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Research Article

Reconfigurable Interdigital Bandpass Filter for wireless Applications

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Abstract: The new age wireless applications demand sharp rejection of unwanted signals at MHz frequencies. This necessitates the design of low loss, high attenuation bandpass filters. This paper proposes the design of reconfigurable interdigital bandpass filter for wireless applications using varactor diode tuning mechanism. An electronically tunable bandpass filter at 1.2GHz is designed and simulated using Advanced Design System (ADS)simulation tool from Keysight. The tuning is achieved by changing the biasing voltage from 0V to 9V of the varactor diode with the tuning range of 1GHz to 1.4GHz having a bandwidth of 200MHz and the insertion less than 3dB and the return loss is more than 10dB.

Keywords: Interdigital Bandpass (IDBPF), Advanced Design System (ADS), Fractional Bandwidth (FBW)

1. Introduction

Anelectronically tunable, capacitively loaded interdigital band pass filter is presented in this development. The tuning element is a reverse-biased varactor diode. The resonators of the tunable filter are shortened interdigital fingers with varactor diode at the ends. The coupling is carefully controlled by the geometry of the fingers and tuning is performed by changing the bias on the varactor diodes. Since both the interdigital fingers and the diodes are carefully and fabricated in batch, this filter can easily be produced in large quantities.The design of a varactor-loaded interdigital filter is like the capacitively loaded comb-line filter but is adapted for the interdigital topology. The interdigital filter is a symmetric filter of coupled resonators. The first finger at the input and output port is a shorted line that acts as an impedance transformer for the filter. This is the only line with a fixed termination. The interior coupled lines are shorted at one end and loaded with varactor diodes at the other end. To allow for biasing, large capacitors are added. When the bias voltage is changed, the thickness of the depletion region of the varactor diodes changes. This alters the capacitance of the varactor, for tuning the resonant length of fingers. The width and separation of the interior lines are determined only by the bandwidth of the normalized filter response function and is independent of the center frequency. The center frequency of the filter is determined by the resonant lengths of the lines which is tuned by the varactors. The tuning range for the filter is limited by the fixed lengths of the input and output finger lengths, the internal impedance of the filter, the range of capacitance of the varactor diodes, and the electrical length of the fingers.

2. Design of interdigital bandpass filter

The term interdigital is because of the geometrical structure of the filter(Fig.1). It means in between the fingers or the resonators. The figure shows the general structure of the interdigital filter, which consist of n parallel resonators arranged parallelly one after the other, which are coupled to each other[1]. This type of filters mainly used for microstrip designs. The electrical length of these resonator fingers is of (λ/4) quarter wavelength. These resonators are called transmission line resonators, they act in TEM mode(Transverse Electromagnetic Mode), which are conducting at one end and grounded at another end. The filter dimensions are shown in the figure.1 where l1, l2, l3 ……. ln represents the length of the resonator, W1, W2, W3….., Wn represents the width of the resonator fingers, S1,2, S2,3 ……. Sn-1,n represents the spacing between the fingers. The coupling between these resonator fingers is achieved through adjusting the spacing between these fingers. Y1……Yn represents the characteristic admittance of the resonators.The filter is given with the input and output feed, that are tapped lines having admittance Yt which is equal to Y0 characteristic admittance of the source or load, θt is the distance of the feed from the shorted end[2].

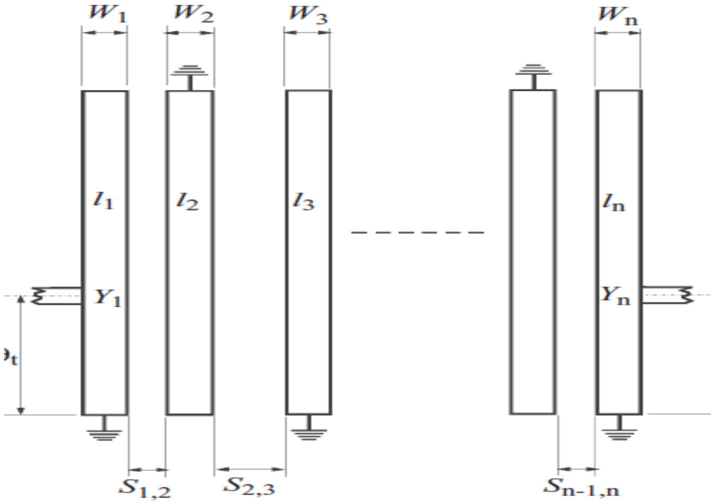


Fig.1: Interdigital Bandpass filter.

