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Diplexer design for 4G Mobile Communication using Lumped Component Filters

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ABSTRACT

In this paper, various orders of lumped components band pass filters for the diplexer design were investigated to operate for the multi- bands of the LTE antenna i.e. 698 – 960 MHz and 1710 – 2700 MHz. The main aim behind the design of the diplexer was that there is a need to reduce the size of the diplexer without compromising the performance of the diplexer to a greater extent. In contrast to this, high degree of miniaturization was accompanied with great deal of degradation in the performance of the diplexer

KEY WORDS: Diplexer, Heterogeneous, Stub Filters, LTE, Antenna, Transceiver.

I. INTRODUCTION

The 4G (Fourth Generation) mobile communication has recently been the focus of intense research in developing its standards, features and applications that would exceed those of 3G while keeping the communications device size compact. This would, in turn, impose high demands on the design of the handheld device, in particular, design of the transceiver since its size controls the overall device size. This work is focused on investigating the various filters design techniques for the miniaturization of the diplexer without compromising the performance of the diplexer to a greater extent.

A diplexer is an important part of the transceiver circuit as it allows the signals from multi-band LTE(Long term evolution) antenna to be separated and processed by two separate receivers at the same time to achieve the high data rate requirements of the 4G network. It consists of three ports of which P_1 (Port 1) is for the input or in other words, it is the common port, whereas, P_2 (Port 2) and P_3 (Port 3) are for the splitted subbands respectively [1]. The main function of the diplexer is to separate the signals for the upper and lower LTE frequency bands from the combined spectrum of frequencies at the common port of the diplexer and make them available on the two output ports with minimum leakages between them to support the parallel processing of the signals for the lower and upper frequency passbands. In this case the upper and lower LTE (Long Term Evolution) frequency bands i.e. 698 – 960 MHz and 1710 – 2700 MHz are to be split from a combined frequency spectrum.

Rest of this paper is divided ino the following parts. Section II shows the background of this work. Section III is describing the motivation for this paper. Section IV represents the filter design technique and their tradeoff, size and performance. Section V explains in detail our proposed purely lumped components diplexer design. Section VI concludes our work and specifies the future work that can be done for miniaturization, while maintaining acceptable performance of the diplexer.

II. BACKGROUND

4G is the future of mobile communication and it is expected to replace the existing 3G (3rd Generation) networks completely in the next few decades. It is designed to provide high speed and multimedia services based on IP (internet protocol). 4G would be an integrated global network that would allow voice, data, and streamed multimedia to be available to the users anywhere and at any instant of time at high data rate. Fig. 1 shows that 4G systems are going to incorporate all the systems from different networks i.e. different private, public, personal area, operator based and adhoc networks and would be an IP based integrated system [3].

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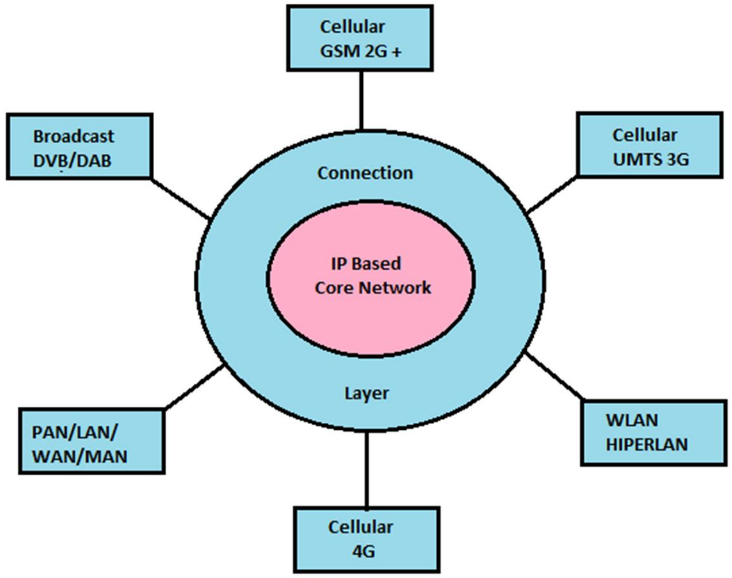


Fig. 1. Seamless connections of networks [3].

The multiplexer is an important part of the microwave front end as it is used for the separation of channels which are used in various applications i.e. radar, transceivers etc. The multiplexer give different frequency bands to every channel so that it can operate at high bandwidth [5]. One of the well-known multiplexer is a diplexer which multiplexes a combined spectrum of frequencies into two sub-bands.

The dual frequency band operation in the latest communication systems requires a diplexer to be used in the design of a transceiver so that a single antenna can operate at two different frequency bands to both transmit as well as receive. To fulfill the high requirements of the latest transceiver design the diplexer should be planar and compact [6]. Diplexer is a three port device that separates two frequency bands from a combined frequency spectrum and makes them available on the two output ports while keeping the interference between the signals to the minimum and the two ports can be fed to two different receivers for parallel processing [8].

The design of a diplexer involves two different filters with respective frequencies having distinctive non-overlapping pass bands. If the pass bands of the filters are close to each other there will be an adverse effect on each other due to that. This detrimental effect will cause the return loss to decrease and insertion loss to increase whereas destroying pass band's symmetry and flatness [8].

Most widely used diplexer for wireless communication consists of two bandpass filters, however, the main hurdle in the design of the diplexer is that it's size is never small enough [9]. On the other hand the modern trend in the design of the diplexer is to achieve high performance while keeping the cost and size to minimum. Bandpass filters are a good choice to achieve this because they can be fabricated on a dielectric substrate with low cost [10]. An increase of sections in diplexer help in increasing the bandwidth of the passb and causing increase in losses as a tradeoff [12].

III. MOTIVATION

As the users of the wireless handheld devices have grown rapidly during the last decade there is an ever-growing demand for higher data rates and increased features & applications available in modestly sized communication devices. The endeavor of the future 4G network is the flawless connectivity of the user of handheld terminals anywhere and at anytime. This puts high demands on the diplexer hardware so that it can allow the handheld devices to operate at different frequency bands in a heterogeneous network. The diplexer plays a vital role in the reduction of the size of the handheld terminals by reducing the transceiver's circuitry. The dual band operation of the multi-frequency LTE antenna requires a diplexer which is used for multiplexing the received signals into two different receivers based on their frequency. The diplexer has been researched at large since 1960's because they are indeed a vital part of communication [2].

In [4], a fully integrated planar triplexer using microstrips for multiband UWB has been presented. Three flat sub-bands in the frequency band 3.1–4.8 GHz for multiband UWB have been achieved. The triplexer can be integrated into a printed circuit board using a commercial process technique at low cost, even though the guard-band has only a relative bandwidth of 0.7% between the three subbands. The triplexer uses three filters with a combined broadside- and edge-coupled structure. Keeping in sight the functionality, the diplexer and triplexers are similar and the only difference in diplexer design is that it has one output port less than the triplexer. In the diplexer design, two filters are used for splitting the upper and lower frequency passbands of the combined spectrum [8].

