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Design and Analysis of a Three-Stage Decimation Filter for Signal Processing Applications

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Abstract:- The research uses the FDA tool of MATLAB to consider and show the design of a decimation filter with three stages. The decimation filter lowers the signal's sampling rate while maintaining the necessary data. Since the single stage filter is particularly challenging to build and has poor frequency response due to the need for more coefficients, three stages of filters are taken into consideration. In filter design, a CIC filter is taken into account in the first stage, followed by FIR filters in the following two stages, which are decimated after each stage.

Keywords:- *Decimation filter, Decimation factor, CIC filter, FIR filter.*

I. INTRODUCTION

Where digital signal processing is involved, the sampling rate of the system will be excessively high, necessitating the usage of decimation filters. The decimation filter provides a way to lessen the by lowering the sample rate while maintaining the necessary data, the system can reduce its sampling rate. The original, high frequency data will be eliminated, and the data will have their sampling rate decreased by a factor M (a positive integer).

II. FILTER EXPLANATION

A. Decimation filter

Decimation filters are a particular class of digital signal processing filters that are used to lower sampling rates for signals. By preserving the low frequency component while filtering the high frequency component, they remove unwanted signal and high frequency noise from the signal before lowering sampling rates. Decimation filters are used in video and audio processing to reduce the amount of storage space needed for high sampling frequency data and the amount of computations needed to analyse vast amounts of data.

B. Design of Decimation filter

Decimation filter design involves choosing the type of filter, specifying the filter, and figuring out the filter coefficients. The initial stage in filter design will be to determine the decimation factor, passband frequency, stopband frequency, and passband and stop band attenuations. The specifications, demands, and applications will guide the choice of filter type. Analogue and digital filters are the two main types, and for the majority of digital signal processing, digital filters are preferred since they can conduct mathematical operations on both sampled data and disregarded continuous time signals. FIR (finite impulse response) and IIR (infinite impulse response) are the two major types of filters used in digital filters.

FIR filters are taken into consideration because of its linear phase response, ability to filter multiple rate signals, stability, and increased accuracy. With this approach, the CIC filter (cascaded integrator and comb) and FIR filters are utilized to construct in the decimation filter. By comparing the input sampling frequency to the output sampling frequency, one can determine the decimation factor. Here, the first stage of the three-stage decimation filter is a CIC filter, while the following two stages are FIR filters. The signals are then decimated using the decimation factors 64 and 8 at each stage of filtering.

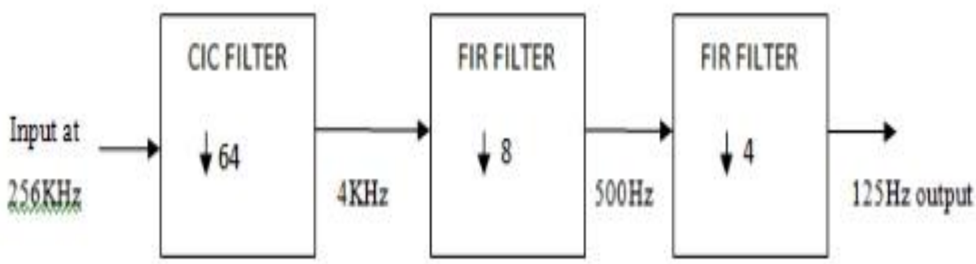

Fig. 1: Three stage decimation filter

Since higher order filters are more difficult to design because they require more data storage, multi stage filter designs, specifically three stage decimation filters, are taken into consideration as per the specifications listed below. When decimation filter is considered in single stage by using only a FIR filter, the order (16190 filter order) of filter will be more.

