Reconfigurable Bandpass Filter for Bandwidth Control in IMT-Advanced

Gajendra Kant Mishra, D.K. Upadhyay, J. Sahay, Sanjay Kumar

Abstract – **A novel reconfigurable microstrip Bandpass filter (BPF) for centre frequency (f_c) 3.5 GHz is proposed in this paper. A Square ring microstrip structure with gap coupled feed has been used. A new comb-tooth structure is proposed, where combination of tooth connection is responsible for the variation of bandwidth, this scheme has been used to achieve a fractional bandwidth (FBW) variation of 0.85 to 6.48%. Further, a 3.5 GHz Square ring reconfigurable filter for five distinct bandwidth (BW) state has been fabricated for experimental verification.**

Keywords – **Comb-tooth structure, International Mobile Telecommunication-Advanced, Bandpass filter**

I. Introduction

The reconfigurable microwave filters are essential components for transmitter and receiver front end for improving the capability of both current as well as future wireless communication system. The recent Bandpass filters are very much useful in minimizing the interference by selecting suitable portion of the available spectrum. Number of ways is possible to realize a reconfigurable bandpass filter however for all of them it is mandatory to conserve their reflection loss and transmission loss over the range specified [1].

The research in reconfigurable filter design can be divided into two major directions of frequency control and bandwidth control. A large number of BPF have been investigated to control centre frequency by varying the electrical length of filter resonator. This has been achieved in continuous way with the help of varactors or in discrete steps by the use of pin diode [2-9]. Apart from that a reconfigurable filter based on varying characteristics impedances by the help of a net type stepped-impedance resonator (SIR) has also been reported [10]. A very less effort has been made on BW control for reconfigurable BPF due to lack of the availability of methods to vary the inter resonator coupling [1].

However there are some research contributions for Bandwidth control both with tunable frequency [11-16] and fixed centre frequency [17-23].

In [11] BW tunability has been achieved by placing variable coupling reducers between adjacent filter resonators. A combline filter with varactor diode has been used for BW control as reported in [13]. Two inter stage coupling methods, parallel coupling and taper coupling for BW control is presented in [14].

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The loop shaped dual mode resonator tapped and perturbed with varactor diode for passband reconfigurability has been reported in [15]. Ref. [16] discusses the method of BW control by controlling inter resonator coupling.

In [17] a reconfigurable filter exhibiting broad-range variability of filter's passband width is presented. The filter relies on passive circuit architecture, combined with discrete tuning. The filter has relatively smaller size, (due to its relatively higher frequency operation), low fractional bandwidth but is comparatively lossy in nature (-2.1 dB). A varactor-tuned microwave BPF was reported in [18]. It was a bandwidth reconfigurable BPF realized with simple open and short stub structure loaded with varactors. In [19] the estimation of Electromagnetic (EM) coupling strength for different structures by J inverter topology scheme has been described. On the basis of the analysis a compact filter was designed using interdigital capacitors and etched slots. To achieve higher bandwidth control, a reconfigurable filter block consisting of a branchline coupler with switchable stub, short circuit coupled line and short circuit stub were investigated [20-22]. The filters reported in [21] and [22] have large fractional bandwidth but are larger in size as compared to the proposed bandpass filter. The filter proposed in [23] has relatively larger size and is lossy but have larger FBW.

The proposed filter in this work is totally dedicated for the application in International Mobile Telecommunications-Advanced (IMT-A). The size of the reported filter is 19.8 x 14 mm^2. A novel design structure approach for bandwidth variation which will be known as 'Comb-tooth structure' is presented. The various tooth combinations result in a wide range bandwidth variation for the constant centre frequency. A fractional bandwidth variation of 0.85-6.48% at centre frequency 3.5 GHz was observed which is suitable for IMT-A applications [24].

The paper is divided in five sections. Section II contains a discussion for BPF design concepts. Section III describes how the filter was implemented. Section IV presents a discussion about experimental verification of the proposed work. Finally an overall conclusion of this work is reported in section V.

II. Bandpass Filter Design

The prototype of proposed square reconfigurable BPF is shown in Fig. 1. The design may be divided into two major components, (1) Square ring resonator and, (2) Feed sections with additional patches of variable width 'W'. For the proposed design these additional patches are called as coupling patches. Both the feed sections are having two coupling patches, one on the upper side, and other on the lower side of the feed as shown in the Fig. 1.