Broadband antennas are very useful in many applications because they operate over a wide range of frequencies. Debalina Ghosh' *et al.* [3] deals with ways of converting various resonating antennas to traveling-wave antennas by using resistive loading. Appropriate loading increases the bandwidth of operation of the antennas. Hence, the transient responses of these antennas can be used to determine their suitability for wideband applications with a low cutoff frequency. Authors also illustrates the radiation and reception properties of various conventional ultra-wideband (UWB) antennas in the time domain. An antenna's transient response can be used to determine the suitability of the antenna in wideband applications.

In [5] a miniaturized microstrip triplexer with a common resonator section is proposed. Triplemode SIR design graph is also provided to design the common resonator. In addition, extra transmission-line matching network connecting three filter channels is not needed in our triplexer design. In comparison with the conventional triplexer, the proposed one has more compact size because an extra matching network and two resonators are saved.

A compact diplexer with very high output isolation is proposed by using hybrid resonators [6]. Both the adjacent channel suppressions and isolation are better than 55 dB. This diplexer can be used in the dual-band personal communication system.

In this paper [7], a new type of diplexer is presented. The simulated data show that the micro-strip diplexer has excellent performances of low insertion loss and wider suppression band-stop [13]. Also, the second harmonic falls into the stopband and can be suppressed directly. The diplexer can be used in the satellite communications system.

In this study [9], the dual-bandpass filter is realized using parallel coupled microstrip lines and open-loop stepped impedance resonators (SIRs) loaded with two shunt open stubs, and the matching circuits are developed based upon the single-shunt-stub tuning and the double-shunt-stub tuning which is called π type circuit. The diplexer is designed to support dualband operation at 2.4-2.5 GHz and 4.9-5.8 GHz frequency bands which are used in WLAN applications.

A compact diplexer using a square open loop with stepped impedance resonators is proposed in this paper [10]. The resonator consists of two identical patches which are attached to the inner corner of the square open loop. The bandpass filter and diplexer are used as alternative techniques for the implementation of transmission zeros using an asymmetric feed structures.

IV. FILTERS DESIGN

The design of the diplexer principally requires the design of two filters which will work on the upper and lower frequency passbands of the LTE. These filters can be designed using lumped components filter design technique which is explained in this section with the aid of simulation results.

A. Design Specification

The requirement of the 4G diplexer design is that two filters for the LTE upper and lower frequency passbands i.e. 698 - 960 MHz and 1710 - 2700 MHz at minimum -3 dB attenuation should be designed and combined together along with their matching network in each filter branch. The specification for the response of the filters is that the steepness of the transisition band should be more than -40 dB and the input reflection (S_{11}) should not be more than -6 dB.

The ADS (Advanced Design System) 2009 from Agilent Technologies Inc. software tool was used to analyze and optimize the simulations of the designed filters. The design process consisted of two main steps i.e. use of a simulation tool i.e. ADS to make the schematic of a filter and to optimize it to get the simulation results according to the diplexer design requirements. The second step involves the layout generation using the momentum tool available in ADS and its optimization.

Following are some of the features which make RO4360 substrate ideal for this design [17]

- It is the most balanced material with regards to performance and ease of processing.
- It has the “glass reinforced, hydrocarbon filled ceramic material with high thermal conductivity” and having minimum losses.
- It excels over all other RO (Rogers) substrates as it is lead-free which makes it more environments friendly.
- It has better rigidity which makes it’s processing better for use in multilayer PCB fabrication while keeping the costs low.
- It has more design flexibility and the plated through holes are more reliable.
- It has Dk (dielectric constant) of 6.5 which helps the RF designers to reduce the size of the circuit [15].

Table 1: Substrate Definition

Parameter (Rogers 4360)	Dimension
Relative dielectric constant	6.15
Substrate thickness	0.305 mm
Metal thickness	18 µm
Loss factor	0.003
Metal conductivity	5.8×10^{7} S/m
Conductor surface roughness	0.001

B) Lumped Components Filter Design

The design of the lumped components filter is optimized for smaller size by keeping the minimum order for both upper and lower frequency bands of the LTE and keeping the transition band steepness under the design specification so that the passband is not abridges from its edges. This would also make the number of lumped components less, hence, reducing the parasitic losses associated with each lumped component.

The highpass, lowpass, bandpass, or bandstop filters can be used for the diplexer design however bandpass filter was selected because lowpass or highpass filter also include frequency bands other than the requirement in the passband. Another reason for the choice of the bandpass filter was that it is easily manufacturable on any substrate with less cost of fabrication and high performance [15].

The design of a lumped components filter becomes difficult at high frequency range because in the real environment at high frequencies the behavior of the lumped components is altered as the wavelength at high frequency becomes comparable to the physical dimensions of the lumped components [11]. It is known through classical lumped components theory that the lumped components are stable only for lower frequencies hence the design was initiated with a bandpass filter for lower frequency band of LTE.

The following section contains the design and simulation results which compare the size and performance of the bandpass lumped components filters. In the beginning of the lumped component filter design, the simulations were done on ADS for 3rd order bandpass filter with butterworth response using real lumped components which included the parasitic losses from components manufacturer's specification (AVX Corporation). Fig. 2 shows the schematic of the 3rd order bandpass filter having butterworth response consisting of series and parallel LC tank circuits and their real lumped components values are mentioned in Table 2.

The series LC tank circuit provides low impedance path to the input signal at specific frequency bands and allow the signals to be passed to the output port of the filter. On the other hand the parallel LC tank circuit provides high impedance path to the signal and only stops specific band of frequencies to reach the output port by grounding those signal which are not desired [15].

Table 2

Inductors	Capacitors
L1 = 10 nH	C1 = 22 pF
L2 = 10 nH	C2 = 22 pF
L3 = 6.8 nH	C3 = 3.9 pF