Interdigital Bandpass Filter (IDF) have numerous advantages which include they are very compact in nature; the structure size can be reduced because of their compactness. Due to the large spacing between the resonators and the adjustable spacing, the tolerances that is required for manufacturing can be reduced in a greater way. In many instances the length of the resonator will be shorter than λ/4 (usually, 0.9(λ/4)),which facilitates mid frequency of the filter to be tuned by using tuning element. This helps tuning and maximum unloaded Quality Factor of individual resonator. The in-out coupling is achieved through a contact at the lower impedance value of the resonator [3]. The center frequency of the 2nd passband is focused at 3 times the primary passband mid frequency. The spurious responses can be eliminated completely in between. There is no requirement for dielectric constant because the fabrication of the filter is done in structural forms which are self-assisting. Thus, there are no dielectric losses, it can be removed easily. The loss in interdigital filter is less compared to comb-line filters, and tuning is very easy in IDF [2]. The interdigital filers are very much suited for large bandwidth filters, because the geometry of the filter which performs well compared to the coupled line filters. There are also numerous implementations similarly to the microstrip medium, together with strip-line, coplanar waveguide, and slot-line.

1.1 VARACTOR TUNED INTERDIGITAL BANDPASS FILTER

The varactor tuned interdigital filter designis like the comb-line filter design which are capacitor loaded but is customized for interdigital topology. The interdigital topology consists of a coupled resonator. The initial resonators are a shorted line at the input and output ports which helps for the impedance transformation. The fixed termination is achieved through this single line. The coupled resonators which are inside whose one end is shorted and the opposite end is loaded with the varactor diode. Biasing capacitors are added to achieve biasing. By varying the bias voltage,the thickness of the depletion region also varies in a varactor diode, this alters the capacitance of the varactor diode which tunes the resonator length. The spacing between the resonators and the width of each finger is determined only by bandwidth of the filter and is independent of the center frequency. The resonator length will mainly determine the center frequency, by varying the length of the resonator, which is tuned by varactor diode, the center frequency will also vary. The constant lengths of the In-Out resonator fingers, Varactor capacitance, impedance of the resonators and electrical length of the fingers determine the tuning range of the filter.

1.2 DESIGN SPECIFICATION

The following Table 1 shows the filter coefficients of Chebyshev filter with 0.5 dB ripple, which is used to design different order Chebyshev bandpass filters [5].

TABLE 1: Normalized Filter Coefficients for Chebyshev, Element Values For 0.5 dB Ripple [5]

N	g1	g2	g3	g4	g5	g6
1	0.6986	1.000				

2	1.4029	1.7071	1.9841			
3	1.5963	1.0967	1.5963	1.000		
4	1.6703	1.1926	2.3661	0.8419	1.9841	
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.000

TABLE 2: Calculated Value of EVEN and ODD mode Impedance (ohm)

Zoe 1,2	49.8255	Zoo 1,2	41.6964
Zoe 2,3	48.6985	Zoo 2,3	42.5220
Zoe 3,4	48.6985	Zoo 3,4	42.5220
Zoe 4,5	49.8255	Zoo 4,5	41.6964

The Optimized Dimension of Chebyshev Interdigital Bandpass Filter in terms of Length, Width and spacing are tabulated in Table 3.

TABLE 3: Optimized Values of L, W and S in MM

Parameters	**Values (mm)**
Length (l1=l2=l3=l4=l5)	16.5
Width (w1=w2=w3=w4=w5)	1.1
Spacing ($S_{1,2}$=$S_{4,5}$ &$S_{2,3}$=$S_{3,4}$)	0.55& 2.2

The designed Varactor tuned Interdigital Bandpass filter is designed for center frequency F0 = 1.4 GHz with tuning range from 1.1GHz to 1.7GHz with a bandwidth of 200MHz, Insertion loss at passband is 3dB maximum and the return loss is batter then 15dB. The source and load impedances are selected to be of the standard value of 50 ohms. The maximum input power is 1W (+30dBm). SMA connectors are used to connect the terminals. The size of Varactor tuned IDBPF is 60 mm X 60 mm.

