

## Narrow Band Digital Filter for Carrier Aggregation

Pushpavathi.K.P<sup>1</sup>, B.Kanmani<sup>2</sup>

<sup>1</sup>(Department of Electronics and Telecommunication Engineering, B.M.S. College of Engineering, India)

<sup>2</sup>(Department of Electronics and Telecommunication Engineering, B.M.S. College of Engineering, India)

<sup>1</sup>Corresponding Author: [pushpakp.tce@bmsce.ac.in](mailto:pushpakp.tce@bmsce.ac.in)

### To Cite this Article

Pushpavathi.K.P and B.Kanmani, "Narrow band Digital Filter for Carrier Aggregation", Journal of Science and Technology, Vol 5, Issue 5, Sep-October 2020, pp70-77

### Article Info

Received:10-05-2020

Revised:05-08-2020

Accepted:10-08-2020

Published:17-08-2020

**Abstract:** Digital signal processing takes its place in the field of research as digital systems are taking over the world. The digital filters form the important part of any digital system. Digital filter realizations are improving each day. Commonly designed digital filters use higher order of filter to achieve narrow transition band. One of the applications of narrow transition band filters may be for the user equipment (UE) that uses LTE-Advanced (long Term Evolution) technology. Carrier Aggregation is one among the significant mechanisms of LTE-Advanced. It provides for the wide bandwidth so that the capacity can be increased. Narrow band filters may be used for extracting the desired signal from this wide bandwidth. This paper explores the narrow band FIR filters with the introduction of the small transition band.

**Keywords:** narrow band filters, transition band, carrier aggregation, frequency sampling method, LTE-Advanced, digital filters

## I. Introduction

The world is transforming to more of the digital nature with digital signals. This demands more bandwidth to carry the digital information, and hence the quest for increased data rate. One such solution for the increased bandwidth is the technique called carrier aggregation. This feature of LTE – Advanced, combines the LTE carriers to form a single channel of wider bandwidth.

LTE systems are one of the wireless communication services that offer high data rate with larger bandwidth. They use OFDM and have out-of-band emission (OOBE) that is high, greater side lobes, high peak-to-average power ratio (PAPR)<sup>1</sup> and interference. Filtering is one among the typical methods to limit OOBE. Entire bandwidth is divided into number of smaller sub channel and each sub channel is filtered with appropriate filters.

3GPP allows certain standard bandwidths<sup>2</sup> that are combined as required providing the aggregated bandwidth of about 100MHz (say 5 X 20MHz). Ideally this is expected to provide a data rate of about 1Gbps (say 5 x 299.5Mbps) in the downlink and 500Mbps (say 5 x 75.376Mbps) in the uplink. Data rates 299.552 Mbps and 75.376 Mbps are the peak data rates for 20MHz system bandwidth as per the specifications in the downlink and uplink respectively<sup>3</sup>. The user equipment (UE) providing access to LTE –advanced is able to use the aggregated bandwidth to experience the high data rate. Such user equipment need suitable filter to filter out the neighboring component carriers. The filters may have to be changed for different values of component carriers to demodulate them. At the signal processing end, the narrow band filter designed to filter the undesired or the spurious signals find its importance. The paper is followed by briefing the carrier aggregation, filters used for LTE, the narrow band FIR filters and the simulation study.

## II. Carrier Aggregation

The technique used in LTE-Advanced wherein two or more component carriers are combined to provide larger bandwidth. The user can thus avail a bandwidth that is very much greater than that of the single channel<sup>4</sup>. This can be done by aggregating contiguous carriers or non-contiguous carrier aggregation. For example, 4 contiguous or non-contiguous component carriers of 20 MHz can be aggregated to obtain a bandwidth of 80MHz (4 X 20 MHz)<sup>3</sup>. The user with LTE-Advanced can use multiple bands simultaneously while the non LTE-Advanced user is able to

transmit or receive on the individual carrier. One possible combination for aggregation of the UMTS bands may be 1.8GHz of band 3 +2.1GHz of band1 + 2.6GHz of band 7<sup>3</sup>. The carriers must have their center frequencies spaced at multiple of 300 KHz<sup>3,5</sup>. It is one of the enhancement techniques at the physical layer of the LTE-Advanced systems which will support the flexible bandwidth operations. Release 10 or LTE-Advanced allows for aggregating two carriers, one from 800MHz band and another from 2100MHz band with band width of two carriers need not be the same<sup>6</sup>. Aggregation of more than two carriers is studied that shows that more the carriers were aggregated; the greater was the data rate<sup>7</sup>. We now have aggregation of three component carriers being demonstrated with increased data rate<sup>5</sup>.