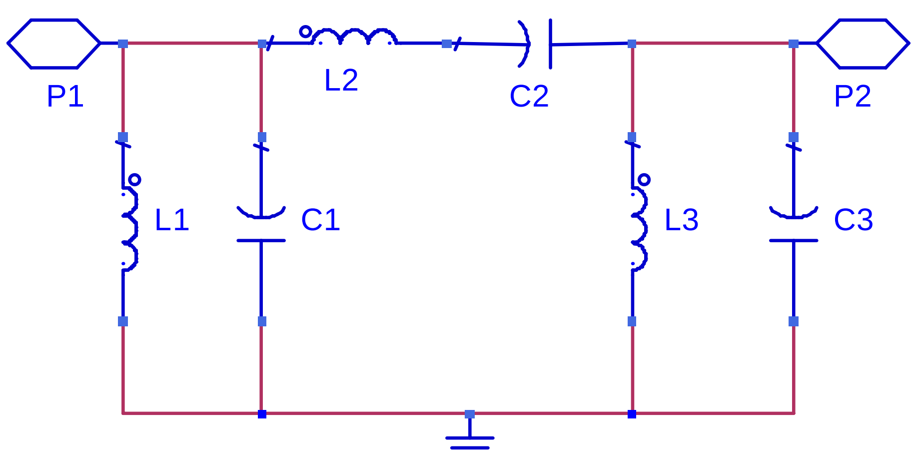
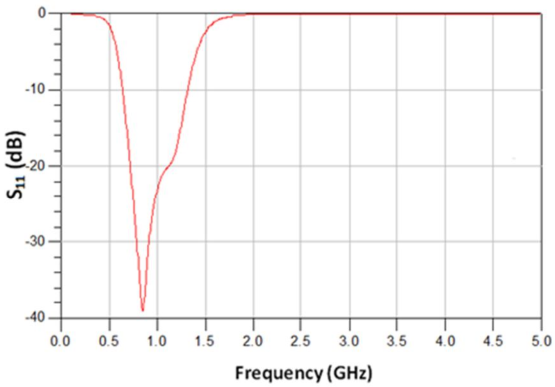
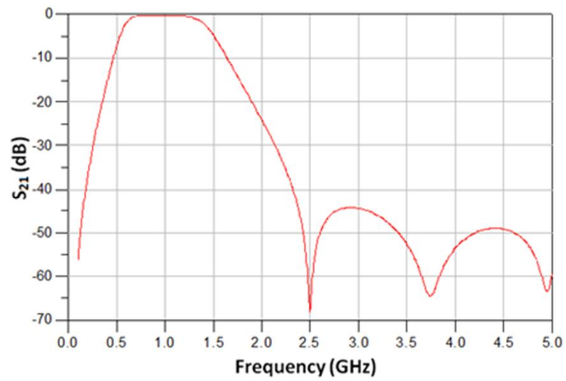


Fig. 2. Schematic of the 3rd order real lumped components bandpass filter with butterworth response for lower frequency band.

Fig. 2 shows real lumped components details which includes typical paracitics for 0805 SMD package specified by AVX Corporation. Fig. 3 (a) shows the schematic level simulation result of input reflection S_{11} of the 3rd order bandpass filter with butterworth response for lower frequency band which is -39 dB that satisfies the design specification. Fig.3 (b) shows the simulation result of the forward transmission S_{21} of this filter having a passband of 571- 1437 MHz which is 230 % increased from the LTE lower band specification. The passband is kept higher from the specifications to give margin for losses during the integration of the filters for diplexer design. It can be further seen from fig. 3 (b) that the transition region is very less steep however as the band gap between the upper and lower frequency band of the diplexer is high i.e. 750 MHz, the minimum steepness according to the design specification is sufficient for the filters to have non-overlapping passbands.



(a)



(b)

Fig.3. Simulation results of the 3rd order real lumped components bandpass filter with butterworth response for lower frequency band on a schematic level: (a) input reflection S_{11}, and (b) forward transmission S_{21}.

Fig. 4 shows the group delay on the schematic level of the 3rd order bandpass filter for lower frequency band and it is observed that the maximum delay is 1.5 ns and the delay variation is around 0.2 ns.

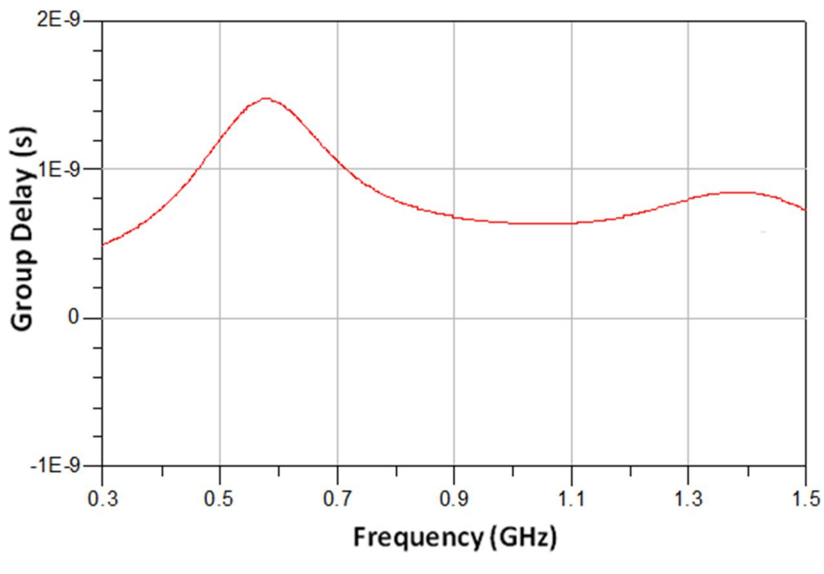


Fig. 4. Group delay of the 3rd order real lumped components bandpass filter with butterworth response on a schematic level.

In the next phase of the real lumped component filter design the order of the filter was reduced from 3rd to 2nd as shown in schematics of the fig. 5. It can be observed that the numbers of lumped components are also reduced and their real lumped components values are listed in the Table 3.

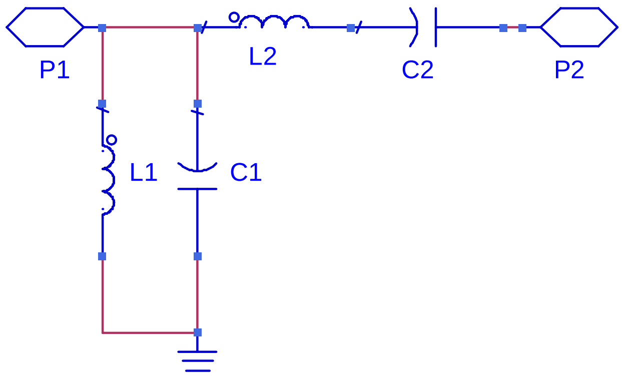


Fig. 5. Schematic of the 2nd order real lumped components bandpass filter with butterworth response for lower frequency band.

Fig. 5 Real lumped components details including typical paracitics of 0805 SMD package specified by AVX Corporation.

Table 3

Inductors	Capacitors
L1 = 10 nH	C1 = 22 pF
L2 = 10 nH	C2 = 22 pF

Fig. 6 shows that simulation results of a 2nd order real lumped components bandpass filter with butterworth response for lower frequency band on a schematic level. This filter has a passband of 461 – 1374 MHz and its passband has increased 248 % as compared to the LTE specification which is higher than the 3rd order bandpass filter for lower freqeuncy band. However the steepness of the filter's response is decreased from the design specification hence this filter can't be used for the lower frequency band of the diplexer design.

