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Compact Tunable Filters For Broadband Applications

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Abstract

Microwave filters are essential components of modern communication systems. Miniaturization of microwave filters is of much demand in today's rapidly changing communication world with ever more growing wireless applications. The paper presents compact tunable band pass filters to provide multiple bands of operation. The filter employs tunable/chip inductors along with an inter-digital coupled line for introducing transmission zeros on both band edges. Tunability is achieved by varying the inductor values. The stop band attenuation is improved by etching Complementary Split Ring Resonators (CSRR's) and Defected Ground Structures (DGS) in the ground plane.

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*Keywords:*Chip inductor; tunable inductor; inter-digital coupled lines; tunabilty

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1. Introduction

Modern communication systems require multiple operating bands for meeting the modern trends which cannot be met by a single filter prototype. Tunable filters can achieve desired responses by using adjustable tuning elements embedded into a filter topology[1] thus avoiding the necessity of switching between several filters. Tunable filters greatly simplify the transceiver design and play a major role, especially in the area of wideband and multimode transceivers[2]. A viable solution for eliminating the bulky filter bank and switching network is replacing them with a

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tunable band pass filter. The focus of recent works on tunable filters has shifted from maximizing the tuning range to better control of filter behavior while it is tuned to obtain different pass band frequencies. The most important demand for tunable filters is in multiband wireless communication systems, Cognitive Radio (CR) and satellite communication systems[3].

Various configurations of tunable bandpass filter include micro electro mechanical systems, semiconductor diodes and ferroelectric films[4]. Tunable filter employing varactor diodes realized using ferroelectric barium strontium titanate (BST) thin films is reported[4]. RF MEMSs are increasingly used in the design of tunable filters. Tunable filter operating in 1GHz range reported uses three MEMS tunable capacitor banks[5].

2. Tunable Filter Design

When choosing technology adequate for a given application, factors like cost, power consumption and size are to be considered along with performance and operating frequency. Varactor diodes, RF MEMSs, ferroelectrics, liquid crystals and optical switches are the various methods employed for tuning[6]. The use of varactor diodes has many disadvantages including high insertion loss and unacceptable distortion. RF MEMs offer low loss, high Q and good linearity but have poor switching speeds. Ferroelectric materials also introduce high dielectric losses although they are readily tuned. Liquid crystals have high linearity, require low tuning voltages but have slow switching times. On account of the above limitations tuning is incorporated in the proposed filter by using chip and tunable inductor which offer compact size, cost effectiveness, design flexibility and wide tuning range.

3. Tunable Filter Using Chip Inductors and CSRRs

Parametric analysis is carried out on a reported planar UWB band pass filter[7]. The conventional design of band pass filters is to use Stepped Impedance Resonators (SIRs) and quarter wavelength coupled lines. The stepped impedance open stub forms a parallel LC resonator which decides the lower cut off frequency. By embedding chip inductors of variable values in the open stub, the lower cut off frequency can be tuned according to the requirements. The UWB filter with two chip inductors L is shown in figure 1[7].

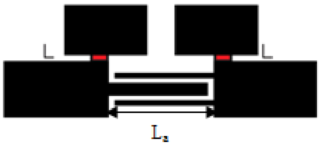


Fig. 1. UWB Filter with chip inductors[5]

3.1 Simulation Results

The structure is simulated on a substrate of dielectric constant 4.4 and height 1.6mm, using FEM based simulator HFSS from Ansys Corporation. The variation of lower cut off frequency on varying the value of chip inductor L is shown in figure 2.

The inter-digital arm of the band pass filter decides the upper cut off frequency. The results of the parametric study conducted by varying the length L_a of coupled arm are shown in figure 3(a). But arm length variation in inter-digital structure is practically not easy. Without changing the structure, length variation is achieved by incorporating chip inductors of different values in the inter-digital structure. The variation of upper cut off frequency with different values of chip inductors L_l in the coupled arm is illustrated in figure 3(b).