### ***Filters for LTE***

The aggregated bandwidth basically contains sub-bands. Each sub band has its center frequency at its center. The aggregated bandwidth has guard band at both the ends of the aggregated band width and guard resource. Guard resource varies in size based on the bandwidth of the adjacent sub bands on both sides<sup>8</sup>. Filters can be used to select the desired frequency band while filtering out the neighboring component carriers. Filters may also have to be changed for different component carriers and bandwidths. The user equipment should be capable enough to efficiently cancel the interference<sup>6</sup>.

The application of digital filter in LTE is well established. Some of the Filters used in LTE include dyadic filters<sup>9</sup>. Here, the authors present the efficient IIR filter approach that builds up the filter bank with dyadic structure of discrete wavelet transformation and can be implemented efficiently on the hardware. The wavelet coefficients can be used as FIR filter coefficients in the design of digital FIR filter<sup>10</sup>. These wavelet filter exhibits good frequency response with no overshoot.

There are band selection filters that are based on Bulk Acoustic Wave (BAW) filters<sup>11</sup>. This paper provides the solution for compactness and compatibility in modern transceivers, mobile applications and evaluates the effect of BAW filter on demodulation performance of UE receiver in LTE.

FIR filters are used to reduce the intermodulation effects caused due to the non-linearity of the components used and hence obtained the receiver de-sense to be low<sup>4</sup>. At present, there are user equipment's capable of using carrier aggregation in the downlink, while receiving the signals in different bands simultaneously. User equipment will be subjected to lot of interferences called blockers<sup>9</sup>. The required LTE signal is generally embedded in several blockers (interferences) of various kinds with very low power level. Hence narrow band filters with sharp slopes become necessary to retrieve the desired LTE signal.

### ***Digital Filters***

Filters are the circuits that allow the desired range of frequencies to pass through while rejecting the undesired bands. Digital filters offer much research scope today. Digital Finite Impulse Response (FIR) filter are more immune to noise and are precise than their analog counterpart. Being called the all - zero filters, they are always stable as the FIR sequences are stable. These sequences can be designed to have the linear phase characterized frequency response and are always realizable<sup>12</sup>. This makes them find their applications in places like data transmission and speech processing where frequency dispersion is undesired.

## **III. Narrow Band FIR Filters**

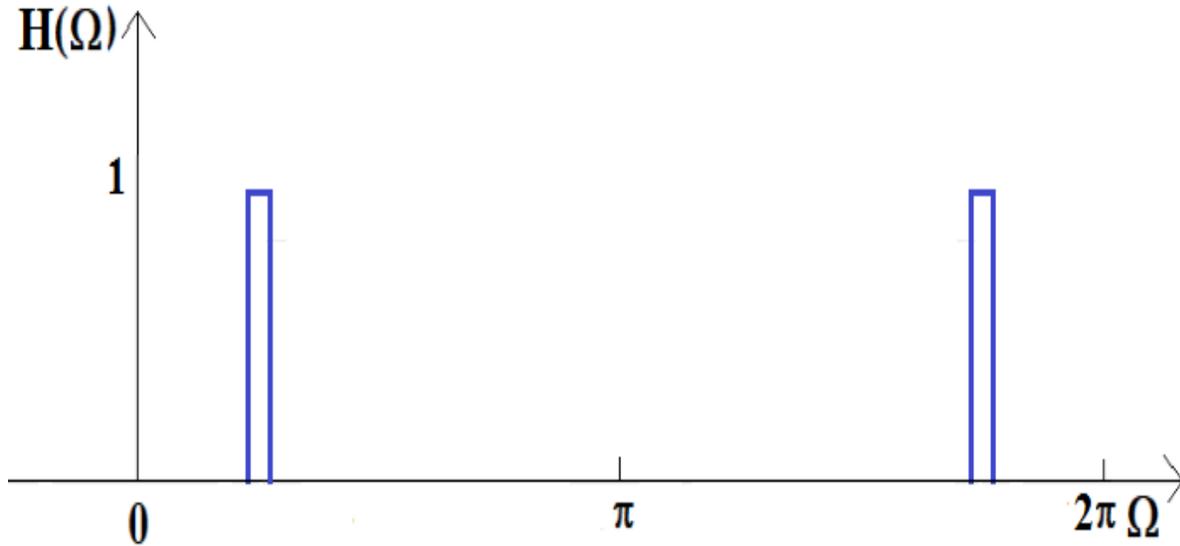
Narrow band filters may be either the narrow band pass filters or the narrow band reject filter. They are used to either pass or block the desired frequency band respectively.