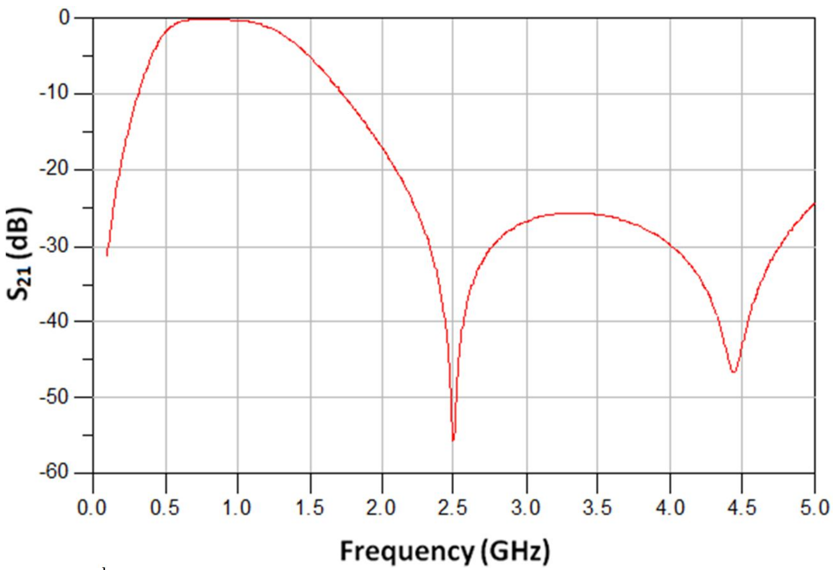
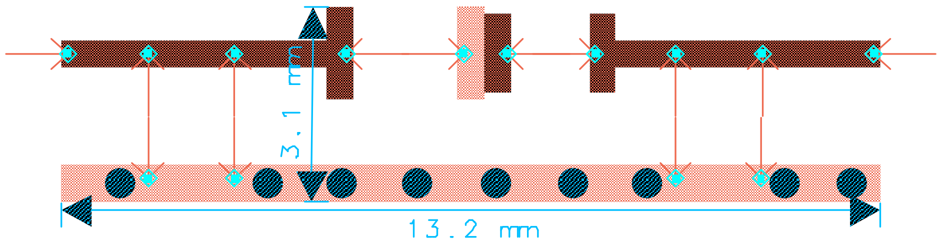


Fig. 6. Simulation of the 2nd order real lumped components bandpass filter with butterworth response for lower frequency band on a schematic level.

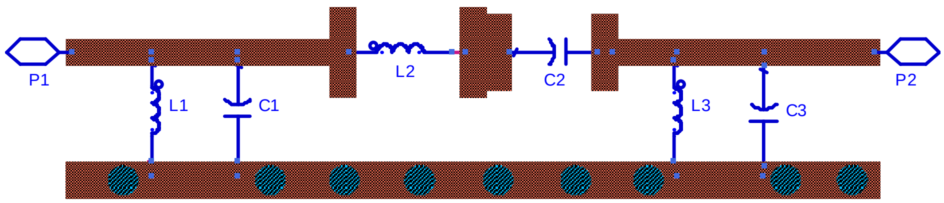
The next step in the design of the real lumped component bandpass filter was to generate the layout of the selected filter i.e. 3rd order bandpass filter for the lower frequency band.

Fig. 7 (a) shows that a copper trace is used for replacing the ideal wire as it is not possible to generate the layout of the ideal wire in ADS. This problem was solved by creating the layout component of the copper trace and using it in the schematic level for simulation as shown in fig. 7 (b), the real lumped components parameters can be seen from Table 4.

The copper trace width is 0.43 mm which is calculated in ADS using line calculator with roger substrate RO4360 properties to provide characteristic impedance of 50 Ω. It can also be seen from this figure that the length of the layout is 13.2 mm and the width of the layout is 3.1 mm which makes the size of the filter very small.



(a)



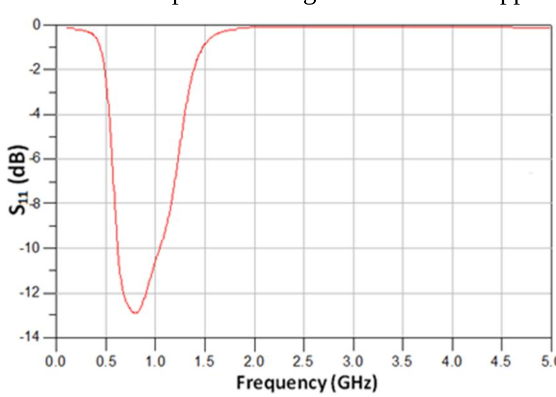
(b)

Fig. 7. Copper traces of the 3rd order bandpass filter with butterworth response for lower frequency band: (a) layout component, and (b) layout component with real lumped components in a schematic level.

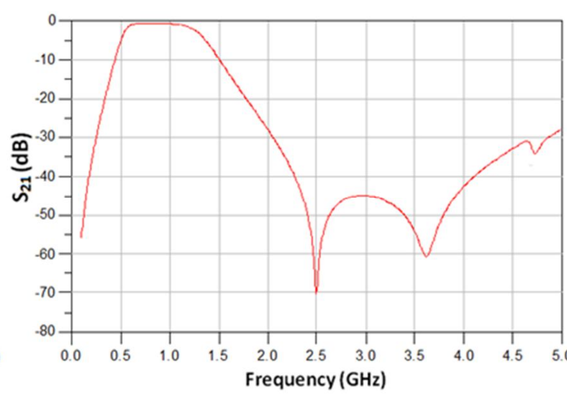
Table 4

Inductors	**Capacitors**
L1 = 10 nH	C1 = 2.2 pF
L2 = 10 nH	C2 = 2.2 pF
L3 = 6.8 nH	C3 = 3.9 pF

Fig. 7 shows real lumped components details which includes typical paracitics for 0805 SMD package specified by AVX Corporation. Fig. 8 (a) shows the simulation result on layout level of the 3rd order bandpass filter with butterworth response for lower frequency band showing input reflection S_{11} which is -13 dB, and is acceptable as per design requirements. On the other hand fig.8 (b) shows the simulation result of the forward transmission i.e. S_{21} of this filter with a passband of 540 – 1287 MHz which is 14 % reduced from its schematic level simulation results because of impedance irregularities in the copper trace.



(a)



(b)

Fig. 8. Layout level simulation results of the 3rd order real lumped components bandpass filter with butterworth response using copper traces for lower frequency band: (a) input reflection S_{11}, and (b) forward transmission S_{21}.

Fig. 9 shows the layout level group delay of the 3rd order bandpass filter with butterworth response using copper trace for lower frequency band and it is observed that the delay variation is around 0.1 ns and maximum delay is 1.7 ns.

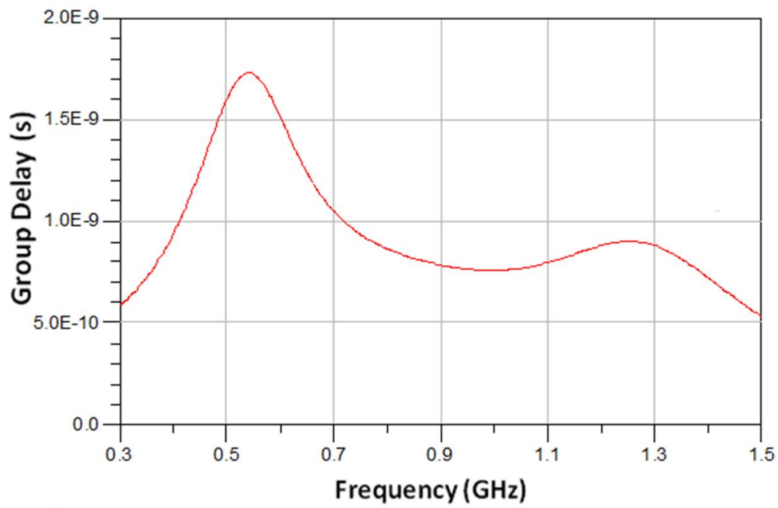


Fig. 9. Group delay of the 3rd order real lumped components bandpass filter with butterworth response using copper traces for lower frequency band on a layout level.