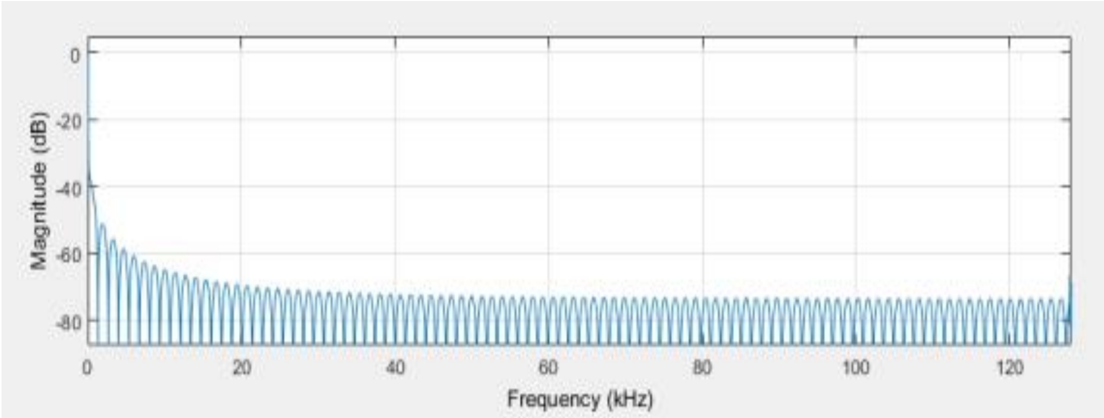

Fig. 2: Decimation filter using single stage FIR

C. Specifications

Table 1: Specifications

$F_{Sampling}$	256000Hz
F_{pass}	60Hz
F_{stop}	100Hz
A_{pass}	1dB
A_{stop}	80dB

CIC filter is a type of digital filer which are computationally more efficient lowpass filter which can be used as decimation filters. CIC filter can be implemented by additions and subtractions only and it does not require filter coefficients, multiplications and no data storage. The main building block of CIC filters are integrator also known as accumulator which is a single pole IIR filter which has unity feedback which can be implemented by the equation

$$Y[n] = y[n-1] + x[n]$$

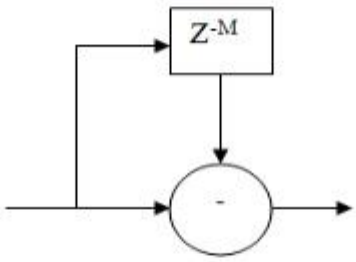

Fig. 3: Basic comb structure of CIC filter

The transfer function in z domain for comb filter is given by $H_C(z) = 1 - z^{-RM}$

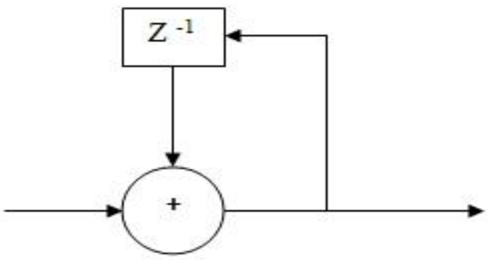

Fig. 4: Basic integrator structure of CIC filter

The transfer function in z domain for integrator is given by is $H_I(z) = \frac{1}{1-z^{-1}}$

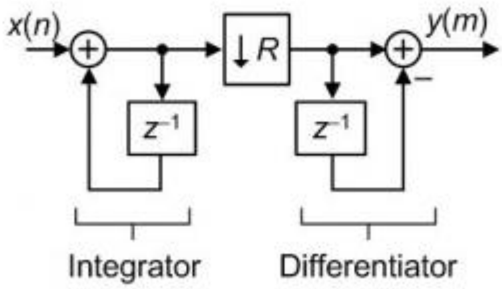

Fig. 5: Efficient CIC filter implementation

To implement efficient decimation filter, comb structure should be operated at lower frequency f_s/R where R is a decimation factor .The comb has a differential delay of 'M' samples per stage and it is restricted to 1 or 2.