Narrow transition band digital filter with linear phase characteristics is studied for the OFDM system for various QAM channel conditions<sup>1</sup>. The bit error rate (BER) performance was also discussed using a novel Interpolated Band pass Method (IBM). It is compared with the popular Frequency Response Masking (FRM) approach. Their method showed less complexity and power consumption. The interpolated band pass filtering approach is considered to design the narrow transition band FIR filters<sup>13</sup>. They derived the expressions for the optimal interpolation factor to obtain the narrow transition band. They analyzed the complexity minimization problem in the FIR structure designed according to the mentioned approach and summarize that hardware requirements is less and relatively less power dissipation is needed.

### ***Frequency Sampling Method***

In this work, Frequency Sampling Method (FSM) is used to design the narrow band filters as this method of designing the FIR filters are computationally easier compared to the window method<sup>14</sup>. The narrow band FIR filter is studied for sharp transition band and for the small transition band.

Let  $H(\Omega)$ , be the frequency response of the desired digital filter as in figure 1.



**Figure 1.** Narrow Band Pass filter with zero transition band.

We now take  $N$ , equally spaced samples from one period of the desired frequency response. The samples are identified as the  $N$ -point Discrete Fourier Transform  $H[k]$  as in equation 1. One can then compute the impulse response  $h[n]$ , through the inverse Discrete Fourier Transform as given in equation 2.

$$H[k] = H(\Omega) \Big|_{\Omega = \frac{2\pi k}{N}} \quad k = 0, 1, \dots, N-1 \quad (1)$$

$$h[n] = \frac{1}{N} \sum_{k=0}^{N-1} H[k] e^{j2\pi nk/N} \quad n = 0, 1, \dots, N-1 \quad (2)$$

However, it is also possible to implement the filter, directly from its frequency samples  $H[k]$ , using the frequency sampling structure shown in figure 2, with  $N$  parallel branches, where the branch gains,  $H[k]$  exhibit a complex conjugate symmetry given by equation 3.

$$H[k] = H^*[N-k] \quad (3)$$

The two parallel branches in the frequency sampling structure shown in figure 2, with complex conjugate symmetry in the coefficients  $H[k]$  and  $H^*[k]$ , can be grouped together, and simplified as shown in figure 3. Hence, each complex conjugate pair can be represented by the following second order structure, where