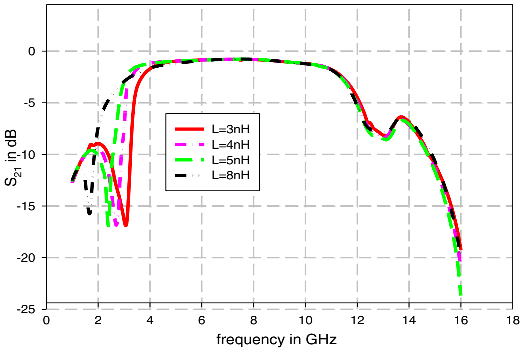
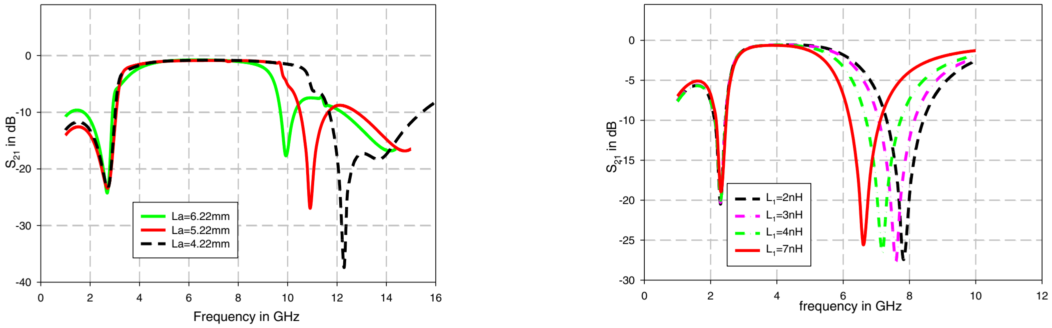


Fig. 2. Variation of lower cut off frequency for various values of chip inductor L



(a). Variation of upper cut off with coupled arm length L_a

(b). Variation of upper cut off frequency with varying values of chip inductor L_1

Fig. 3. Variation of Upper cut off frequency with L_a and L_1

Tunabilty is achieved by incorporating the above two results in the band pass filter with chip inductors[8] placed in the LC resonant circuit and inter-digital coupled arm as shown in figure 4. The structure is compact with an overall dimension of 17mm x 10mm. The band notch property of CSRRs[9] is exploited to get the sharp roll off at the upper band edge. Stopband attenuation is improved by placing more CSRRs with slightly different resonant frequencies periodically [10, 11]. The proposed structure with three inductors and CSRR's to achieve tunability is shown in figure 4.

Simulations are performed with different chip inductor values and experimentally verified. Bandwidth achieved

W1=4.44, W2=2.6, W3=3,W4= 5.53, La=6, Go=0.3, Wc=0.61,Ws=0.3
Top surface

R_1=1.7,R_2=1.35, R_3=1.2, R_4=1.72, G=0.3
Bottom Surface

Simulated S_{21} with and without CSRR

Fig. 4. Filter Layout with three chip inductors and CSRRs (All Dimensions are in mm)

is 2.6-8.6GHz with chip inductor (L) 6.5nH in the inductance arm and 7.4nH (L_1) in the inter-digital arm and 3-7.3GHz with chip inductor 4.7nH (L) in the inductance arm and 12nH (L_1) in the inter-digital arm. The simulation results of S_{21} plot and group delay is shown in figure 5. The group delay is flat over the entire passband ensuring the suitability of the filter for communication applications.