The proposed filter is symmetrical in shape. The gap coupled feeding technique is used for exciting the resonator. As discussed earlier, the variation in the width W of coupling patches provide variation in coupling capacitance between the resonator and the feed sections. Due to variation in coupling capacitance between the input feed and the resonator, and the output feed and the resonator, variation in BW is achieved.

Zeland, IE3D simulation tool has been used for simulation. The analysis of the effects of variation in width 'W' of the coupling patches are presented in Figs. 2 and 3 and summarised in Table I.

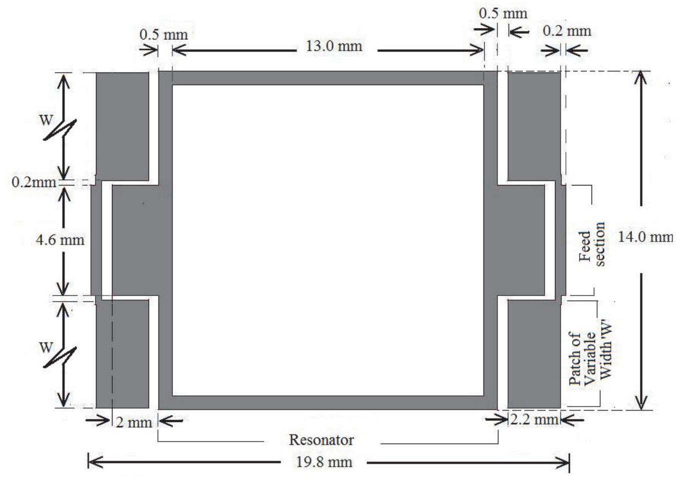

Fig. 1. Layout of the bandpass filter with variable width coupling patch

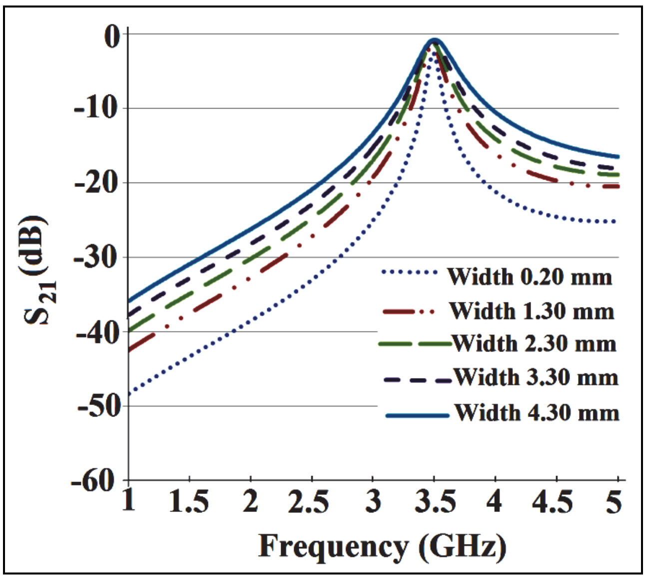

Fig. 2. Insertion loss vs. frequency plot for the layout of Fig. 1

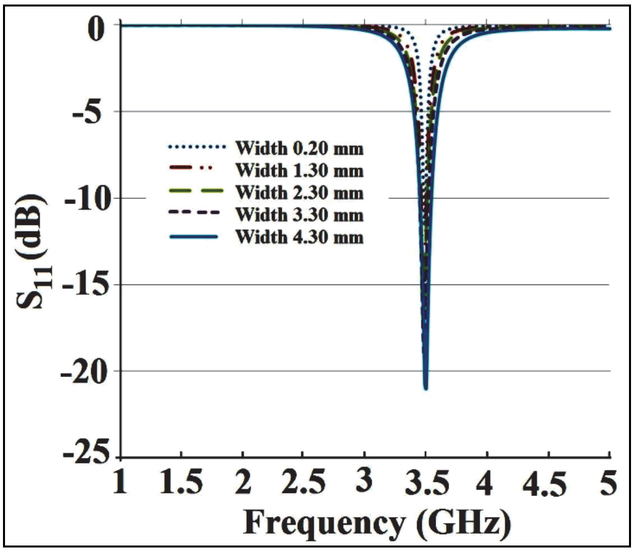

Fig. 3. Reflection Loss vs. frequency plot for the layout of Fig. 1

TABLE I
SUMMARIZED OUTCOME OF FILTER FOR VARIABLE WIDTH W

W (mm)	f_c (GHz)	S11 (dB)	S21 (dB)	BW (MHz)	FBW (%)
0.20	3.511	-11.71	-2.60	30	0.85
1.30	3.504	-15.69	-1.56	98	2.79
2.30	3.498	-17.37	-1.25	136	3.88
3.30	3.506	-18.69	-1.06	169	4.82
4.30	3.502	-20.6	-0.85	227	6.48

From Table I, following inference have observed, which are used to develop the proposed reconfigurable ring patch BPF

1. Increasing W increases FBW.
2. Increasing W improves passband reflection loss.
3. Increasing W improves passband insertion loss.

The coupling patches of variable width 'W' are divided into various small sections, which result a comb-tooth structure as shown in Fig. 4. The proposed structure has five teeth, denoted as A, B, C, D, E. Each tooth has width 'T' except tooth A, whose width is 0.2 mm. The spacing between the two consecutive teeth is 'S'. The amount of bandwidth variation as well as the minimum and maximum bandwidth depend on the values of 'T' and 'S'. Thus the values of T and S must be chosen on the basis of application requirement. In the reported design, the values of T and S are taken as 0.5 mm each.

