Performance Enhancement of Microstrip Hairpin Band Pass Filter Using Dumbbell DGS and Split Ring Resonator DGS

K.Vidhya and T.Jayanthy

***Abstract*—In this paper, five pole chebyshev microstrip band pass filter is designed using hairpin resonators. A dumbbell shaped defected ground structure and square split ring resonator DGS are presented to suppress the second and third order harmonics of bandpass filter. Dumbell and square split ring resonator defected ground structure cells are etched under feed lines for improving stop band rejection without affecting the centre frequency and insertion loss of basic filter. For effective suppression of higher order harmonics open stubs are also used at the input and output feed lines. A five pole chebyshev microstrip band pass filter is designed with 700 MHz bandwidth at the centre frequency of 2.5 GHz. Band pass filter is simulated using ADS 2009 software. The simulated results of conventional band pass filter, dumbbell DGS bandpass filter and SRR DGS bandpass filter are compared and tabulated. Compared to dumbbell DGS bandpass filter, SRR DGS bandpass filter has improved suppression at second harmonic frequency.**

***Index terms*—Bandpass, Chebyshev, DGS, Hairpin Resonator, Openstub, Stopband.**

I. Introduction

Microstrip band pass filters [1]-[2] are essential high frequency components in microwave communication systems. Modern microwave communication system requires microstrip bandpass filters with improved performance for out-of-band and in-band responses, reduced size, high rejection and low insertion loss. There have been new design techniques such as Photonic band gap (PBG) [3]-[4], Ground plane aperture (GPA) to improve the quality of the system. PBG is a periodic structure which is designed to reject particular frequency band. PBG structures cannot be used for the design of microwave components because of difficulties in modeling and there will be radiation from the periodic etched defects. When GPA is used under microstrip line, the line properties could be changed significantly because of variation of characteristic impedance with the width of the GPA. Filters based on Defected ground structures are proposed to overcome these problems.

Several techniques have been proposed so far for harmonic suppression of bandpass filter such as photonic band gap structures and spurline filters. But these structures increase the circuit design complexity. In this paper dumbbell shape DGS and SRR DGS are proposed for suppression of harmonics. The first DGS was proposed by Park et al [5] where DGS is designed by connecting two DGS cells with a narrow slot. The effective capacitance and inductance of the transmission line is increased using the DGS which contains wide and narrow etched areas [6]-[7]. The dumbbell shape defected ground structure was analyzed [8]- [10]. Markoes et al, have demonstrated the dependence of the resonant frequency of SRR on the dimensions of the ring [11]. Compact narrow band pass structures were designed using complementary circular split ring resonators [12]. The electromagnetic resonances in SRRs are numerically and experimentally studied in [13]-[14]. Pendry et al. have investigated that an array of SRRs exhibits negative permeability near its resonant frequency [15].

The proposed microstrip filter is designed using dumbbell DGS and SRR DGS. DGS is a technique where ground plane is modified intentionally to enhance performance of the filter. It improves the steepness of the roll off and the selectivity of the filter.

Many people have presented numerous design techniques for the realization of bandpass filters such as parallel coupled line, combline and split ring resonators. The disadvantage of parallel coupled line filter is that it suffers from spurious response which degrades the pass band and stop band performance of the filter.

Split ring resonators [16] suffer from large resonance frequency variation and large circuit losses. The size of the filter designed by using parallel coupled line [17]-[18] is quite large and has limited selectivity because of the use of half wavelength resonators. Band pass filters designed using hairpin resonator is small in size rather than BPF having coupled lines. By designing filters with hairpin resonators these disadvantages can be conquered.

At lower microwave frequencies hairpin resonator filter is the most widely used filter. This filter structure has the advantage of compact size and low cost. Design is based on chebyshev response because chebyshev response is more selective than that of Butterworth filter. In this paper five pole chebyshev hairpin filter design is presented. To enhance the performance of the filter, dumbbell DGS, SRR DGS and open stubs are used under input and output lines of the proposed filter.