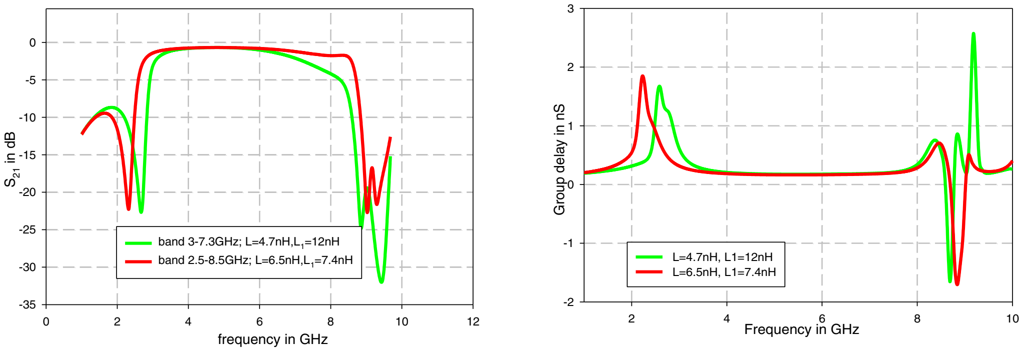


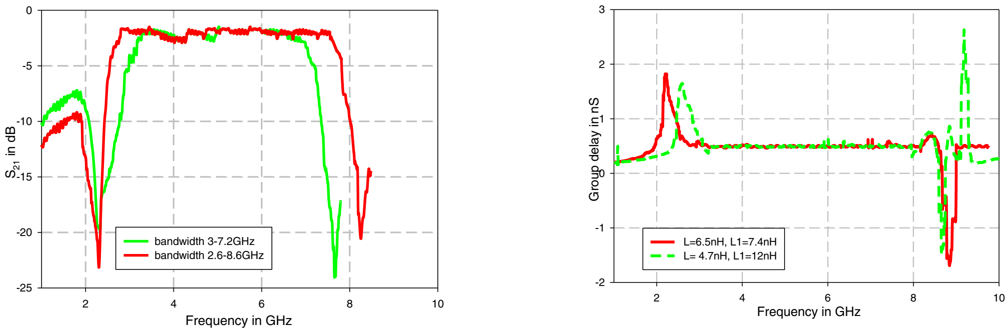
Fig. 5. Simulated $S_{21}$and Group Delay for two different bands

3.2 Fabrication and Experimental Results

Fabrication of the prototype filter structure is done on FR4 substrate with relative permittivity 4.4, loss tangent 0.02 and thickness of 1.6mm. Standard photolithography process is used for fabrication. Figure 6 shows the photograph of the fabricated filter along with SMA connectors. Measurements are taken using Agilent 8753ES Vector Network Analyzer.

Fig. 6. Photograph of fabricated filter

Measured S_{21} plot and group delay in the two distinct bands is shown in figure 7. The insertion loss is less than -3dB including those introduced by the SMA connectors. This can be brought down by using less lossy dielectric material. Slight discrepancies may be attributed to the errors in the fabrication process. Flat group delay in the passband reveals the linear phase nature of the filter making it suitable for communication applications

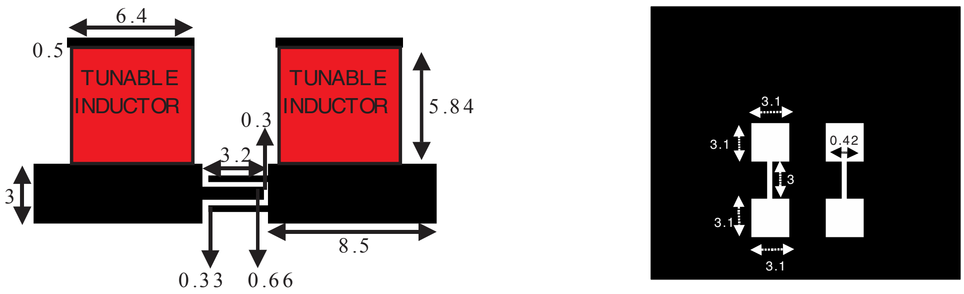


Measured S_{21} Measured Group Delay

Fig. 7. Measured Responses with Chip inductors

4. Tunable Filter Using Tunable Inductors And DGS

The proposed tunable bandpass filter consists of two LC resonators on an inter-digital coupled line. The LC resonators incorporate tunable inductors[12]. The capacitors are realized through low impedance open stubs. Insertion of the tunable inductors, with a footprint of 5.84sqmm, cause reduced coupling between LC resonators and coupled line, resulting in increased insertion loss in the passband. This is accounted for by introducing Defected Ground Structure (DGS). Dumbbell shaped DGS is used. The DGS also improves the roll off rate at the upper band edge[13,14]. The structure is compact with an overall dimension of 20mm x 17mm. The proposed structure with two tunable inductors and DGS is shown in figure 8. The optimized spacing between the centres of the DGS is 6.1mm.

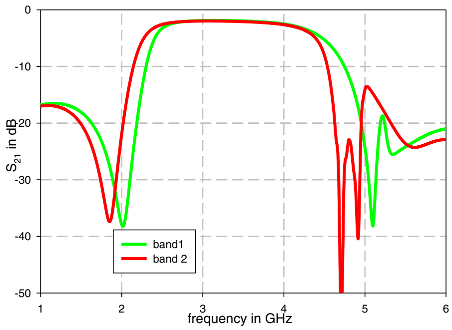


Top Surface Bottom Surface

Fig. 8.Tunable Bandpass Filter
(All Dimensions are in mm)

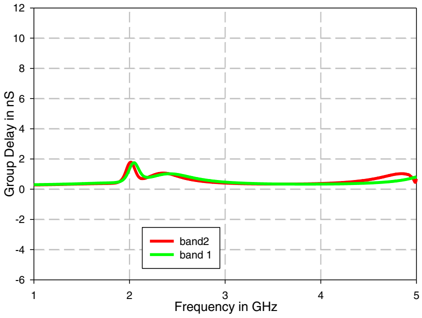
4.1 Simulation Results

Tunable inductors are provided with three tap positions. Maximum inductance value obtained in a tap position where entire turns are included and minimum value obtained in a position with minimum number of turns. Inductance range for the 9nH tunable inductor used in this work is 8.2-9.7nH.Simulation results are obtained by varying the inductance value within this tunable range[14]. The passband is obtained for two distinct bands with band1 and band 2. Group delay obtained is constant for both the bands. The simulated S_{21} and group delay are shown in figure 9.