$$H[k] = a[k] + jb[k] \quad (4)$$

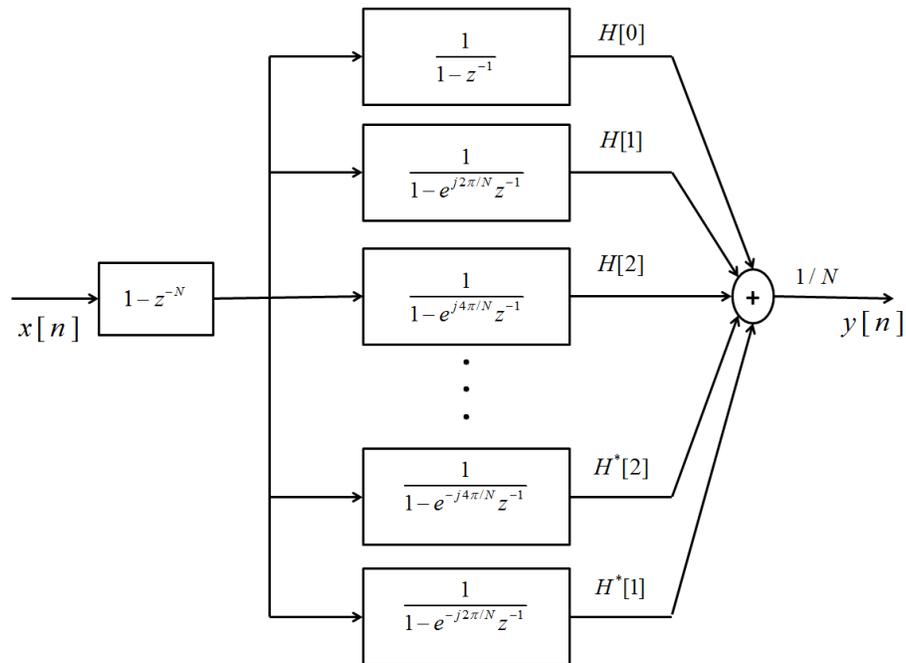
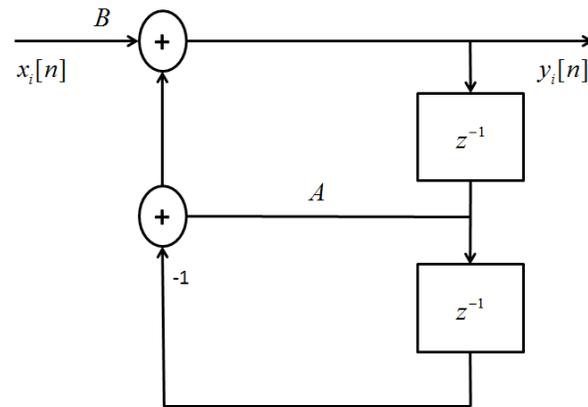


Figure 2. Frequency sampling structure of an FIR filter with N frequency samples  $H[k]$



$$A = 2a[k] \cos(2\pi k / N)$$

$$B = 2(a[k] \cos(2\pi k / N) + b[k] \sin(2\pi k / N))$$

Figure 3. Considering the two parallel branches with complex conjugate symmetry in the branch frequency samples

### Narrow Band Pass Filters

The practical implementation of narrow band pass filter using the frequency sampling structure, is beneficial, as in this case, most of the frequency samples as zero, together with extremely few non-zero samples. The number of non-zero samples depends on the width of the pass-band, and number of samples N. For example, if the narrow band pass filter has only two non-zero samples then, filter can be implemented by the simple structure of figure 3, where the constants A and B, depend on the frequency samples  $H[k]$  and  $H^*[k]$ , preceded by the block with transferfunction  $(1-z^{-N})$ , and followed by the gain  $(1/N)$ . Of course, use of the frequency sampling structure is not essential, and one can implement the filter by computing the filter impulse response  $h[n]$ , given by equation 2.

