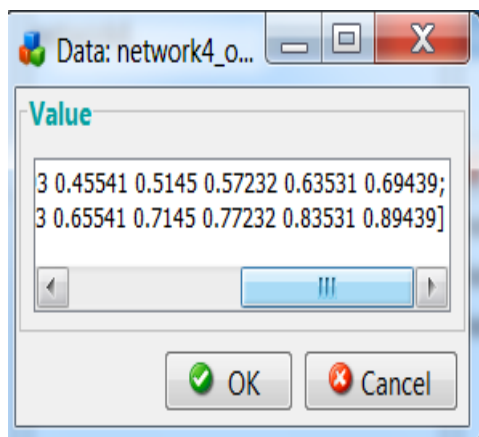

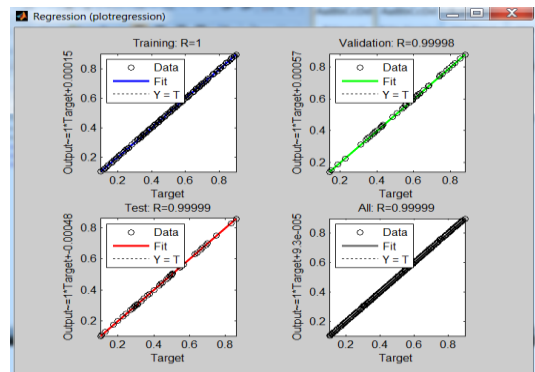Figure 15.2 Result of FFBP network for Kaiser Window

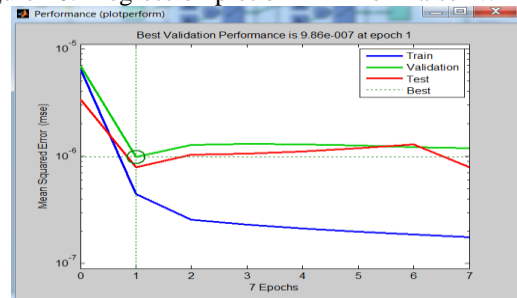Figure 16. Regression plot of FFBP for Kaiser Window

Figure 17. Performance plot for FFBP for Kaiser Window
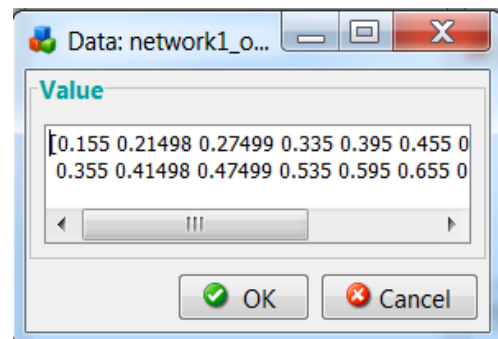
b) radial basis function (RBF)

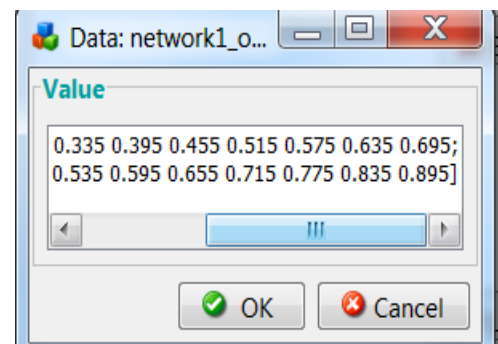Figure 18.1 Result of RBF network for Kaiser Window

Figure 18.2 Result of RBF network for Kaiser Window

Table 1. Result of hamming window using ANN

Test input (Filter coefficient)	hamming Window (actual cut off Frequency)		Output of artificial neural network (calculated cut off frequency)				Mean Square Error			
			FFBP		RBF		FFBP		RBF	
h(n)	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}
$h_1(n)$	.155	.355	.1557	.3557	.155	.355	.00000049	.00000049	0	0
$h_2(n)$	.215	.415	.21743	.41743	.215	.415	.0000059049	.0000059049	0	0
$h_3(n)$	.275	.475	.27453	.47453	.275	.475	.0000002209	.0000002209	0	0
$h_4(n)$	.335	.535	.33561	.53561	.335	.535	.0000003721	.0000003721	0	0
$h_4(n)$	.395	.595	.3951	.5951	.395	.595	.00000001	.00000001	0	0
$h_5(n)$	.455	.655	.45499	.65499	.455	.655	.0000000001	.0000000001	0	0
$h_6(n)$	.515	.715	.51485	.71485	.515	.715	.0000000225	.0000000225	0	0
$h_7(n)$	.575	.775	.574	.774	.575	.775	.000001	.000001	0	0
$h_8(n)$	.635	.835	.63556	.83556	.635	.835	.0000003136	.0000003136	0	0
$h_9(n)$	.695	.895	.69486	.89486	.695	.895	.0000000196	0000000196	0	0

