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DESIGN OF MICROSTRIP HAIRPIN BAND PASS FILTER USING DEFECTED GROUND STRUCTURE AND OPEN STUBS

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Abstract: A dumbbell shape defected ground structure is proposed to suppress the second and third harmonics of five pole microstrip hairpin band pass filter. Two pairs of dumbbell shaped DGS cells are used at the input and output feed lines of band pass filter. The DGS is operated as a low pass filter to suppress second and third order harmonics. DGS 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 third order harmonic open stubs are added to dumbbell DGS module under both feed lines. Open stubs are used at the input and output port to improve the out-of-band suppression. 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 harmonics are suppressed by 23 dB and 48 dB at second and third harmonics respectively. Extra stop band rejection to the second harmonic frequency is achieved by using open stubs at the input and output feed line. The return loss of the proposed filter is -32 dB.

Index terms: bandpass, chebyshev, DGS, hairpin resonator, openstub, stopband.

1. 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), 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. The first DGS was proposed by Park et al [3] 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[4]-[5]. The dumbbell shape defected ground structure was analyzed [6]- [8].

The proposed microstrip filter is designed using hairpin resonator ,defected ground structure and open stubs. DGS is a technique where ground plane is modified intentionally to enhance performance of the filter. It improves the steepness of the roll off. The selectivity of the filter is improved using DGS.

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 [9] suffer from large resonance frequency variation and large circuit losses. The size of the filter designed by using parallel coupled line [10]-[11] is quite large and has limited selectivity because of the use of half wavelength resonators. Band pass filters designed using hairpin resonator is small

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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 and open stubs are used under input and output lines of the proposed filter

2. Design

2.1 Design 1: Design of conventional hairpin filter

Hairpin line filters are compact structures. By folding the 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

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

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

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

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.

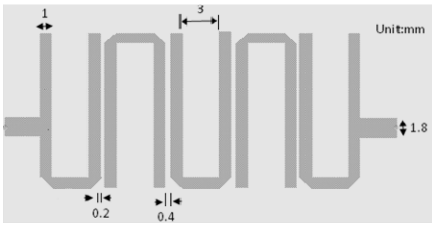


Fig. 1: Layout of conventional 5 pole microstrip bandpass filter

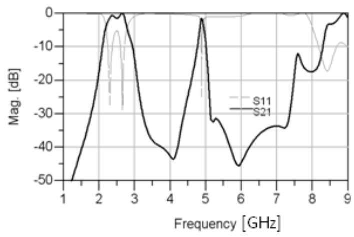


Fig. 2: Simulated response of Conventional B.P.F

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.

2.2 Design 2: Design of 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)

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

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

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

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

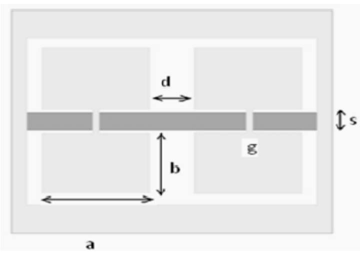


Fig. 3: Layout of Two dumbbell shaped DGS module

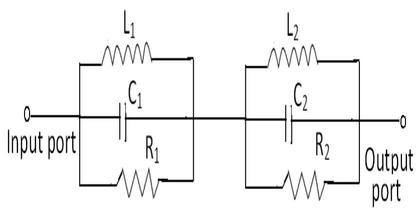


Fig. 4: Equivalent circuit of Dumbbell DGS module

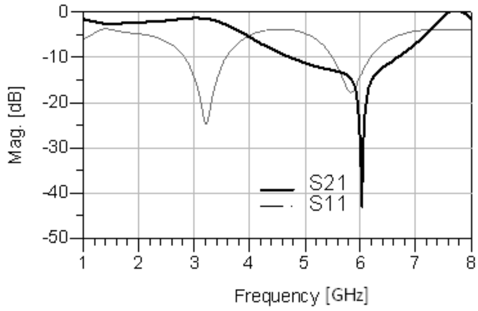
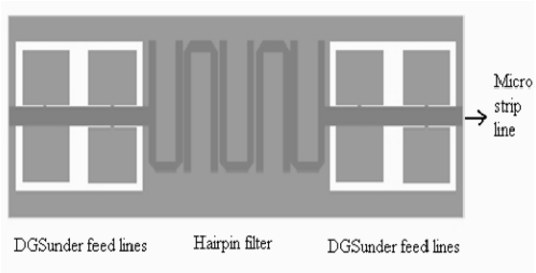


Fig. 5: Simulated response of Dumbbell DGS module

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 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.

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.



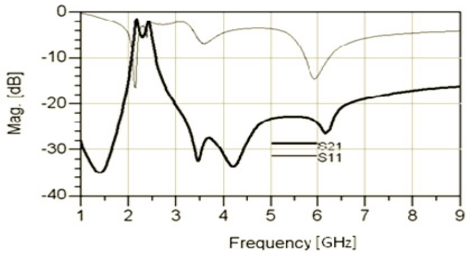
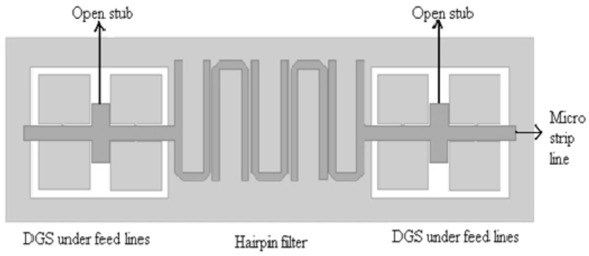


Fig. 6: Layout DGS assisted microstrip B.P Fig. 7: Simulated output of microstrip B.P.F using DGS

2.3 Design3: Design of B.P.F. using open stubs and DGS

The proposed 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 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 DGS and open stubs are used to achieve 23dB and 48dB suppression at 5 and 7.5 GHz respectively



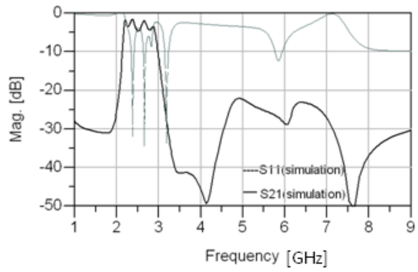


Fig. 8: Layout of B.P.F using open stub and DGS cells Fig. 9: Simulated response of B.P.F

3. 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 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. 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 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. The results of band pass filters are summarized in Table.1.

Table 1: 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

4. Conclusion

In this paper 5 pole chebyshev hairpin BPF is designed using dumbbell shape 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. Due to stop band properties of DGS second and third harmonics are suppressed by 23dB and 18 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. S_{21} at the third harmonic frequency is about 48 dB. This is achieved by designing band pass filters using DGS and open stubs. The stop band properties of DGS and open stubs provide wide and deep stop band characteristics. The return loss of the filter is improved by designing B.P.F with DGS and open stubs. The return loss is -32 dB. The wide stop band with an average attenuation of 23 dB is achieved up to 9 GHz.

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