1.3 DESIGN APPROACH AND SIMULATION

A Varactor tuned microstrip Interdigital Bandpass filter (IDBPF) is designed for L-band frequency using the design equations and line-calc tool in ADS, the values of L, W and S of the resonator is obtained and are optimized to get the desired output. The Varactor tuned Interdigital Bandpass filter has designed for F0 = 1.4GHz, with a step size of 200MHz of tuning frequency. A layout of Varactor tuned Interdigital Bandpass filter is created by using all these values. The substrate used is RTD6010 having thickness 1.27mm and Dielectric constant of 10.2 and conductor thickness is of 35 microns.

After Designing a Layout, an EM-Setup is conducted,which requires substrate material, conductor material, hole connection and top Air layer.RTD6010 Substrate is used having 1.27mm thickness and dielectric constant of 10.2. The conductor is a copper material having thickness of 35 micron. A connection to the top and bottom surface of the substrate is made through a via Hole. The start and the stop frequencies along with step is given for the final EM-simulation.

1.4 VARACTOR CIRCUIT

The main step in designing a tunable microstrip filter is that selecting a proper varactor diode. Initially capacitors were added to the conducting end of the resonators to know the capacitance range which is required for the tuning purpose. As per our requirements an SMV1231 varactor diode is selected. The data sheet of that particular varactor diode provides all the required information and parameter along with the spice model. By looking at the spice model a circuit of varactor diode is created by using a non-linear capacitor. A symbol of the varactor circuit is created which is used for co-simulation purpose. There are two circuits with and without voltage supply any one of these can be used for co-simulation with voltage supply can be used where there is no need to provide one more voltage supply in the co-simulation,where voltage Tuning can be done directly.

Without voltage supply can also be used as a varactor diode in co-simulation by giving voltage supply and by choosing voltage as a tuning element. A simulation can be carried out by doing all these setups. The varactor diode SMV1231 is selected according to our requirement. The Equivalent varactor circuit is designed, by studying the datasheet.

1.5 CO-SIMULATION OF THE LAYOUT

The next step after layout design is co-simulation, where diode and capacitors are added (Fig.2) for the simulation. The reversed biased voltage is applied to the diode and tuning is achieved by varying the voltage supply, as voltage varies the frequency shift will happen. In a layout designing of micro-strip filters a lumped component cannot be added, which is possible during co-simulation, to achieve the desired output. The co-simulation requires s-parameter and substrate details. In figure.2 the conducting end is directly connected to the varactor diode along with the biasing capacitors and voltage supply. The detailed picture is shown below. The symbol which is created by using the varactor circuit is used in the co-simulation shown in figure.2. five diodes are used in the simulation process.

To block DC voltage flowing to ground capacitors were added which also acts as a biasing capacitor, total 7 capacitors were added, in which 5 capacitors will acts like dc block and other two capacitors that is near to the voltage supply will allow dc voltage fluctuations to ground. Individual voltage supply can be given as well as a single bias voltage connecting all diodes. The next step after layout design is co-simulation, where diode and capacitors are added(Fig.2) for the simulation. The reversed biased voltage is applied to the diode and tuning is made.As the voltage varies the frequency shift will happen.