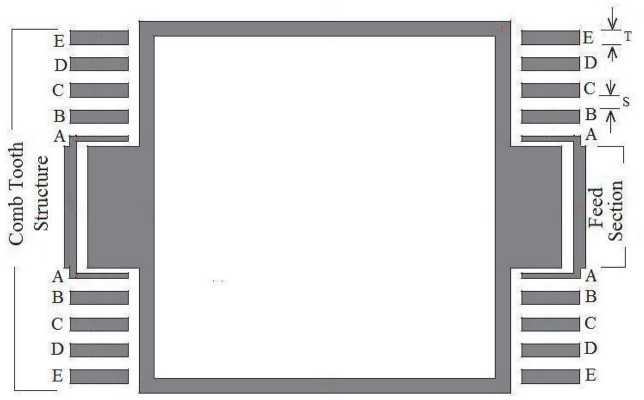

Fig. 4. Layout of the proposed bandpass filter

A higher-order filter for bandwidth control can also be realized by cascading the number of resonators to the reported filter, shown in Fig. 4. The order of the filter will depend upon the number of resonators being used in cascading. Such a higher order filter will have high selectivity, while maintaining the same return loss for the respective BW for related tooth combinations.

III. Design Implementation

The Reconfigurability can be achieved by using pin diode or RF MEMS switch. However due to high cost and rare availability of switches the shorting point method has been used. For shorting the teeth thin copper wires of thickness 0.20 mm were used. The filter is developed on Rogers RT/duroid 5870 material; dielectric constant, (ε_r), 2.33, thickness (*t*) of 1.57mm; loss tangent, $\tan(\delta)$, 0.02. On the basis of design, five combinations of teeth connections are possible as summarised below in Table II.

TABLE II
Tooth Combination

Case	Connection Combination
1.	No tooth is connected
2.	Teeth A and B are connected
3.	Teeth A, B and C are connected
4.	Teeth A, B, C and D are connected
5.	Teeth A, B, C, D and E are connected

The symmetry of the design is always maintained. The layout details of the filter are shown in the Fig. 4. Five cases of combinations are listed in Table II. In order to connect any of the two teeth both the teeth required to be shorted. The bandwidth variation is observed only when any of the teeth is connected to tooth A, which is directly connected to the feed. The simulated results for five cases listed in Table II are shown in Figs. 5 and 6.