CIC filter is used with decimation factor 64, with number of sections 3, sampling frequency 256 KHz, and with differential delay 1 the below response can be obtained and the output sampling frequency will be 4 KHz can be seen in below frequency response in MATLAB The output of CIC filter produces a constant value 262144 as given in below figure which is a 18 bit data and one signed bit in addition to that so the bit growth of CIC filter is 19 bit when input 1 bit, decimation factor 64, differential delay as 1 and number of sections of CIC is 3

Bit growth = Input to CIC filter + [Number of sections of CIC filter * log2 (Differential delay ∗ Decimation factor)]
Bit growth = 1 + [3 ∗ log2 (1 ∗ 64)] = 19bits

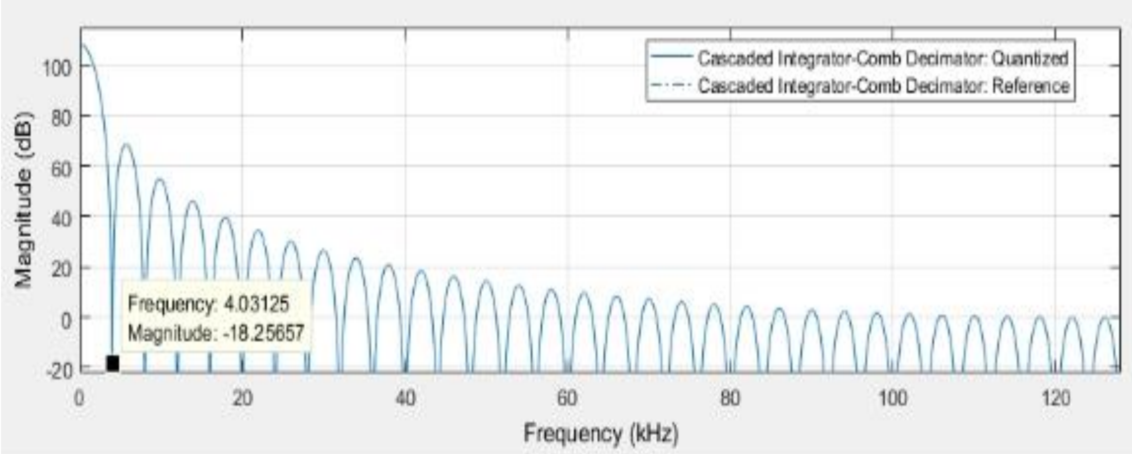

Fig. 6: First stage CIC filter magnitude frequency response

The following figures show the magnitude frequency response of the other two stages of FIR filters, which are employed in the next two stages based on requirements and benefits. The sampling frequency is 4 KHz, the passband frequency is 60 Hz, the stopband frequency is 300 Hz, the passband attenuation is 0.1 dB, and the stop band attenuation is 60 dB. This results in the filter order being 45, and 46 filter coefficients are produced.

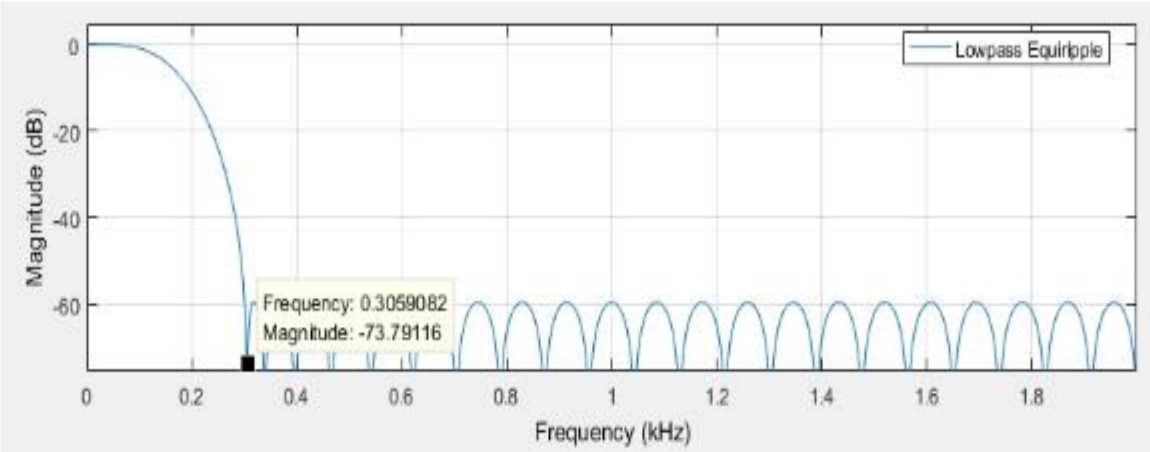

Fig. 7: Second stage FIR filter magnitude frequency response

The sampling frequency is 500 Hz, the passband frequency is 10 Hz, the stopband frequency is 60 Hz, the passband attenuation is 0.1 dB, and the third stage of the FIR filter has the following parameters. When stopband attenuation of 80 dB is taken into account, the filter order is 33, and the filter coefficients are 34. The frequency response of a third stage FIR filter is shown in the below figure.