Table 2. Result of hanning window using ANN

Test input (Filter Coefficient)	hanning Window (actual cut off Frequency)		Output of Artificial Neural Network (calculated cut off frequency)				Mean Square Error			
			FFBP		RBF		FFBP		RBF	
h(n)	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}
$h_1(n)$	.155	.355	.15528	.35528	.155	.355	.0000000784	.0000000784	0	0
$h_2(n)$	.215	.415	.21459	.41459	.215	.415	.0000001681	.0000001681	0	0
$h_3(n)$	.275	.475	.27504	.47504	.275	.475	.0000000016	.0000000016	0	0
$h_4(n)$	.335	.535	.33394	.53394	.335	.535	.0000011236	.0000011236	0	0
$h_4(n)$	.395	.595	.3895	.5895	.395	.595	.00003025	.00003025	0	0
$h_5(n)$	.455	.655	.4532	.6532	.455	.655	.00000324	.00000324	0	0
$h_6(n)$	.515	.715	.51187	.71187	.515	.715	.0000097969	.0000097969	0	0
$h_7(n)$	.575	.775	.57321	.77321	.575	.775	.0000032041	.0000032041	0	0
$h_8(n)$	.635	.835	.63453	.83453	.635	.835	.0000002209	.0000002209	0	0
$h_9(n)$	.695	.895	.69285	.89285	.695	.895	.0000046225	.0000046225	0	0

Table 3. Result of Kaiser Window using ANN

Test input (Filter coefficient)	Kaiser Window (actual cut off Frequency)		Output of artificial neural network (calculated cut off frequency)				Mean Square Error			
			FFBP		RBF		FFBP		RBF	
h(n)	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}	f_{c1}	f_{c2}
$h_1(n)$	.155	.355	.15567	.35567	.155	.355	.0000004489	0000004489	0	0
$h_2(n)$	.215	.415	.21418	.41418	.21498	.41498	.0000006724	0000006724	.0000000004	.0000000004
$h_3(n)$	.275	.475	.27404	.47404	.27499	.47499	.0000009216	.0000009216	.0000000001	.0000000001
$h_4(n)$	.335	.535	.33475	.53475	.335	.535	.0000000625	.0000000625	0	0
$h_4(n)$	.395	.595	.39593	.59593	.395	.595	.0000008649	.0000008649	0	0
$h_5(n)$	.455	.655	.45541	.65541	.455	.655	.0000001681	.0000001681	0	0
$h_6(n)$	.515	.715	.5145	.7145	.515	.715	.00000025	00000025	0	0
$h_7(n)$	.575	.775	.57232	.77232	.575	.775	.0000071824	.0000071824	0	0
$h_8(n)$	.635	.835	.63531	.83531	.635	.835	.0000000961	.0000000961	0	0
$h_9(n)$	.695	.895	.69439	.89439	.695	.895	.0000003721	.0000003721	0	0

6. RESULT

In this experiment three tables have been achieved. First is for hamming window second is for hanning window and last third one is for Kaiser Window. By help of the table 1, 2 and 3. Various error graphs between desired and obtained frequency are drawn for various windows.
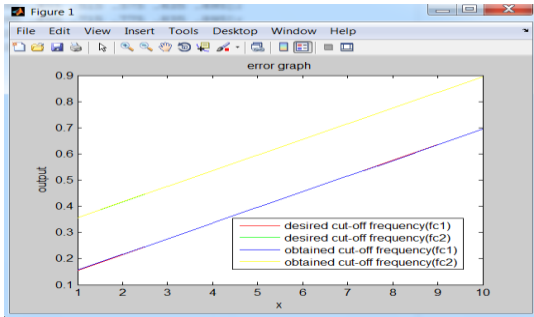

Figure 19. Error graph between desired cut-off frequencies and obtained cut-off frequencies for hamming window with FFBP
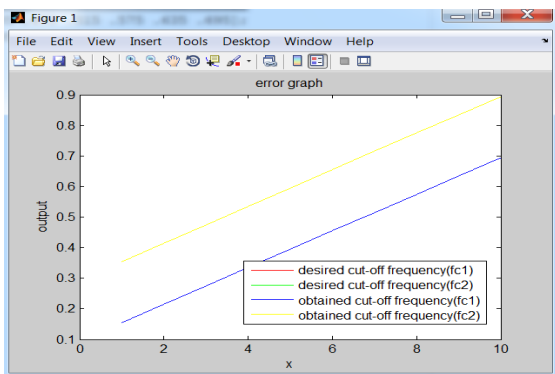