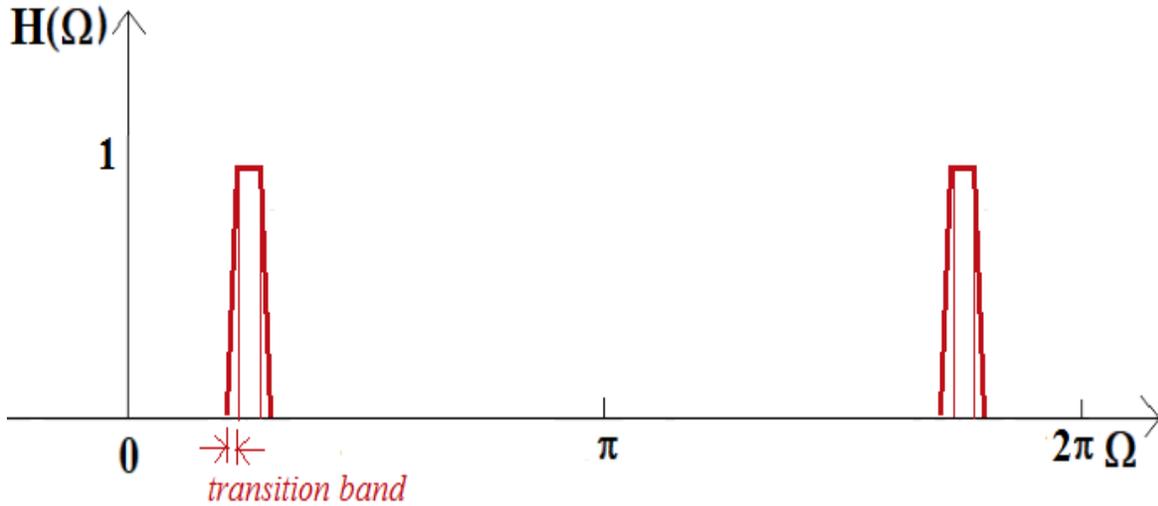


Figure 4. Narrow Band Pass filter with zero transition band.

User equipment (UE) using LTE- Advanced requires narrow band digital FIR filters. A practical implementation of the filter shown in figure.1 has the drawback of the Gibbs phenomenon, through significant ripples in the stop band of the filter. In order to reduce the spectral content in the stop band, we introduce a small transition band in the frequency response of the desired filter, as shown in figure 4. The width of the transition band is equal to the resolution of the sampling ( $2\pi/N$ ). We attempt to compare the frequency response of the designed filter when the frequency response has a zero transition band, with that of a small transition band. As expected, the introduction of the transition band significantly reduces the spectral content in the stop band.

For the given frequency response, we compute the frequency samples  $H[k]$ , then the impulse response of the filter, using equation 2. We then obtain the frequency response of the designed filter using equation 5, and compare the response of the designed filter with that of the desired filter. In the next Section, we compare the results for narrow band pass filters with zero transition bands, and with non-zero transition band.

$$H(\Omega) = \sum_{n=0}^{N-1} h(n)e^{-j\Omega n} \quad (5)$$

#### IV. Simulation Study

In this work, the frequency response of the narrow band filter with sharp transition band and with small transition band is compared. The implementation of the narrow band filter is based on the frequency sampling method. The given frequency response  $H(\Omega)$  as shown in figure 1 is sampled into  $N$  uniformly spaced samples as shown in figure 5 for  $N=64$ , with  $N$  being the order of the filter. Figure 6 shows the samples of the filter response with introduction of small transition band for  $N=64$ .

The design is verified by computing the frequency response and observed that frequency response of the designed filter has lot of spectral content in the stop band, though the width of the pass band is narrow as shown in figure 7. We try to overcome the above by introducing a small transition band in the frequency response as shown in figure 6. The design was again tested for the spectral components in the stop band to be minimized as in figure 7. Similarly figure 8 shows the frequency response for the filter with  $N=256$ .

We also observed that the greater the order of the filter, the steeper the transition band becomes and the response is found to be better with less ripples. Hence, commonly designed FIR filters use higher order to obtain the narrow transition band. This may add to the complexity of the system. Complexity in the implementation of hardware of FIR filter depends on the number of multipliers being used<sup>13</sup>. Frequency Sampling Method is ideally suited for hardware implementation of the narrow band filter as most of the DFT coefficients are zero. The path with zero coefficients need not be realized<sup>12</sup>. Hence the designed filter can be converted to hardware implementation.

Figure 9 shows that the spectral content in the stop band is decreasing with the increasing in the value of  $T_a$ , and increasing after a certain value.  $T_a$  is the magnitude of the filter coefficient in the transition band. Hence the value of  $T_a$  with lesser spectral content is chosen for the study.