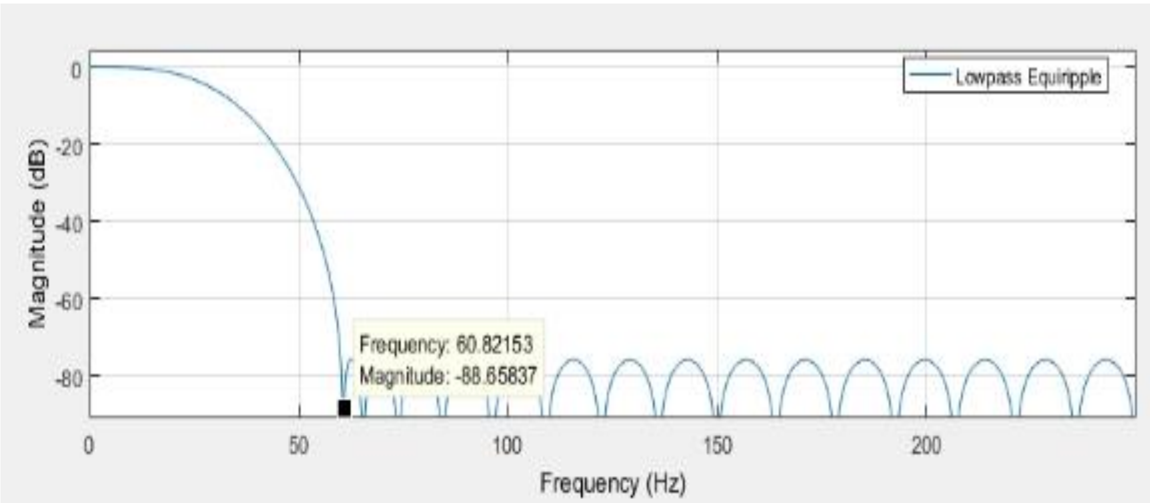

Fig. 8: Third stage FIR filter magnitude frequency response

The three-stage decimation filter design is very good at reducing the amount of samples in a signal while preserving its properties. The CIC filter initially offers high levels of decimation and anti-aliasing, and a subsequent FIR filter enhances the signal quality. This design enables greater flexibility for particular applications and optimizes the filter properties.

Applying FFT to obtain a single-sided spectrum for the input signal will allow all of the frequency components in the input signal to be easily observed. When considering input signal with random noise, different frequencies will be obtained as illustrated in the below image.