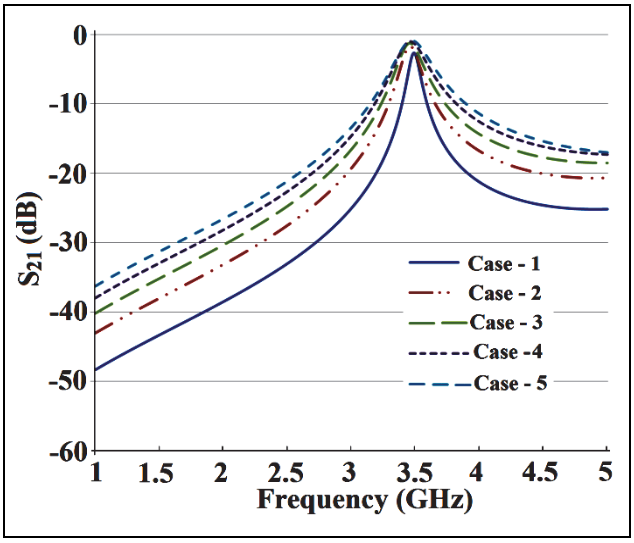

Fig. 5. Insertion loss vs. frequency plot for the layout of proposed filter shown in Fig. 4

Figs. 5 and 6 show the insertion loss and reflection loss characteristics of the bandpass filter respectively for different tooth connections. The minimum bandwidth of 30 MHz has been obtained for case 1 with passband insertion loss, -2.345 dB, passband reflection loss, -11.61 dB at centre frequency of 3.511 GHz. The maximum bandwidth has been obtained for case 5 with bandwidth of 214 MHz, passband insertion loss of -0.828 dB, reflection loss, -20.58 dB at centre frequency of 3.50 GHz.

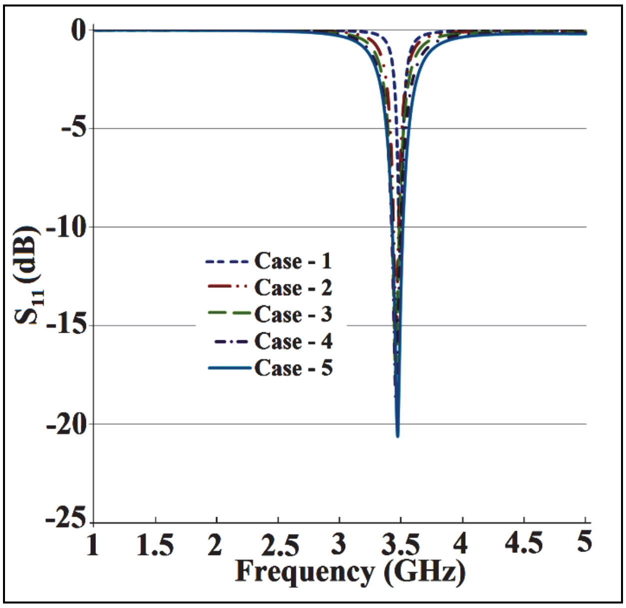

Fig. 6 .Reflection loss vs. frequency plot for the layout of proposed filter shown in Fig. 4

IV. Experimental Verification

This section discusses about the development of bandpass filter and its measurement results. The fabricated prototype of the proposed bandpass filter is shown in Fig. 7. However in this figure shorting of tooth has not been shown for clarity of the figure.

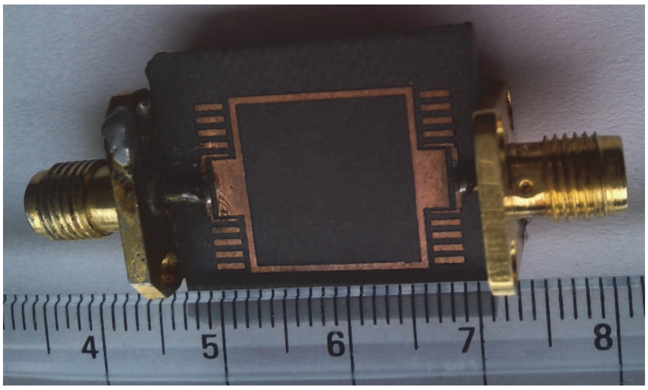

Fig. 7. Fabricated prototype of proposed Bandpass filter

A vector network analyzer (VNA) has been used for the parameters measurement of the fabricated filter prototype.