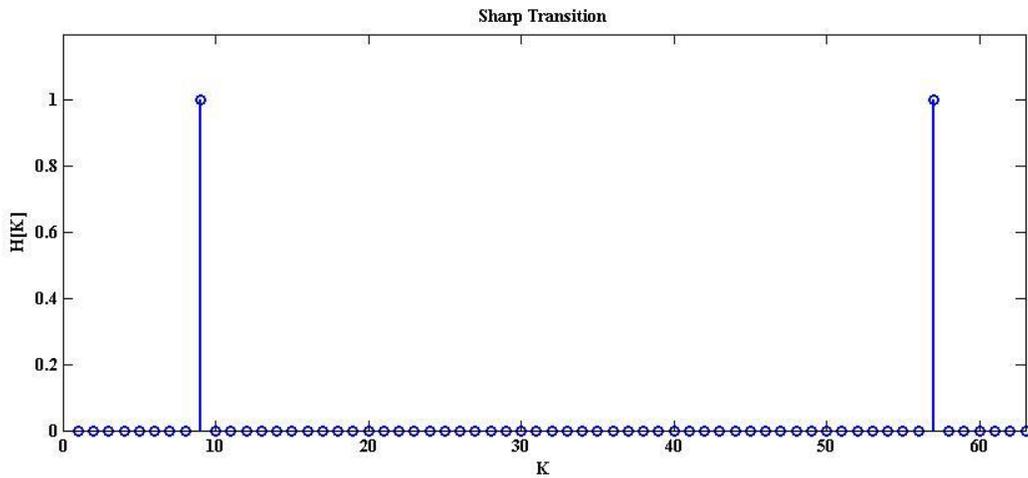


Figure 5. Frequency samples of filter with sharp transition

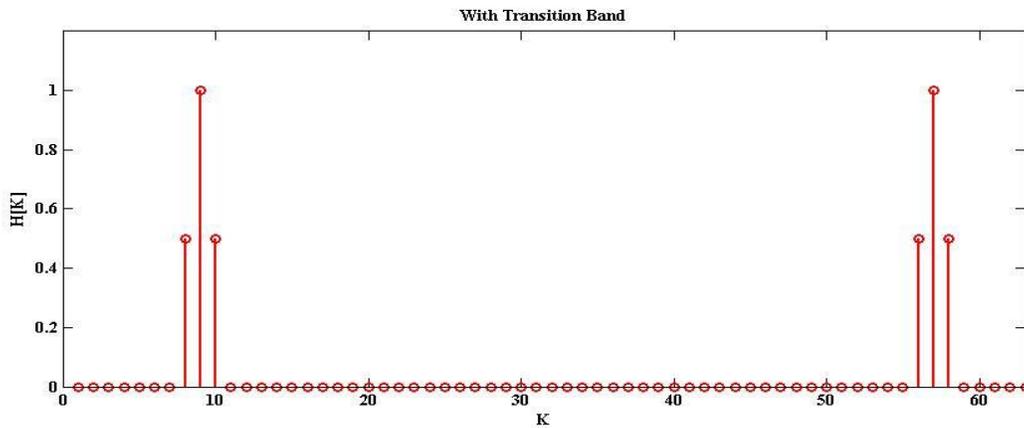


Figure 6. Frequency Samples of filter with small transition band

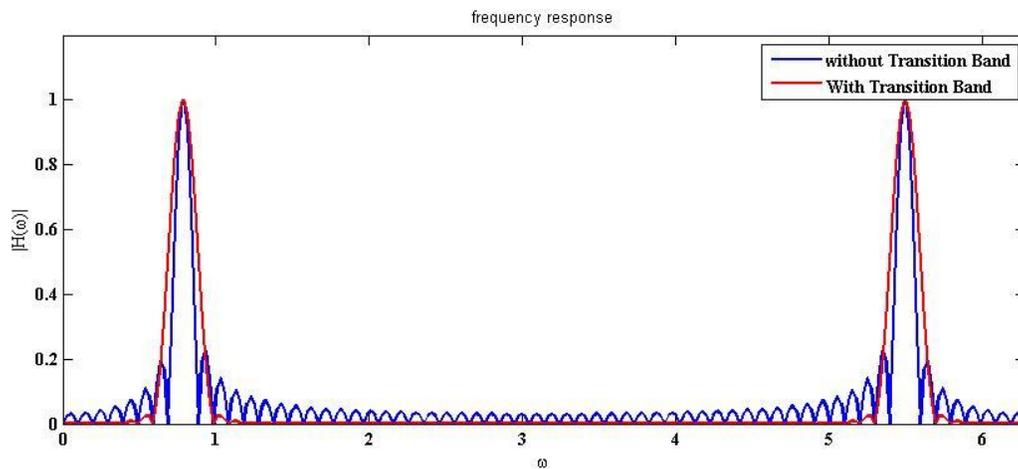


Figure 7. Frequency response of FIR narrow band filter

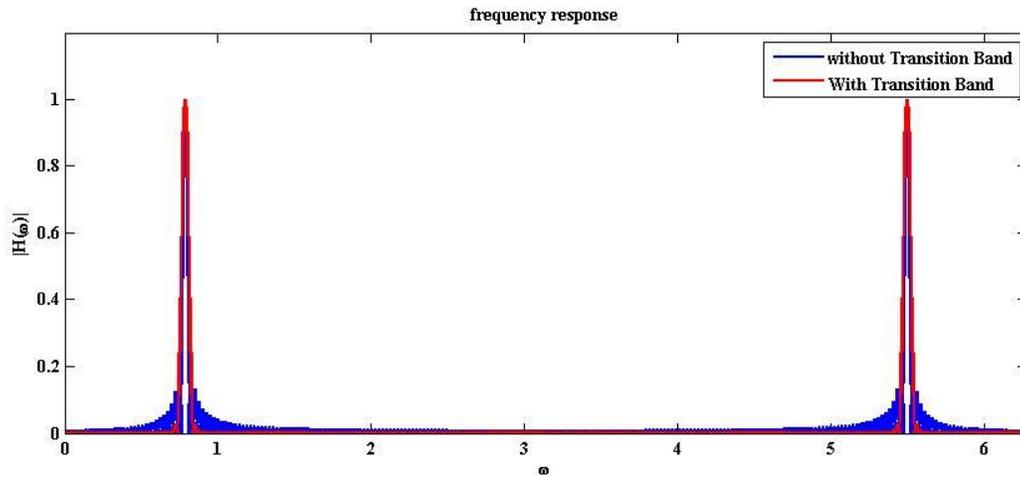


Figure 8. Frequency response of FIR narrow band filter for N=256

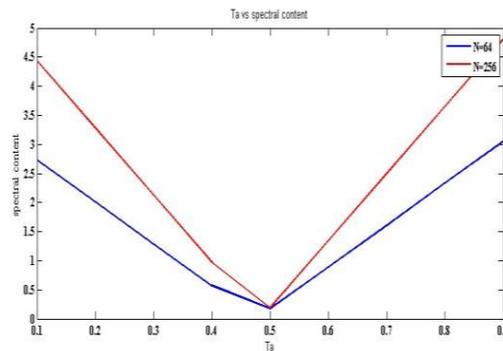


Figure 9. Plot of  $T_a$  v/s spectral components in the stop band

**Table no1:** Shows that the spectral content in the stop band is minimized with the introduction of the small transition band while it is increased in the pass band.

**Table no1:** Shows spectral content in pass band and the stop band.

Order of filter	Stop band		Pass band	
	Sharp transition	Smooth transition ( $T_a=0.5$ )	Sharp transition	Smooth transition ( $T_a=0.5$ )
16	1.2946	0.0682	5.8488	8.0740
32	2.3810	0.1465	5.8280	8.1181
64	3.4502	0.1766	5.8242	8.1193
128	4.5190	0.1844	5.8207	8.1193
256	5.5866	0.1864	5.8185	8.1193

## V. Conclusion

FIR filters are preferred over the IIR filters as they are stable. All the poles lie at the origin. They have very small non zero samples and hardware implementation becomes easy, except for the small increase in the width of the pass band. This work shows that, the introduction of the transition band results in good response of the filter performance. There is a huge reduction in the spectral component in the stop band with the small increase in the

spectral content in pass band, when transition band is introduced. Hence, suitable to suppress the other carrier in the LTE –Advanced environment.