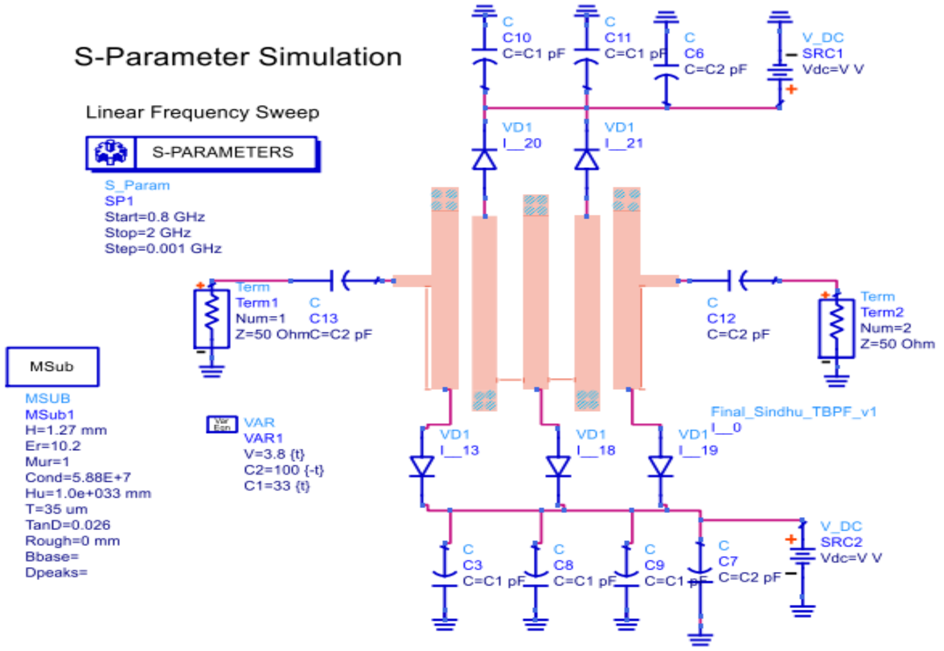


Fig.2: Co-Simulation of the Layout using Varactor Diode.

1.6 SIMULATION RESULTS

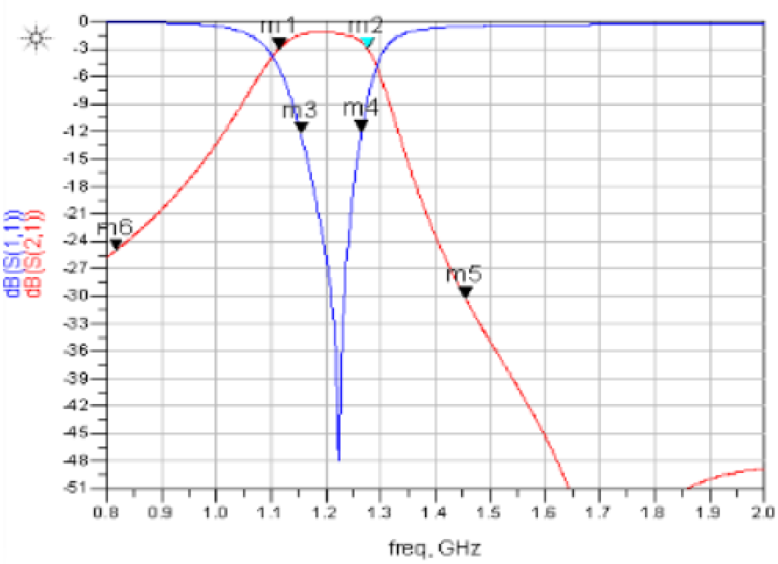


Fig.3: Insertion and return loss of bandpass filter at 1.2GHz.

The simulation results of IDBPF shown in Figure.3. At 1.2GHz with the insertion loss (S2,2) and return loss (S1,1)having bandwidth of 200MHz. The output is measured using the Network analyzer and voltage is supplied with the help of DC voltage supply. Markers are used to measure S-parameters.

Similarly, we can check for all other required Frequency.

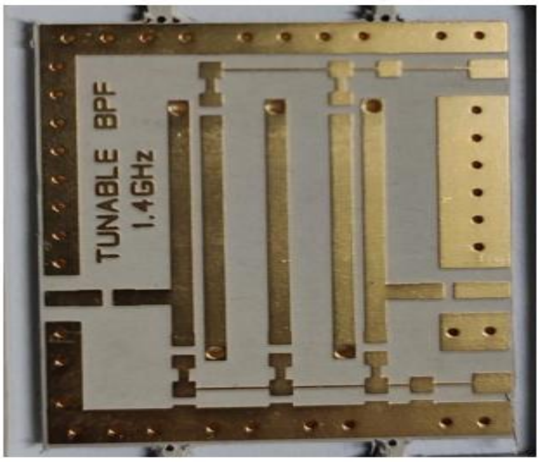
In the given figure. 3, by supplying a reverse voltage of 2.55V, the frequency will be shifted 1GHz to 1.2GHz having 200MHz bandwidth and -2.9dB insertion**($S_{2,1}$)**, -11.9 dB return loss**($S_{1,1}$)**.

1.7

1.8 RESULTS OF FABRICATED MICROSTRIP TUNABLE FILTER

After completing the co-simulation and obtaining the desired results, the PCB layout is design and can be exported as DXF file for fabrication process.