II. Design

A. *Design 1: Design of conventional hairpin filter*

Hairpin line filters are compact structures. By folding the

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parallel coupled half wavelength resonators in to u shape hairpin resonator is obtained. To allow for bending a sliding factor is introduced. This makes the design compact. A band pass filter is designed to have a fractional bandwidth of 0.28 at a centre frequency of 2.5 GHz. A 5 pole chebyshev low pass prototype with a pass band ripple of 0.1 db is used. The element values are $g_0=g_6=1.0$, $g_1=g_5=1.1468$, $g_2=g_4= 1.3712$ and $g_3=1.9750$. These low pass element values are used to determine the design parameters of band pass filters such as coupling coefficient and external quality factor. The band pass filter parameters can be calculated by

$$Q_{e1}=g_0 g_1/FBW \quad (1)$$

$$Q_{en}=g_n g_{n+1}/FBW \quad (2)$$

$$Mij=FBW/g_i g_{i+1} \text{ for } i=1 \text{ to } n-1 \quad (3)$$

where M_{ij+1} are the coupling coefficients between the adjacent resonators and $Q_{e1}$and Q_{en} are the external quality factors at the input and output and FBW is the fractional bandwidth of the filter. The layout and simulated response of conventional filter are shown if Fig.1 and 2

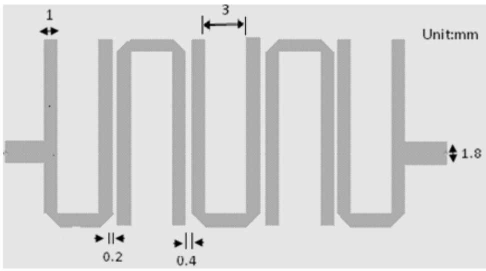

Fig. 1: Layout of conventional 5 pole microstrip bandpass filter

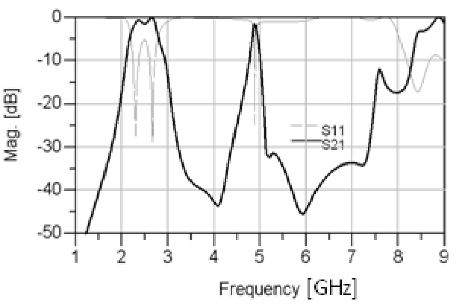

Fig. 2: Simulated response of Conventional B.P.F

The low pass prototype element values and FBW are substituted in to the equations (1) – (3) to obtain the design parameters for the filter. The results are

$$Q_{e1}=Q_{e5}=4.0957$$

$$M_{12}=M_{45}=0.223$$

$$M_{23}=M_{34}=0.170$$

The overall response of the band pass filter is determined by the coupling between the resonators. So the coupling coefficient is related to the spacing between the resonators. The coupling coefficient can be varied by varying the spacing between the resonators by using the formula

$$K=(f_2^2-f_1^2)/(f_2^2+f_1^2) \quad (4)$$

The spacing for the required quality factor can be determined by using the above formula where $f_1$and f_2 are the two peak resonances. These resonance frequencies are obtained from the simulated response S_{21} For two resonators.

The band pass filter is designed to have tapped line input and output. The tap distance affects the overall bandwidth performance of the filter and therefore the quality factor is affected. The tapping location t is obtained as 6mm. The characteristic impedance of the tapped line is obtained such that it matches to the 50Ω terminating impedance. For the proposed filter characteristic impedance of tapped line is 68.4Ω and the width is 1.8mm.

B. Design 2: Design of dumbell DGS assisted band pass filter

DGS is an periodic or non periodic defected structure in the ground plane of micro strip line. By etching a slot in the ground plane of micro strip circuit, DGS cell can be realized. The current distribution in the ground plane is disturbed due to the etched slot. The inductance and capacitance of the microstrip line is altered due to this change in current. So the resonant properties of microstrip line can be changed by changing the size and shape of the slot

Fig.3 shows the dumbbell shaped DGS module. The simulated S parameters of dumbbell DGS unit is similar to the butterworth type low pass response. The DGS pattern can be easily fabricated. It needs less circuit sizes. It can be easily designed and implemented compared with PBG structures. The dumbbell shape DGS is composed of two a × b rectangular defected areas. Two rectangular defected areas are connected by a thin connecting slot. The dumbbell DGS has the advantages of stop band and slow wave effect.

Fig.4 shows the equivalent circuit of dumbbell DGS circuit. The rectangular area of DGS increases the effective inductance of microstrip line and the connecting slot improves the effective capacitance of the microstrip line. So two rectangular areas and connecting slot correspond to added inductance and capacitance respectively. The equivalent circuit contains a pair of parallel L-C which resonates at the resonant frequency. When the etched area increases it leads to lower cutoff frequency. When the gap distance increases the attenuation pole moves up to higher frequency.