### References

- [1]. Subhabrata Roy, Abhijith Chandra, “Design of narrow transition band digital filter: an analytical approach”, in *Integration the VLSI journal*, volume 68, September 2019, pp 38-49
- [2]. Alastair Brydon, “Summary of 3GPP Standards Releases for LTE”, [unwiredinsight.com/2012/3GPP-LTE-releases](http://unwiredinsight.com/2012/3GPP-LTE-releases).
- [3]. RapeepatRatasuk, Dominic Tolli ,AmritavaGhosh , “Carrier Aggregation in LTE-Advanced”, in *IEEE 71st Vehicular Technology Conference*, Taiwan, 16-19 May 2010
- [4]. HamedGheidi, Hayg-TanielDabag, Youjiangliu, Peter M. Asbeck, Prasad Gudem, “ Digital Cancellation Technique to mitigate receiver desensitization in cellular handsets operating in carrier aggregation mode with multiple uplinks and multiple downlinks”, *IEEE Radio and Wireless Symposium(RWS)*, USA, 25-28 January 2015
- [5]. Pushpavathi.K.P,” Studies on Carrier Aggregation in LTE-Advanced” *International Journal of New Innovation in Engineering and Technology*, Volume 13, Issue 1 February 2020, ISSN: 2319-6319, pp 021-025
- [6]. BilijanaBadic, Andrea F. cattoni, Michael Dieudonne , Jonathan Duplicy, Peter fazekas, Florian Kaltenberger , Istvan .Z Kovacs, Guillaume Vivier, “Advances in Carrier Aggregation and Multi user MIMO for LTE-Advanced: outcomes from Samurai project “ - November 2012
- [7]. Liston Kiwoli, Anael Sam and Emmanuel Manasseh, ”Performance analysis of Carrier Aggregation for various Mobile Network Implementations Scenario Based on Spectrum Allocated”,in *International Journal of Wireless and Mobile Networks (IJWMN)*, Vol. 9, No. 5,October 2017, pp 41-53
- [8]. IbraheemShayea, Mahamod Ismail, RosdiadeeNordin,” capacity evaluation of Carrier Aggregation Techniques in LTE-Advanced systems”, in *International Conference on Computer and Communication Engineering (ICCCE 2012)*, 3-5 July 2012 , KualaLumpur,Malasia
- [9]. Thomas Schlechter, Michael Lunglmayr,”Optimised Filter Design in LTE systems using nonlinear optimization “, *European Wireless 2011* April 27-29, 2011, Vienna, Austria
- [10]. Pushpavathi.K.P, B Kanmani, “FIR Filter design using Wavelet Coefficients” , *International Conference on Wireless Communications Signal Processing and Networking (WiSPNet)* , 21-23 March 2019, Chennai, India
- [11]. V.Silva Cortex, V Chauhan, R Weigei, G Fischer, A Hagelauer, “Nonlinear BAW Filter model Effects on the performance of an LTE receiver”, *IEEE international Ultrasonic Symposium (IUS)*, France, 18-21 September 2016.
- [12]. Lawrence R Rabiner ,Berdard Gold,” *Theory and Applications of Digital Signal Processing*”, – pp 50,Book, Prentice hall.
- [13]. Subhabrata Roy, AbhijithChandra,”On the order Minimization of Interpolated Band pass Method Based Narrow Transition Band FIR Filter design”, – in *IEEE transactions on circuits and Systems-1: Regular papers*, vol.66. no 11, November 2019
- [14]. Pushpavathi. K . P, B Kanmani,”Frequency Sampling method of FIR Filter design: A comparative study”, in *International Conference on Electrical,Electronics,Communication,Computer and Optimization Techniques (ICECCOT)*, 14-15 December 2018, Mysore,India.