The Varactor tuned interdigital filter is fabricated using RTD6010 having dielectric constant 10.2 and thickness of 1.27mm.The fabricated filter before assembly looks like as shown in the figure.4, for that filter the diodes and capacitors are added and soldered to make a complete finalized model along with the SMA connectors which is added to the 50 Ohm track as shown in figure.5.These two SMA connectors acts like input and output ports which is connected to the network analyzer which works from 1GHz to 18GHz. ATC Capacitors were used which is of 33 pF and 200 pF for biasing purpose.



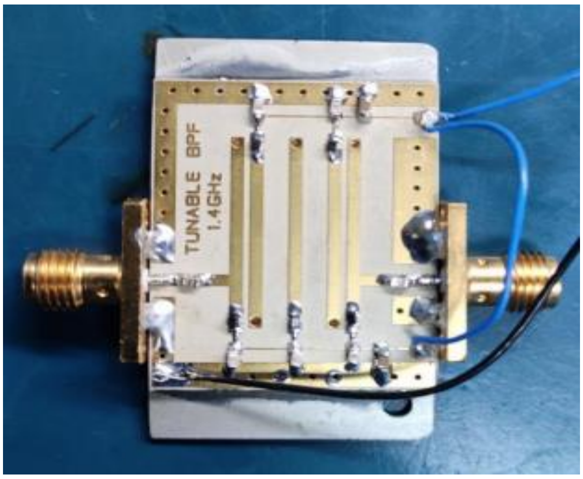


Fig.4: Fabricated filter before assembly.

Fig.5: Fabricated filter after assembly.

By using Network Analyzer, we can evaluateS-parameter of IDBPF, which gives information about Frequency,Insertion Loss ($S_{2,1}$), Return Loss ($S_{1,1}$),Rejection, Ripple and Flatness. By varying the bias voltage, frequency shift is achieved.

In the given Figure. 6, it shows when the reverse voltage changes 0V to3.6V, the frequency will be shifted 1GHz to 1.21GHz (Fig.6) having bandwidth of 205MHz along with the S-parameters which gives details about losses.

The figure.6 shows the frequency response, Insertion Loss, Return loss and Bandwidth of the designed tunable interdigital filter.

Similarly, we have checked for all other required Frequency by changing the reverse biased voltage and the results are given in the below table 4.

```
Tr1 S21 Log Mag 10.00dB/ Ref -40.00dB [F2]
Tr2 S11 Log Mag 10.00dB/ Ref -40.00dB [F2]
Tr3 S22 Log Mag 10.00dB/ Ref -40.00dB [F2]
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2  1.1971001 GHz -1.9176 dB     2  1.1971001 GHz -17.339 dB     >2  1.1971001 GHz -13.055 dB
3  1.2477477 GHz -2.2299 dB     3  1.2477477 GHz -12.965 dB      3  1.2477477 GHz -13.275 dB
4  695.03604 MHz -31.779 dB     4  695.03604 MHz -0.0880 dB      4  695.03604 MHz -0.1290 dB
5  1.3000000 GHz -3.1968 dB     5  1.3000000 GHz -21.716 dB      5  1.3000000 GHz -16.315 dB
  BW:  205.6627930 MHz
cent:  1.217649170 GHz
 low:  1.114817774 GHz
high:  1.320480567 GHz
   Q:  5.9206
loss: -1.9176 dB
```

Fig.6: Frequency response of Bandpass Filter at 1.21GHz in Network Analyzer.

Table 4: Complete summary of the measured results during testing

Centre Frequency	Varactor Tuning Voltage	Band Width	Insertion Loss in dB ($S_{2,1}$)
1GHz	0V	161MHz	-3.31
1.1GHz	1.9V	184MHz	-2.24
1.15GHz	2.52V	201MHz	-2.59
1.21GHz	3.6V	205MHz	-1.91
1.25GHz	4.3V	214MHz	-1.88
1.29GHz	5.7V	253MHz	-3.23
1.35GHz	9V	235MHz	-1.73

3. Conclusion

In this development,we have designed and understood the working of varactor tuned interdigital bandpass filter and the design steps of the same, which is tunable from 1GHz -1.2GHz having 200MHz band with better insertion and return losses.Also, we have observed that, as we reduce the spacing between the line resonators, fractional bandwidth increases (FBW)which is dependent on the coupling between the line resonators. We also observed that as the resonator length increases the frequency decreases and vice versa. The behaviorof varactor diode is observed and the layout designing, co-simulation process is performed using the ADS(Advanced design systems) software tool.

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