The second phase of the real lumped components filter design for diplexer was to design a bandpass filter for upper frequency band of the LTE. The main challenge to design the upper frequency band lumped component filter was to achieve a high bandwidth while keeping the number of lumped component less in order to minimize the parasitic losses. Fig. 10 shows the schematic of a 6th order real lumped components bandpass filter with butterworth response for upper frequency band of the LTE. It is clearly seen from this figure that the number of lumped components have increased as compared to the filter designed for lower frequency band due to the increment in order. Table 5 enlists the real lumped components values.

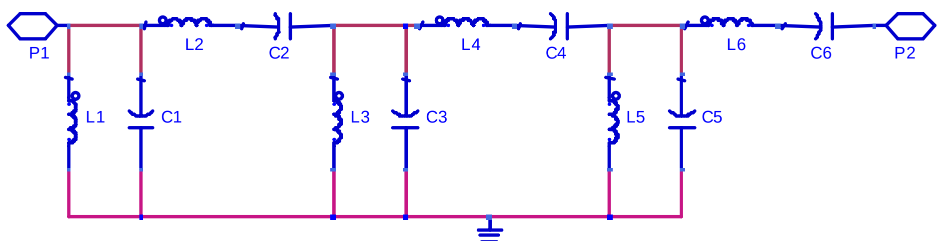


Fig. 10. Schematic of the 6th order real lumped components bandpass filter with butterworth response for upper frequency band.

Table 5

Inductors	Capacitors
L1 = 2.7 nH	C1 = 1.2 pF
L2 = 2.7 nH	C2 = 0.9 pF
L3 = 1.8 nH	C3 = 1.5 pF
L4 = 6.8 nH	C4 = 0.5 pF
L5 = 1.8 nH	C5 = 1.8 pF
L6 = 1.2 nH	C6 = 1.2 pF

Real lumped components details including typical paracitics for 0805 SMD package specified by AVX Corporation. Fig. 11 (a) shows that the schematic level simulation result of the 6th order real lumped components bandpass filter with butterworth response for upper frequency band showing the input reflection S_{11} which is -14 dB and it is acceptable according to the design requirements. On the other hand fig. 11 (b) shows the simulation result of the forward transmission i.e. S_{21} of this filter which has a passband of 1645 – 2853 MHz and its passband has increased 22 % as compared to the LTE specification.

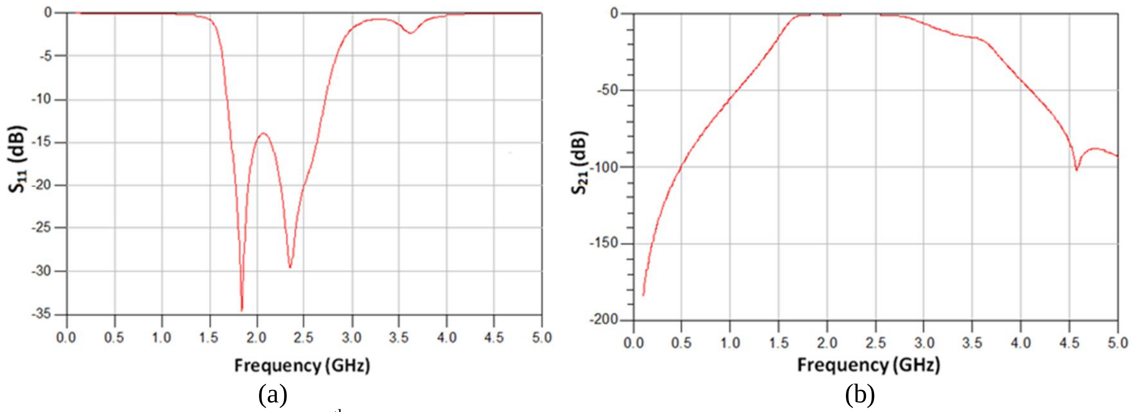


Fig.11. Simulation results of the 6th order real lumped components bandpass filter with butterworth response for upper frequency band on a schematic level: (a) input reflection S_{11}, and (b) forward transmission S_{21}.

Fig. 12 shows the group delay of the 6th order real lumped components bandpass filter with butterworth response for upper frequency band on a schematic level and it can be observed that inband delay variation is approximately 0.1 ns where as maximum delay is 2.1 ns.

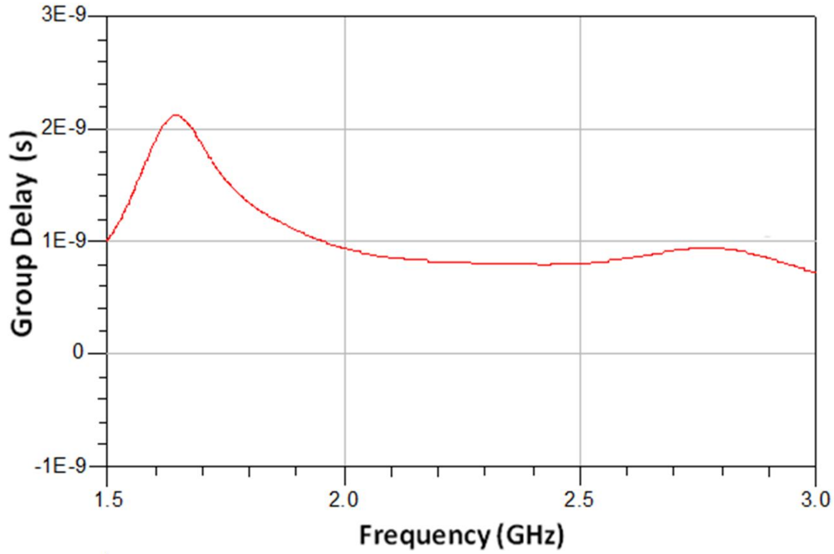


Fig. 12. Group delay of the 6th order real lumped components bandpass filter with butterworth response for upper frequency band on a schematic level.

Similar to the case of lower frequency band real lumped component bandpass filter design, the order of the filter for upper frequency band was reduced from 6th to 5th as shown in schematics of fig. 13. It can be observed that the numbers of lumped components are also reduced. The real lumped components details can be seen from the Table 6.

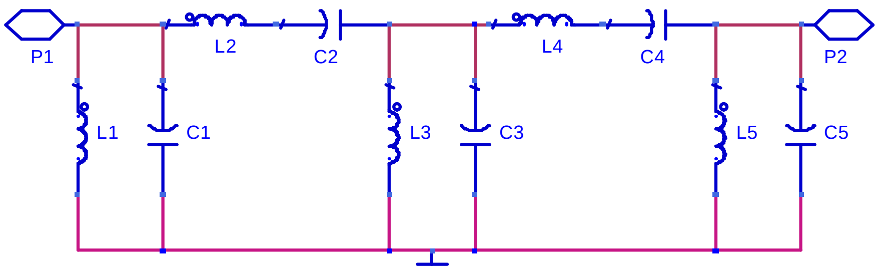


Fig. 13. Schematics of the 5th order real lumped components bandpass filter with butterworth response for upper frequency band.