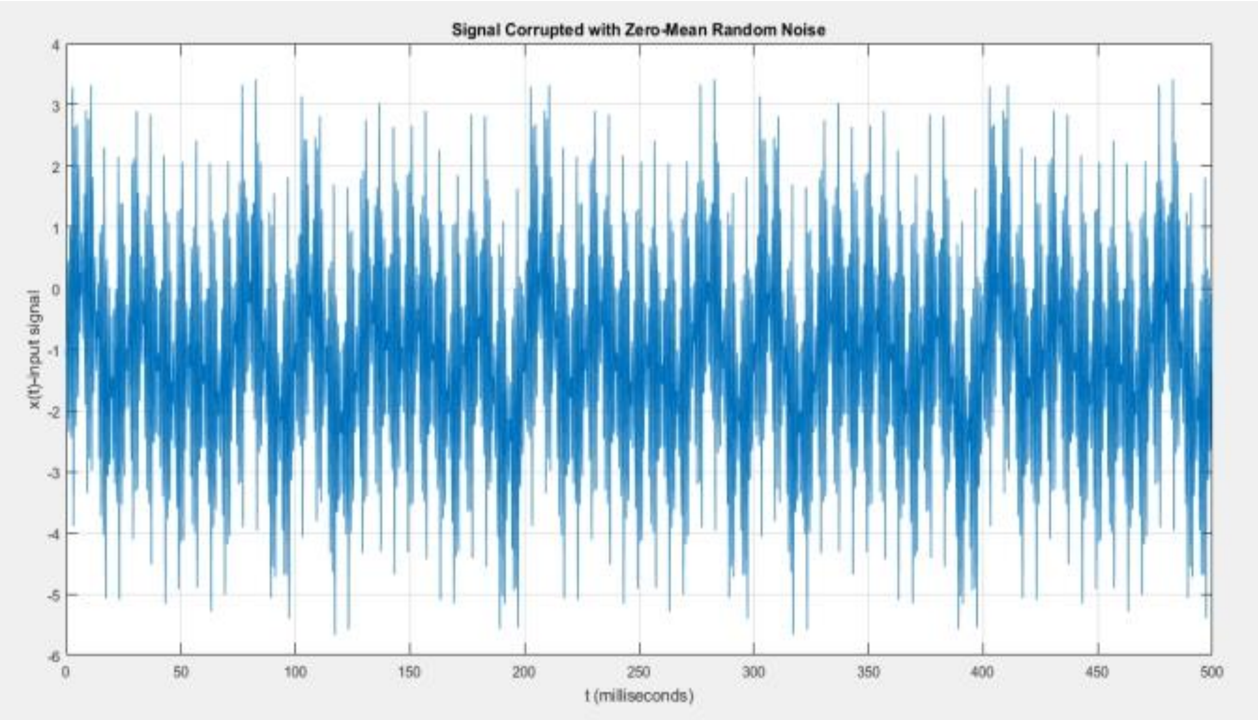

Fig. 9: Input signal with different frequency components

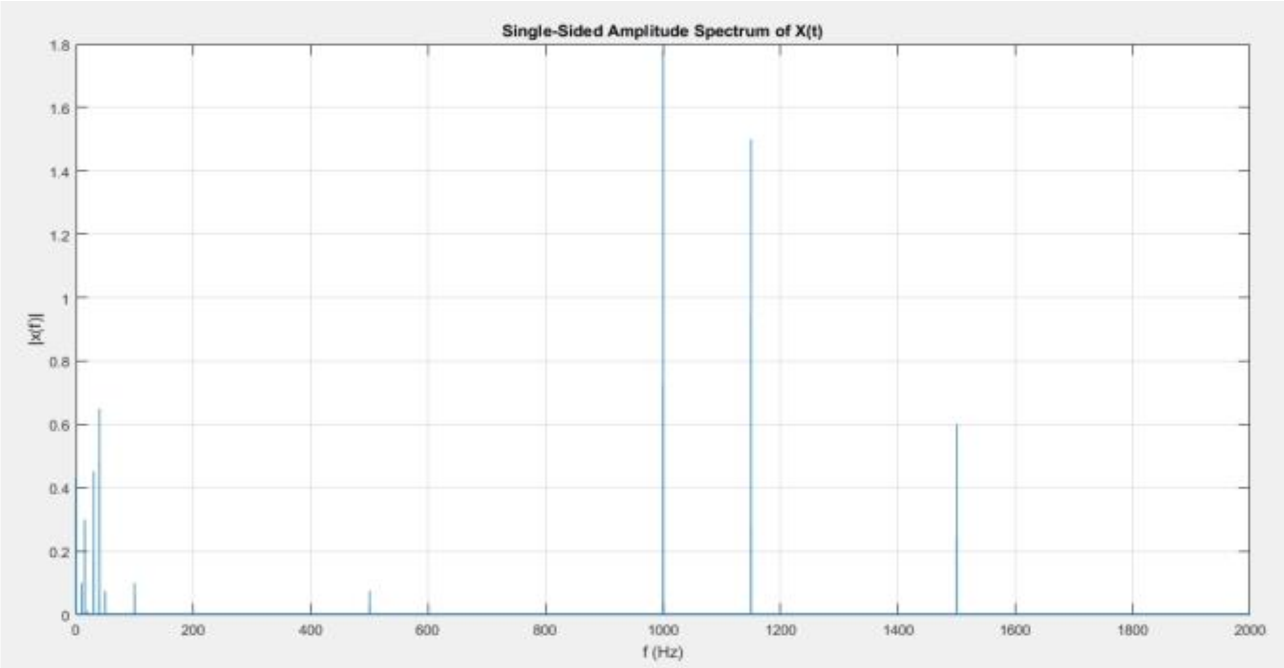

Fig. 10: Single sided spectrum of input signal

The next image provides the frequency responses for all three stages after each stage of filter FFT is completed for verification, making it simple to see which frequencies of information are passed and which are not.