The equivalent circuit parameters can be expressed using the following equations (5), (6) and (7)

$$R(\omega) = \frac{2Z_0}{\sqrt{\frac{1}{|S11(\omega)|^2} - \left(2Z_0\left(\omega c-\frac{1}{\omega L}\right)\right)^2 - 1}} \quad (6)$$

$$C = \frac{\omega_c}{2Z_0\,(\omega_0{}^2 - \omega c^2)} \quad (7)$$

$$L = \frac{1}{4(\pi f_0)^2 C} \quad (8)$$

where f_0 is the resonant frequency and Z_0 is the 50 ohms characteristic impedance of microstrip line, ω_0 is the angular resonant frequency, ω_c is the 3-dB cutoff angular frequency $S_{21}(\omega)$ is the forward transmission coefficient of equivalent network and $S_{11}(\omega)$ is the input reflection coefficient of equivalent network.

Fig .5 shows the stop band characteristics of DGS circuit. The dumbbell shaped DGS module behaves like a low pass filter. It is designed to have a cutoff frequency of 3.6 GHz. The proposed DGS is designed to transmit all the frequencies up to 3.6 GHz and to achieve wide stop band up to 9 GHz

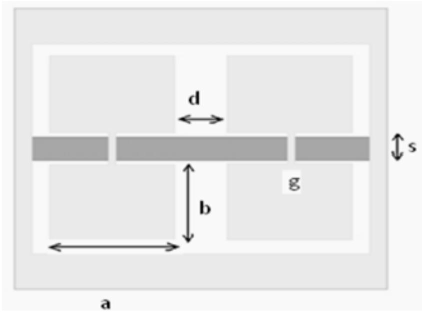

Fig. 3: Layout of Two dumbbell shaped DGS module

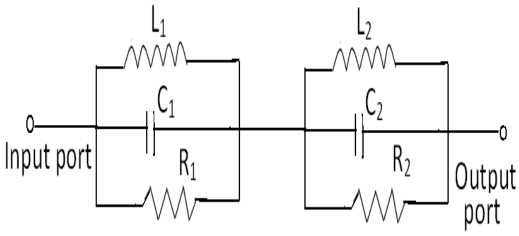

Fig. 4: Equivalent circuit of Dumbbell DGS module

Fig.6 shows dumbbell shaped DGS integrated structure. The suppression of high-order harmonic frequencies of the fundamental frequency 2.5GHz is achieved by using dumbbell shaped DGS. A pair of dumbbell DGS cells is placed under input and output feed lines of band pass filter for rejection of unwanted harmonic frequency components . Two cells are separated by a distance of 4 mm. The dumbbell DGS cell comprised of two rectangular slots of length 8mm and width 6mm. They are connected by a very thin slot of width of width 0.4mm and length 2mm. The 50 ohm microstrip line is having the width of 1.8 mm. This integrated structure provides suppression at 5 and 7. GHz without any effect on original 2.5GHz signal.

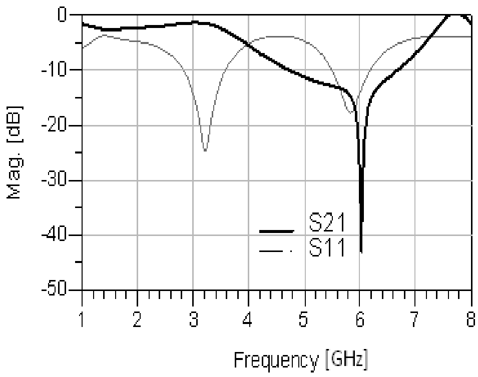

Fig. 5: Simulated response of Dumbbell DGS module

DGS units are impedance building blocks of high frequency high performance filters. To reject second and third harmonics without affecting the centre frequency they are etched under input and output lines of band pass filter. The harmonics are integer multiples of the fundamental frequency. The dumbbell shaped DGS gives wider stop band. This property of DGS is used for suppression of harmonics. The stop band can be widened by increasing the number of DGS units or cells. The second and third harmonics are effectively suppressed by 23dB and 18 dB respectively by including pairs of DGS cells under input and output lines of proposed filter.

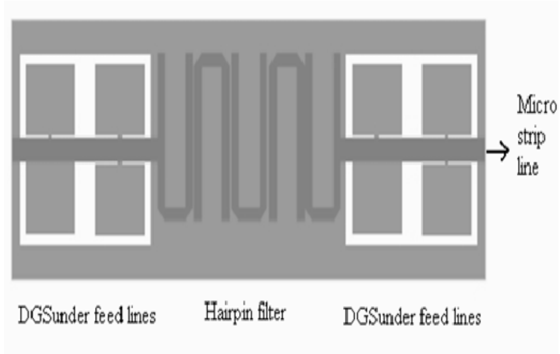

Fig. 6: Layout of dumbbell DGS assisted microstrip B.P.F.