Figure 20. Error graph between desired cut-off frequencies and obtained cut-off frequencies for hamming window with RBF

Figure 19 and 20 shows error graph between desired cut-off frequencies and obtained cut-off frequencies for hamming window with FFBP and RBF.
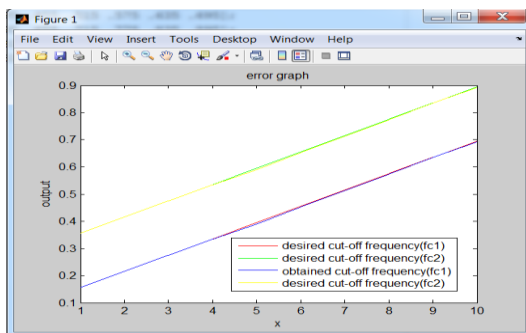

Figure 21. Error graph between desired cut-off frequencies and obtained cut-off frequencies for hanning window with FFBP
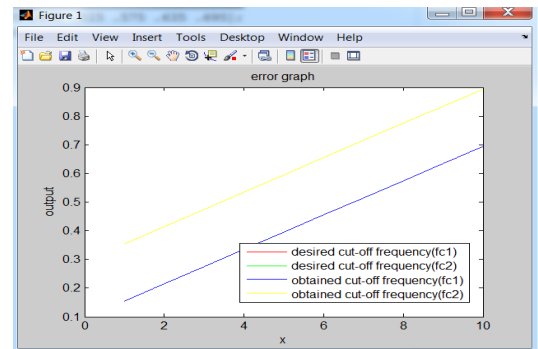

Figure 22. Error graph between desired cut-off frequencies and obtained cut-off frequencies for hanning window with RBF

Figure 21 and 22 shows error graph between desired cut-off frequencies and obtained cut-off frequencies for hanning window with FFBP and RBF.
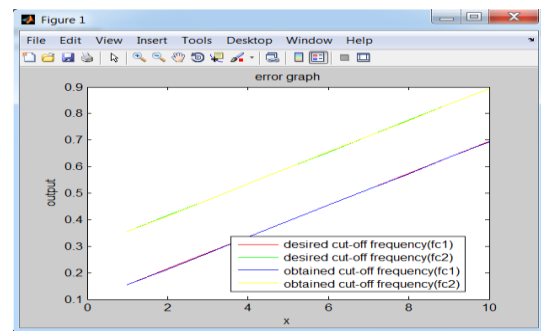

Figure 23. Error graph between desired cut-off frequencies and obtained cut-off frequencies for Kaiser Window with FFBP
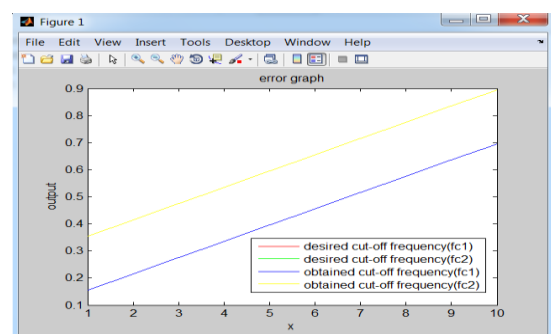

Figure 24. Error graph between desired cut-off frequencies and obtained cut-off frequencies for Kaiser Window with RBF

Figure 23 and 24 shows error graph between desired cut-off frequencies and obtained cut-off frequencies for Kaiser Window with FFBP and RBF.

The cut off frequencies have been calculated from ANN using NN Tool and it can be easily seen that there is very less difference between actual and calculated cut off frequency. In this 121 samples have been used for training and 10 for

testing. So we have seen ANN gives efficient result in less time and it has been given result nearer to the actual one.

7. CONCLUSION

For finding that which window gives better result the mean square error (MSE) has been calculated for each window and for each algorithm. After this and it has been found that all window are given almost same result but hamming window is given the more efficient result than hanning and Kaiser Window. Out of two algorithms i.e. FFBP and RBF it has been found from various error graphs that RBF is best and better result is achieved by this almost same as actual one.RBF has highly accurate algorithm than other.

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[17]digital signal processing by Dr.J.S. Chitode.