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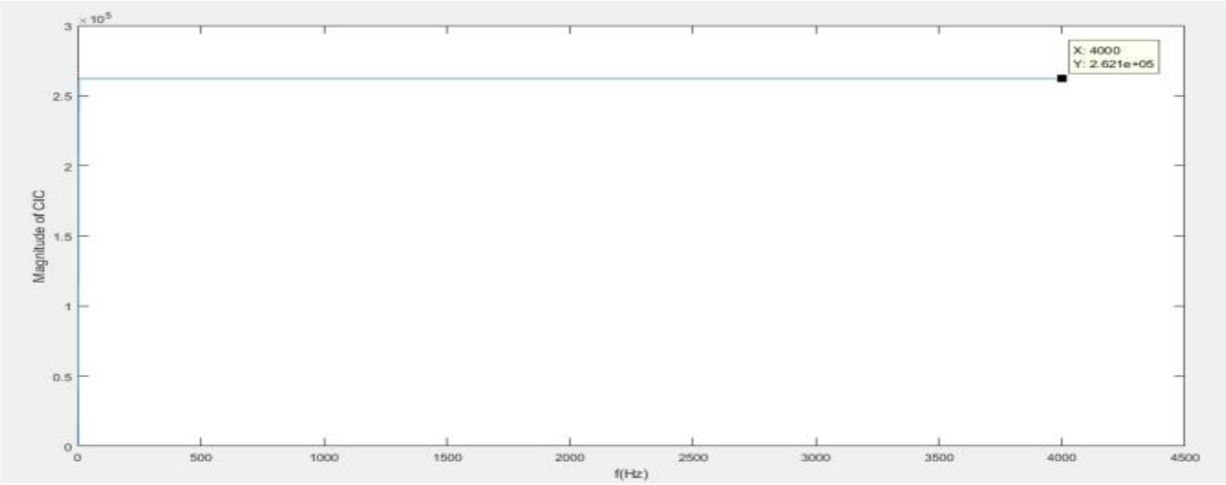

Fig. 11: Frequency response of first stage CIC filter

According to the formula, the output value of CIC is 2 18, or 262144 plus one bit for signed integers. The value up to the 4 KHz frequency is tested here at 19 bit, and it is observed as predicted.