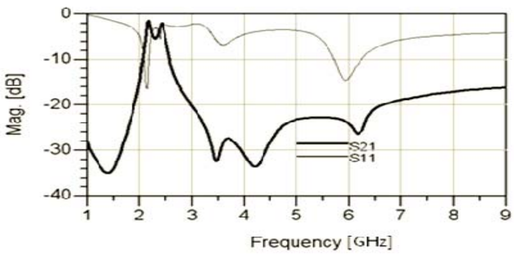

Fig. 7: Simulated output of microstrip B.P.F

C. Design3: Design of improved B.P.F. using dumbbell DGS loaded with open stubs

The proposed dumbell DGS assisted BPF discussed above has the advantage of low in band insertion loss and high spurious suppression. But the disadvantage is that it has insufficient suppression at high frequencies. At both second and third harmonics average attenuation of 23 dB rejection is achieved.

To improve the out of band suppression open stubs are added between first and second dumbbell DGS cells at the input and output feed lines. The open stub is having the width of 2.5 mm. The open stub increases the shunt capacitance of 50 ohms microstrip line and the average suppression of 48dB is achieved at third harmonic frequency.

The resonance characteristics of dumbbell DGS and open stubs are used to achieve 23dB and 48dB suppression at 5 and 7.5 GHz respectively.

D. Design4: Design of square split ring resonator DGS assisted B.P.F

SRR is one of the most popular DGS types. SRR DGS is obtained by etching square split ring defective pattern in the ground plane. An electromagnetic resonance is obtained due to the discontinuity of impedance in defective region and band gap is formed. Two pairs of unsymmetrical SRR DGS cells are etched under the feed line for suppression of unwanted harmonics without affecting the original signal.

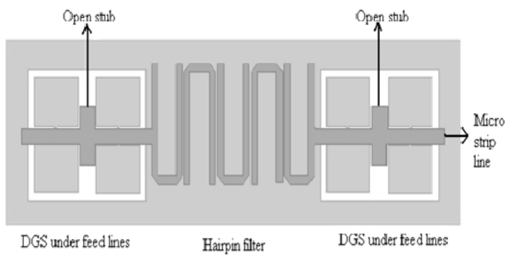

Fig. 8: Layout of B.P.F using open stub and DGS cells

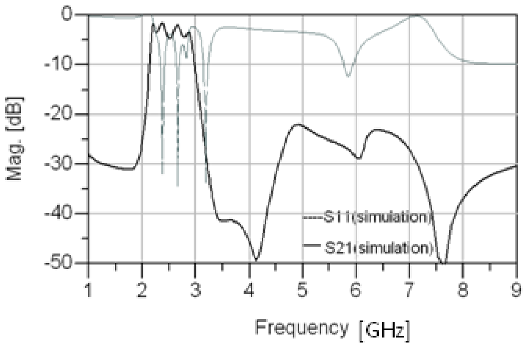

Fig. 9: Simulated response of B.P.F

The SRR acts as a parallel resonator. The parallel resonator will be added to the equivalent circuit of microstrip line by etching split ring defective pattern in the ground plane. The first SRR DGS cell is having the total length of 8.3 mm. The width of the first SRR close to the input port is 0.2 mm and split gap is kept 0.2 mm. when the total length of SRR decreases the resonant frequency increases. In order to have the resonant frequency at 5 GHz the total length of second SRR is increased to 11.9 mm. This SRR DGS cell is tuned to suppress the harmonics at the frequency of 5 GHz. The width and split gap of second resonator is 0.3 mm and 0.2 mm respectively