Table 6

Inductors	Capacitors
L1 = 3.9 nH	C1 = 1.5 pF
L2 = 8.2 nH	C2 = 0.6 pF
L3 = 1.8 nH	C3 = 3.3 pF
L4 = 8.2 nH	C4 = 0.7 pF
L5 = 3.9 nH	C5 = 1.5 pF

Real lumped components details which includes typical paracitics for 0805 SMD package specified by AVX Corporation. Fig. 14 shows the schematic level simulation result of a 5th order real lumped components bandpass filter with butterworth response for upper frequency band, this filter has a pass band of 1369 - 2235 MHz which does not fulfill the requirement of the LTE upperband of 1710 – 2700 MHz, and hence this design could not be used in the diplexer design for the upper frequency band.

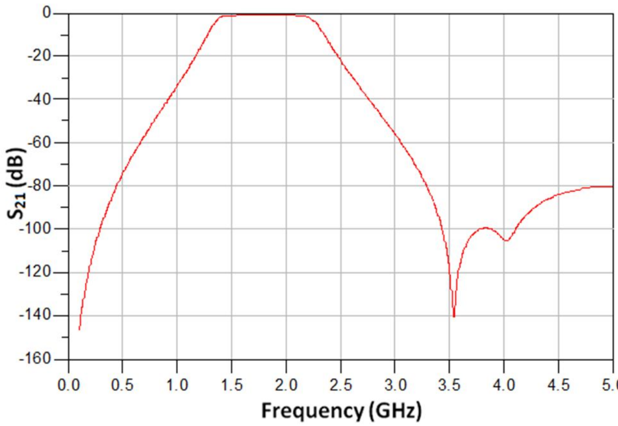
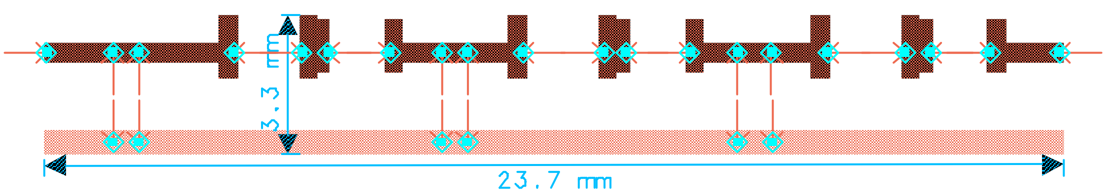


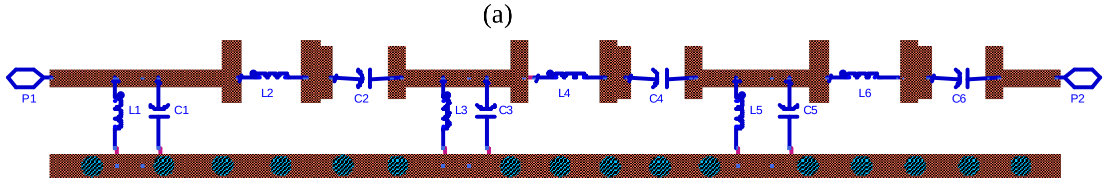
Fig. 14. Simulation of the 5th order real lumped components bandpass filter with butterworth response for upper frequency band on a schematic level.

Finally the upper frequency band real lumped component bandpass filter's of 6th order layout was generated. Fig. 15 (a) shows that a copper trace is used for replacing the ideal wire similar to the case for lower frequency band filter. It can also be seen from this figure that the length of the layout is 23.7 mm and the width is 3.3 mm which makes the size of the filter small.

As it is already discussed in the lower frequency band filter design, the lumped components need to be used with the copper trace layout component in the schematic level as shown in fig. 15 (b). The real lumped components values are enlisted in Table 7.



(a)



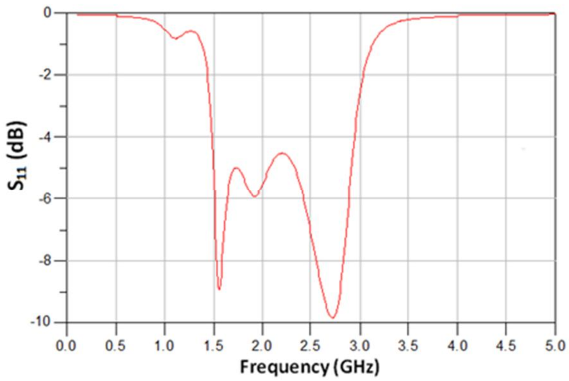
(b)

Fig. 15. Copper traces of 3rd order bandpass filter with butterworth response for lower frequency band: (a) layout component, and (b) layout component with real lumped components in a schematic level.

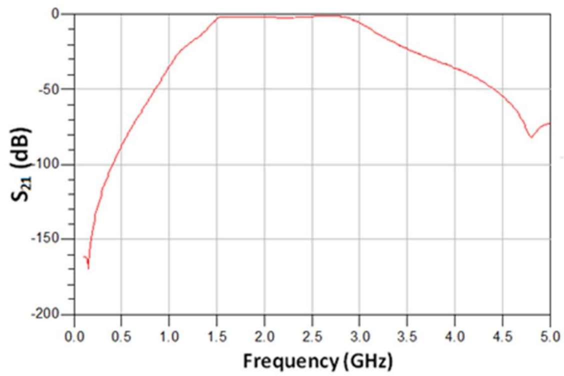
Table 7

Inductor	Capacitor
L1 = 3.9 nH	C1 = 1 pF
L2 = 2.7 nH	C2 = 1.5 pF
L3 = 1.8 nH	C3 = 1.8 pF
L4 = 3.9 nH	C4 = 0.7 pF
L5 = 1.8 nH	C5 = 0.6 pF
L6 = 1.8 nH	C6 = 1 pF

Fig. 16 (a) shows the simulation result on a layout level of the 6th order bandpass real lumped components filter with butterworth response for upper frequency band showing input reflection S11 which is -4.5 dB, that is against the design specification as it is greater than -6 dB, which shows that more energy is bounced back due to impedance irregularities in a copper trace. On the other hand fig. 16 (b) shows the simulation result of the forward transmission i.e. S21 of this filter having a passband of 1500 – 2900 MHz which is 41 % increased from its schematic level simulation result because the losses in the layout level were decreased by tuning of the lumped components.



(a)



(b)

Fig.16. Layout level simulation results of the 6th order real lumped components bandpass filter with butterworth response for upper frequency band: (a) input reflection S_{11}, and (b) forward transmissionS_{21}.

Fig. 17 shows the group delay on the layout level of the upper frequency band, 6th order bandpass filter with butterworth response and it is observed that the delay variation within passband is about 0.4 ns and the maximum delay is 1.9 ns.