The simulated and the experimental results are summarized in Table III. The simulated results show a wide variation in bandwidth i.e. of 30-214 MHz with a very small permissible variation in resonance frequency, measured in kHz range and so can be neglected. The experimental results show same trend as the simulated result however because of the expected fabrication error the respective comparative values are not exactly the same which can be observed from Table III . The graphical comparison of simulated and experimental results for case-1 and case-5 are shown in Figs. 8 and 9 respectively.

TABLE III
SUMMARY OF SIMULATED AND MEASURED OUTCOME

Analysis	Case	f_c (GHz)	S_{11} (dB)	S_{21} (dB)	BW (MHz)
Simulated	1	3.511	-11.61	-2.345	30
Measured		3.498	-10.25	-2.827	21
Simulated	2	3.508	-15.3	-1.621	92
Measured		3.491	-13.8	-2.486	60
Simulated	3	3.503	-17.4	-1.249	135
Measured		3.486	-14.8	-2.375	78
Simulated	4	3.505	-18.8	-0.930	188
Measured		3.482	-17.2	-2.112	90
Simulated	5	3.500	-20.58	-0.828	214
Measured		3.476	-16.13	-1.978	120

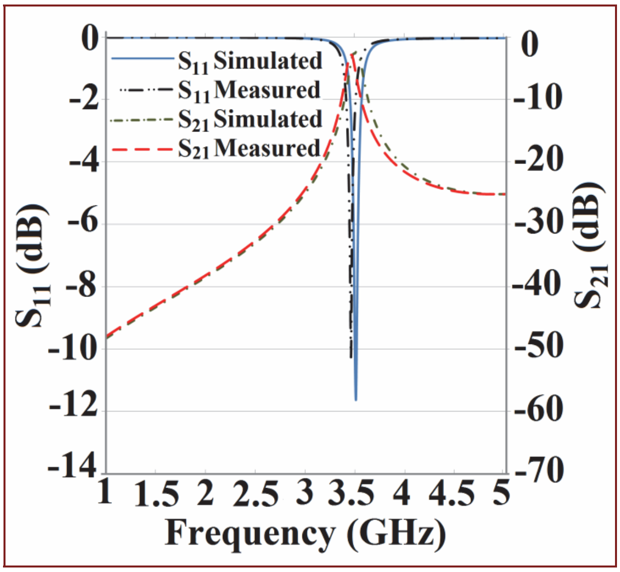

Fig. 8. Simulated and measured result for case -1

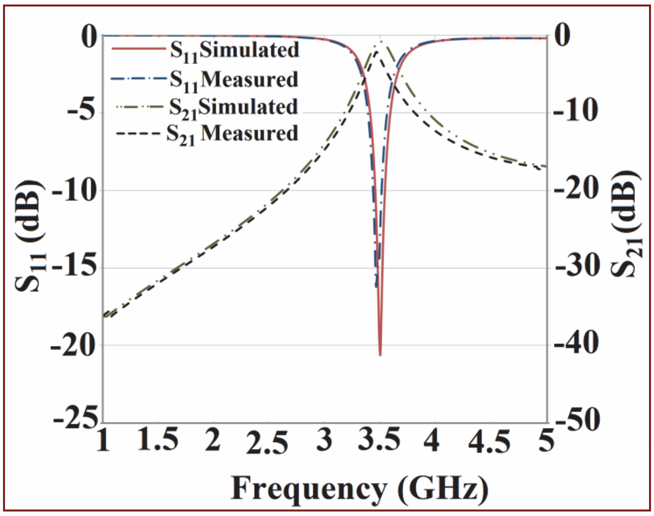

Fig. 9. Simulated and measured result for case –5

V. Conclusion

This paper provides a new approach for BW control for the reconfigurable BPF by connecting the teeth of comb tooth. With this approach a new reconfigurable square ring BPF has been designed on RT duroid 5870 which is operating at resonance frequency of 3.5GHz with FBW of 0.85-6.48 %. The Filter shows good outer band rejection of 44-125 MHz. This scheme is very much useful to achieve required FBW control. It is the width T and spacing S between two consecutive teeth which are responsible for resultant FBW.

Although in this paper shorting point method has been used to realize the reconfigurability, the pin diode or other switching elements such as MOSFET or RF MEMS can also be used to connect the two consecutive teeth to improve the flexibility of design.

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