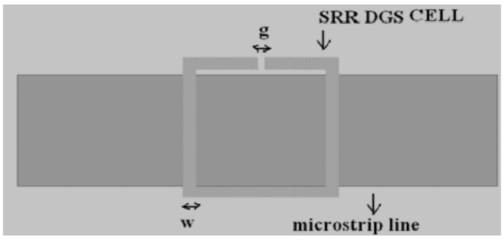

Fig.10 Layout of square split ring resonator DGS cell

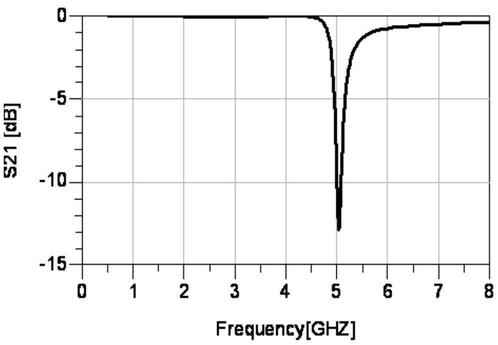

Fig. 12: Scattering parameter S21 variation of first SRR

Fig. 10 shows the layout of SRR DGS cell. SRR DGS cells are etched under the 50 ohm microstrip feed line. Fig.11 shows the simulated result of first SRR DGS cell. It is having the notch at the frequency of 5GHz. The harmonics centered at the frequency of 5 GHz is suppressed due to the resonant properties of SRR DGS.

The simulated result of second SRR DGS cell is shown in Fig.12. The graph shows the variation of scattering parameter S21 with respect to the frequency. The magnitude of S21 is minimum at the frequency of 7.5 GHz. The second harmonic frequency is suppressed due to the band stop property of SRR.

Fig.13 shows the configuration of SRR DGS integrated structure. Two pairs of unsymmetrical SRR DGS cells are placed at both the input and output feed lines. The two cells are separated by a distance of 2 mm. Due to the resonant properties of SRR DGS cells unwanted signals are suppressed

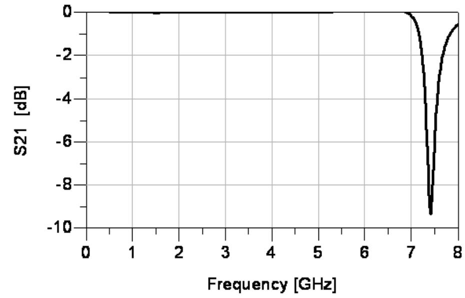

Fig. 11: Scattering parameter S21 variation of second SRR

By properly adjusting the dimensions of SRR cell, the harmonic suppression at desired frequencies can be achieved. The first and second SRR cells are designed to suppress harmonics at the frequencies of 7.5 GHz and 5 GHz respectively.

E. Design5: Design of improved B.P.F. using SRR DGS loaded with open stubs

Fig.15 shows the layout of B.P.F designed using SRR

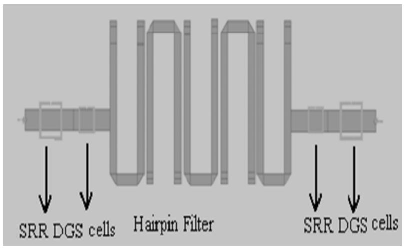

Fig. 13: Layout of B.P.F using SRR DGS cells

DGS and open stubs. The disadvantage of B.P.F designed using SRR DGS is that the harmonic suppression is not sufficient. To enhance the out of band suppression SRR DGS structure with open stubs loaded on the feed line is proposed. To improve the suppression open stubs are added between first and second SRR DGS cell at both the input and output feed lines. The open stub improves the shunt capacitance of microstrip line. By properly adjusting the length and width of the open stub desired harmonic suppression can be achieved. The length of the stub is 7 mm. The width of the open stub is kept 1 mm. Due to the band stop effect of DGS structures and openstubs , the second and third harmonics are suppressed by 54dB and 34dB respectively.

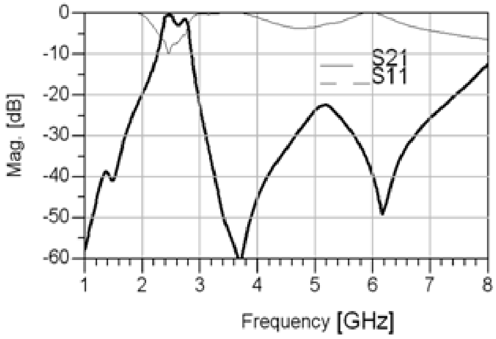

Fig. 14: Simulated response of B.P.F .

III. Results

The conventional and proposed band pass filters are simulated with ADS 2009 software. Fig.2 shows the S parameter performance of the conventional hairpin band pass filter. The pass band centre frequency is at 2.5 GHz and 3dB bandwidth is 700 MHz. The pass band insertion loss is 1dB. The higher harmonics are centered at the frequencies of 5 and 7.5 GHz. The return loss is -26 dB. To improve the performance of the conventional filter, DGS is used.