Simulated S_{21}

L (nH)	Passband (GHz)
8.2	2.21-4.42
9.7	2.4-4.51



Simulated Group Delay

Fig. 9. Simulated Responses with Tunable inductor

4.2 Fabrication and Experimental Results

The structure is fabricated on a substrate with relative permittivity 4.4, dielectric loss tangent 0.02 and a height of 1.6mm. Standard photolithography is used for fabrication. Figure 10 shows the photograph of the fabricated filter along with SMA connectors. The structure is compact with an overall dimension of 20mm x 17mm. Measurements are taken using Agilent 8753ES Vector Network Analyzer.

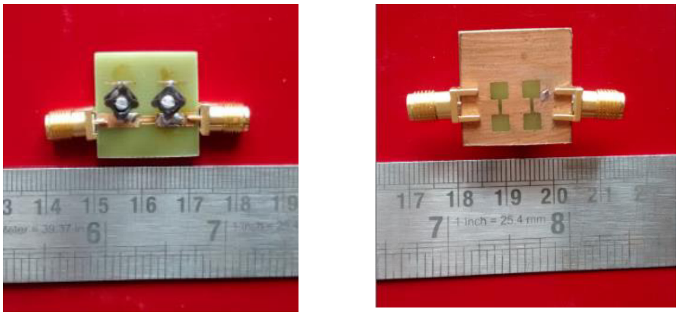
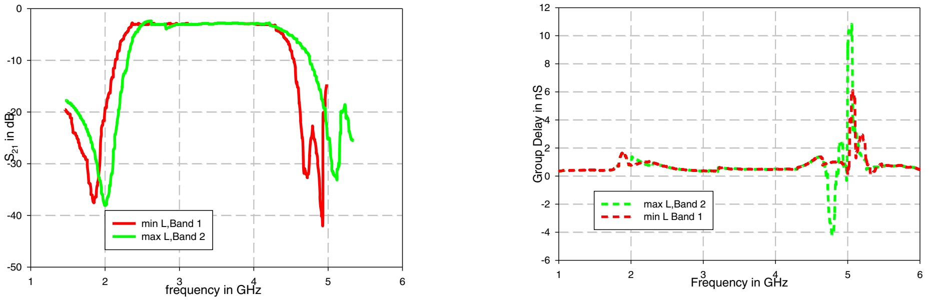


Fig. 10. Photograph of fabricated filter

The measured transmission characteristics and group delay obtained for varying inductance within the tunable range of the inductor (L=9.7nH) is shown in figure 11. The results indicate that tuning of the lower cut off frequency is possible by embedding a discrete tunable inductor. However there is a shift in upper cut off frequency, which can be attributed to the change in overall inductance causing change in centre frequency. The filter is suitable for S-band satellite communication applications.



Measured S_{21}

Measured Group Delay

Fig. 11.Measured Responses with Tunable inductor

5. Conclusion

Compact, high performance, tunable bandpass filters with reduced insertion loss and high selectivity are widely used for wireless and satellite communication systems. In this work design of tunable, high performance band pass filters for broadband applications is proposed. The main goal is to develop sufficiently compact, low cost tunable filters with promising applications in the field of portable communication systems. The proposed miniature tunable filter designs can thus provide a range of useful band of frequency in wireless communication application by selecting proper values of tunable inductor. Bandwidth can be tuned by using tunable inductors. Moreover sharp roll off rate and good stop band attenuation is achieved by placing dumb bell shaped DGS and complementary split ring resonator in the filter structure. The newly designed tuned filter is a stepping stone for future implementations and wide range of wireless applications. Due to the non-availability of tunable inductors suitable for the bands considered, tunability is demonstrated using chip inductors of different values. This structure can be tuned to any band of interest [though in a range limited by CSRR dimensions] by varying the value of chip inductors in the open stub and in coupled lines. The structure is compact, simple and easy to fabricate. The insertion loss is within tolerable limits and the roll off achieved is steep. The flat group delay characteristics of the filters establish their suitability for communication applications.

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