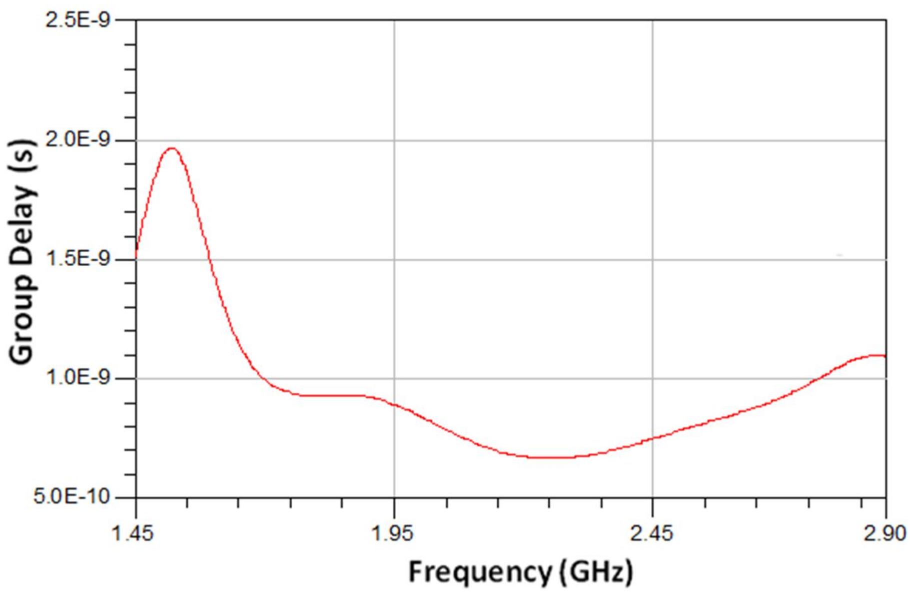


Fig. 17. Group delay of the 6th order real lumped components bandpass filter with butterworth response for upper frequqncy band on layout level.

V. LUMPED COMPONENTS DIPLEXER DESIGN

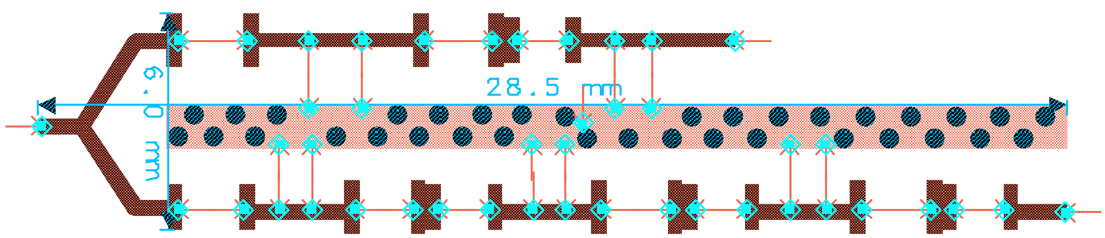
A diplexer consists of three ports of which P_1 is the common port and acts as an input port for the combined frequency spectrum and P_2 and P_3 act as the output ports with two separated subbands. The two output ports should be for the signals of lower frequency passband i.e. of 698 - 960 MHz and upper frequency passband i.e. 1710 – 2700 MHz respectively according to the LTE specifications. In order to divide the combined frequency spectrum into two subbands a diplexer is designed using two filters which are incorporated along with their matching networks. The role of the matching network in the diplexer design is to minimize the interference caused between the signals of the two output ports during the process of filters integration.

The criteria to select the smallest possible size of the filter was to reduce its order to the extent that the minimum transition slope steepness was in accordance with the design specifications. The bandwidth achieved should be higher than the LTE frequency passband specification in order to minimize the losses occurring during the integration of filters for diplexer design.

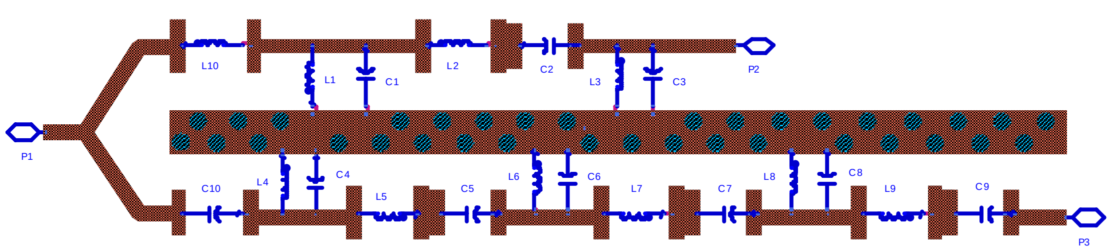
A purely lumped components diplexer can be made with two lumped components filters working for lower and upper frequency passbands of the LTE. The main difficulty with diplexer design is that purely lumped components have the parasitic losses accompanied with every lumped component. In addition to that at higher frequencies the behavior of the lumped components is altered as the wavelength at higher frequencies becomes comparable to the dimensions of the lumped components [11].

For the lower frequency passband the filter designed was a 3rd order bandpass filter with butterworth response and it was integrated with a 6th order bandpass filter with butterworth response as shown in fig. 18. The matching technique used in each branch of the filter was the lumped component technique and each of the filter branches had a lumped component working on the principals of classical physics i.e. consisting of Inductor (L) for lower frequency passband filter and Capacitor (C) for the upper frequency passband filter. The L is open circuit at higher frequencies and C is open circuit at lower frequencies. This matching network blocks the frequency passbands of the neighbouring branch filter so that the incoming signal does not leaks into the wrong branch.

The copper trace was first designed with Zo of 50 Ω in layout level and its layout component were used in the schematic level as shown in fig. 18 (a). As mentioned in the filter design section that the copper trace should be used instead of wire in ADS layout level. The ideal wire has no losses hence it's layout is not realizable without a copper trace which includes the losses of real wire. It can also be seen from the figure that the length of the layout of the copper trace is 28.5 mm and the width is 6.0 mm which shows that the size of the diplexer is very small. On the other hand fig. 18 (b) shows that the schematic of pure lumped components diplexer including copper trace layout with real lumped components. The value details of these components are mentioned in Table 8.



(a)



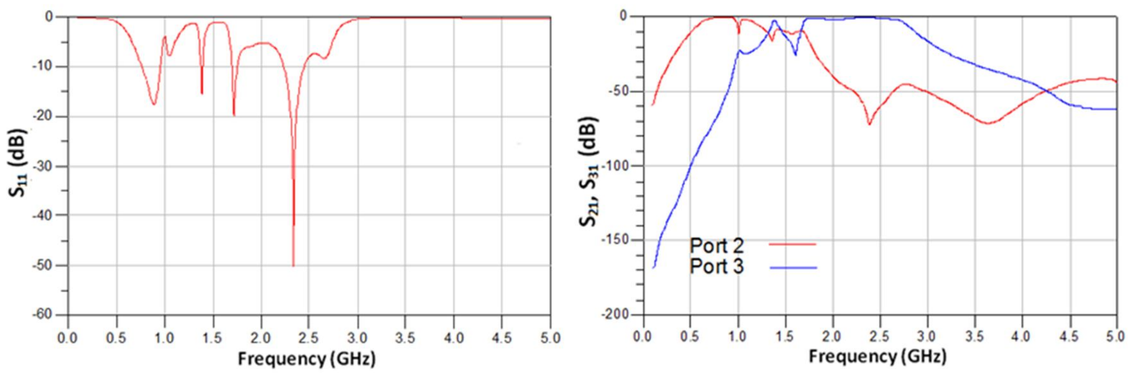
(b)

Fig. 18. Copper traces of purely lumped components diplexer: (a) layout, and (b) layout component with real lumped components in a schematic level.