Fig.7 shows the simulated response of band pass filter designed using dumbell DGS under the both feed lines. The graph shows second and third harmonics are suppressed by 23 dB and 18 dB respectively. Using dumbbell shaped DGS filter has wide stop band characteristics with a minimum attenuation of 23 dB up to 9 GHz. The insertion loss is -2dB which is slightly greater than the conventional filter. This increase in insertion loss is caused by finite insertion loss of low pass filter characteristics of DGS transmission line.

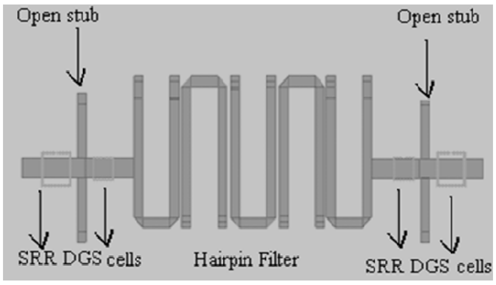

Fig. 15: Layout of B.P.F using openstub and SRR

But this filter has the disadvantage of insufficient suppression at the third harmonic frequency and slow cut-off frequency slope characteristics. This design technique is effective for single harmonic suppression. It can be used for the suppression of second harmonic only. This Problem can be overcome by using open stubs along with dumbbell shape DGS module

Fig.9 shows the S parameter performance of the proposed band pass filter designed using open stubs and dumbbell DGS units. In this design 2 open stubs have been added to improve the out-of-band suppression, sharp cutoff frequency and wide stop band. It shows extra attenuation is achieved at the third harmonic frequency. The third harmonic frequency is suppressed by 48 dB. The effective suppression of harmonics is achieved using design.3. The return loss of the filter is also improved . It is about -32 dB. For the conventional filter the return loss is -26 dB.

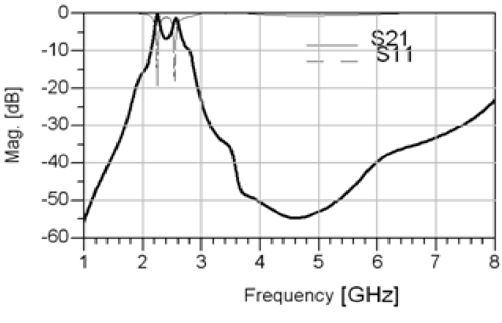

Fig. 16: Simulated response of B.P.F DGS cells

Fig.14 shows the simulated response of band pass filter designed using SRR DGS under both the feed lines. The graph shows second and third harmonics are suppressed by 24 dB and 20 dB respectively. Compared to B.P.F designed using dumbell DGS, harmonic suppression is improved in B.P.F designed using SRR DGS units. The insertion loss is less than 1dB. The insertion loss also reduced compared to dumbbell DGS assisted bandpass filter. Filter has a minimum attenuation of 24 dB up to 7.5GHz

Fig.16 shows the S parameter performance of the proposed band pass filter designed using open stubs and SRR DGS units. In design 5 open stubs have been added to improve the out-of-band suppression. The graph shows extra attenuation is achieved at both the second and third harmonic frequency. The second and third harmonic frequencies are suppressed by 54 dB and 34 dB respectively. The insertion loss is about -4dB. The minimum attenuation of the microstrip bandpass filter is 34 dB up to 7.5 GHz. The results of band pass filters are summarized in Table.1.

TABLE I: Comparison of Results of Band Pass Filters

Types	S_{21} at 5GHz (dB)	S_{21} at 7.5GHz (dB)
Design 1	2	12
Design 2	23	18
Design 3	23	48
Design 4	24	20
Design 5	54	34

IV. Conclusions

In this paper 5 pole chebyshev hairpin BPF is designed using dumbbell shape DGS, SRR DGS and open stubs. Two pairs of DGS structures are etched under the input and output feed lines of proposed filter to reduce the spurious frequencies. In the design of B.P.F using dumbbell DGS and open stubs, second and third harmonics are suppressed by 23B and 48 dB at 5 and 7.5 GHz respectively. By including open stubs in the design of proposed filter improved suppression is achieved at the third harmonic frequency.

In the design of B.P.F using SRR DGS and open stubs, second and third harmonics are suppressed by 54B and 34 dB at 5 and 7.5 GHz respectively. Compared to B.P.F designed using SSR DGS and open stubs, improved suppression is achieved at second harmonic frequency. The stop band properties of DGS and open stubs provide wide and deep stop band characteristics. The out of band suppression is no less than 34 dB until 7.5 GHz

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