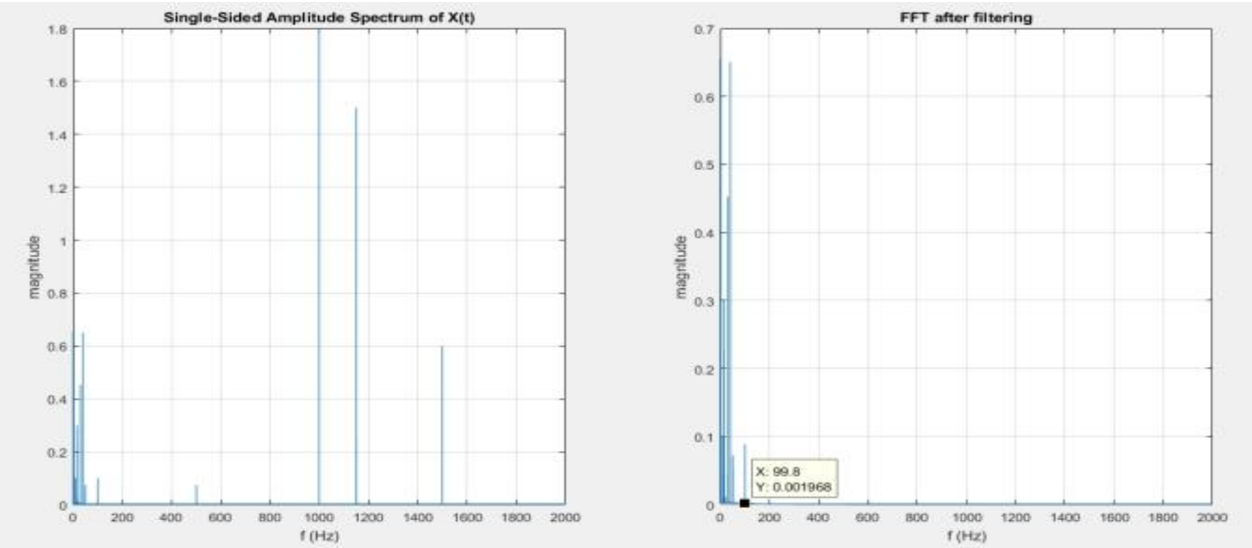

Fig. 12: Frequency response of second stage FIR filter

In the above figure the frequency response of second stage FIR filter is seen, here it is observed that the frequency response till stopband frequency is seen and verified that is till 300Hz.

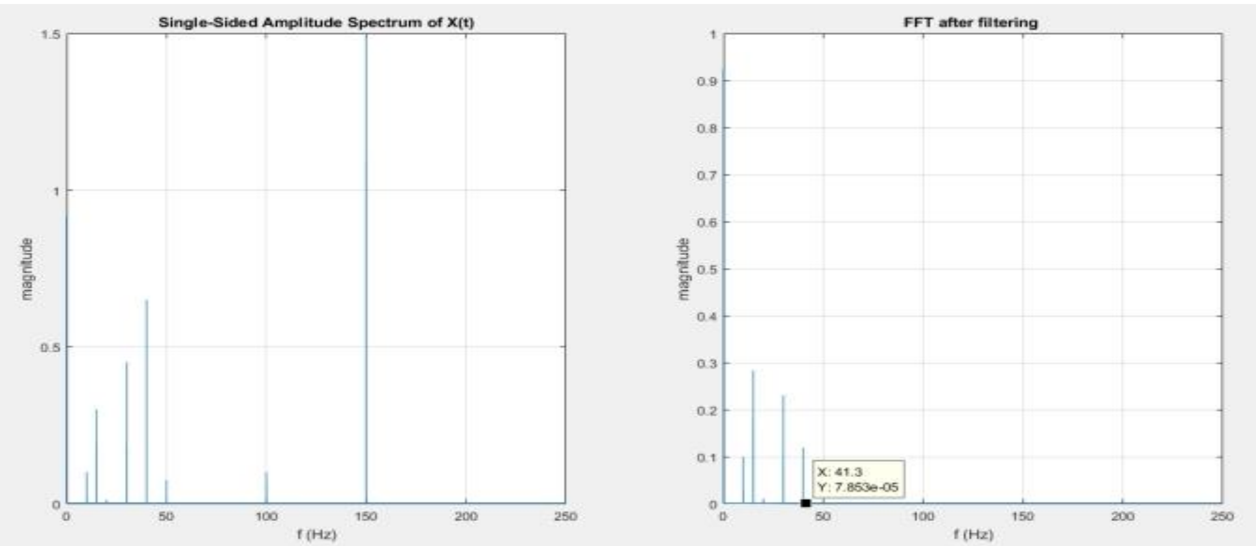

Fig. 13: Frequency response of third stage FIR filter

In the above figure the frequency response of third stage FIR filter is seen, here it is observed that the frequency response till the stopband 60Hz is seen and verified

III. CONCLUSION

The three-stage decimation filter design is very good at reducing the number of samples in a signal while preserving its properties. The CIC filter initially offers a high level of decimation and anti-aliasing, and a subsequent FIR filter enhances the signal quality. This design enables greater flexibility for particular applications and optimizes the filter properties. The various frequency components are taken into account, and the features of CIC and FIR filters are observed and confirmed.

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