Table 8

Inductor	Capacitor
L1 = 8.2 nH	C1 = 1.8 pF
L2 = 12 nH	C2 = 1.5 pF
L3 = 8.2 nH	C3 = 3.3 pF
L4 = 2.7 nH	C4 = 1.2 pF
L5 = 2.7 nH	C5 = 1.8 pF
L6 = 1.8 nH	C6 = 2.2 pF
L7 = 3.9 nH	C7 = 0.9 pF
L8 = 1.8 nH	C8 = 0.5 pF
L9 = 1.8 nH	C9 = 1.0 pF
L10 = 3.9 nH	C10 = 1.5 pF

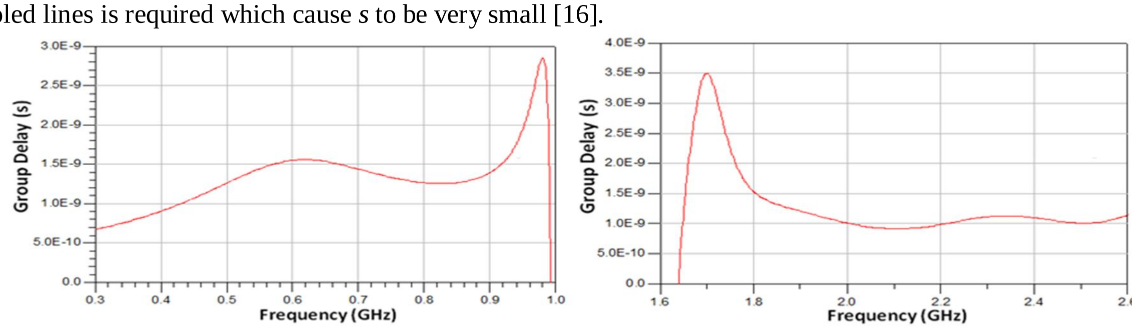
Real lumped components values which includes typical practices for 0805 SMD package specified by AVX Corporation. Fig. 19 (a) shows the simulation result of the layout of the purely lumped components diplexer consisting of the combination of a 3rd order bandpass filter for lower frequency passband and a 6th order bandpass filter for the upper frequency passband. It can be observed from the figure that there are acceptable insertion losses S11 in both bands which are less than -6 dB. On the other hand fig. 19 (b) shows the forward transmission and it can be observed from the figure that the diplexer has a lower frequency passband of 640 – 978 MHz and an upper frequency passband of 1702 – 2712 MHz which are very near to the LTE frequency passbands specifications with minimum margin for losses to occur in real environment. The second observation from this figure is that there are leakages at 1.1 GHz and 1.4 GHz close to the upper and lower frequency passbands.



(a) (b)

Fig. 19. Simulation results of the layout of a purely lumped components diplexer consisting of the combination of a 3rd order bandpass filter for lower frequency passband and a 6th order bandpass filter for upper frequency passband with lumped components as a matching network: (a) input reflection S_{11}, and (b) forward transmission.

Fig. 20 shows the group delay on the layout level of a purely lumped components diplexer consisting of the combination of a 3rd order bandpass filter for lower frequency passband and a 6th order bandpass filter for upper frequency passband with a lumped component matching network. Fig. 19 (a) shows the delay within passband in lower frequency band is nearly 0.3 ns and maximum delay is less than 3 ns where as on the other hand fig. 20 (b) shows in the upper frequency passband the maximum delay is 3.5 ns and the delay variation inband is nearly 0.2 ns. For the achievement of the large bandwidth required for the LTE frequency bands a tight coupling between the coupled lines is required which cause *s* to be very small [16].



(a) (b)

Fig. 19. Group delay of the layout of a purely lumped components diplexer consisting of the combination of a 3rd order bandpass filter for lower frequency passband and a 6th order bandpass filter for upper frequency passband: (a) for lower frequency passband, and (b) for upper frequency passband.

Fig. 20 shows the isolation on the layout level of a purely lumped components diplexer consisting of the combination of a 3rd order bandpass filter for lower frequency passband and a 6th order bandpass filter for upper frequency passband with a lumped component matching network. This figure illustrates the isolation between port 3-2 and its minimum value is 18 dB.

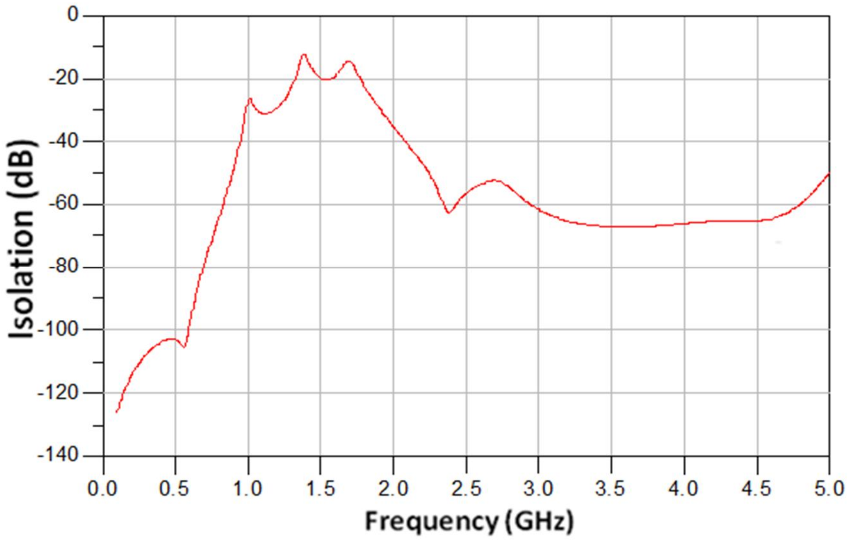


Fig. 20. Isolation of the layout of a purely lumped components diplexer consisting of the combination of a 3rd order bandpass filter for lower frequency passband and 6th order bandpass filter for upper frequency passband between ports 3-2.

VI. CONCLUSION AND FUTURE WORK

In this paper , the objective is to investigate the lumped components filter designs for achieveing reduction of the size of diplexer as well as to achieve the LTE frequency passbands 690 – 960 MHz and 1710 – 2700 MHz. It was concluded that smaller dimensions for diplexer design where achieveable through lumped components however paracitic losses were inherited. The leakages become adverse at the upper band of LTE due to the effect of higher frequencies on the behaviour of the lumped components [11]. The losses associated with the lumped components at upper frequency band of the LTE could be minimised by a distributed components filter design i.e. stub filter can be designed for the upper band of LTE and integrated using transmission line technique with the 3rd order lumped components filter designed in this paper for the lower band of the LTE to over come the losses.

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