Improvement of Passband Characteristics of Microstrip Band Pass Filter by Defected Ground Structures

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Abstract
A scheme for improving the bandwidth of passband of microstrip parallel-coupled bandpass filter using defected ground structure is presented. A proto-type filter with midband frequency at 3.5 GHz and fractional bandwidth of 0.12 has been fabricated with Arlon make PTFE substrate. The simulation has been done by MOM based IE3D software and experimental measurement has been carried out using vector network analyzer. Applying defected ground structures under coupled lines of filter, we have achieved lower passband center frequency at 3.1 GHz and high selectivity of 50 dB/GHz. The bandwidth is also improved from 12% to 42%. The bandwidth can be tuned by varying only the dimension of DGS.

1. Introduction
Modern microwave communication systems especially broad-band and multiband applications in satellite and mobile communications, require high performance bandpass filters having low insertion loss and high selectivity together with linear phase or flat group delay in the passband. In order to fulfill these criteria and to reduce size and cost, there has been a growing interest in designing with planar structure. Under those driving forces many novel types of microstrip filters have been developed [1]. The microstrip parallel-coupled half-wavelength resonator filter, proposed by Cohn in 1958 [2] has been one of the most commonly used Bandpass filter. Recently Chang and Itoh introduced a modified parallel-coupled filter structure to improve the upper stopband rejection and the response symmetry [3].

Recently, defected ground structure (DGS) for planar transmission lines has drawn a wide interest because of their extensive applicability in antenna and microwave circuits [4-6]. DGS etched in the metallic ground plane of microstrip lines, are attractive to obtain unwanted frequency rejection and circuit size reduction. Since DGS have an inherent resonance property, many of them have been applied for improvement of filter circuits.

In this paper, we have design three-pole microstrip parallel-coupled bandpass filter using half-wavelength line resonators, completely parallel to each other. To enhance the passband performance of the filter, we have used rectangular headed dumb-bell shaped DGS structures as proposed by D. Ahn and et.al [4,5]. The proposed DGS cell consists of two rectangular slots connected by a thin transverse slot symmetrically under the microstrip line. Because of the inherent nature of DGS, the slowwave factor is introduced into the circuit that increases towards the edge of the stopband of DGS. This design yields a high effective dielectric constant. Both the electrical length and coupling effect of the resonators are modulated by the slowwave characteristics of DGS, which have been successfully used to tune the passband of the filter. The coupling between the coupled lines of the BPF gets enhanced for a given spacing of the resonators and thus improves the passband performance by providing almost zero insertion loss. In addition to that the effective electrical length of the resonators increases which reduces the cut-off frequency. This gives the filter a compact design.

A method has also been presented in controlling the bandwidth of this BPF by varying only the dimensions of DGS. This finds very importance particularly when there are limitations in changing the spacing between the coupled lines to bring variation in bandwidth.

2. Study of defected ground structure
The rectangular slot heads of DGS cell provide equivalent inductance and thin connecting transverse slot provide equivalent capacitance to the microstrip line. So the line behaves like a LC resonator and its propagation constant is modulated. Propagation characteristic of DGS transmission line changes with the dimension of the DGS cell or number of DGS cell, which yields slowwave characteristics. The resonant frequency can be tuned by changing dimension of rectangular slots or by adjusting the width of transverse connecting slot.

Here, rectangular headed dumb-bell shaped DGS cell consist of two rectangular slots of length 4.4 mm and width 4 mm are connected by a thin transverse rectangular slot of width 0.4 mm and length 2.0 mm symmetrically under 50 ohm microstrip line. We choose PTFE substrate having thickness 0.79 mm and dielectric constant of 3.2. Here an array of three DGS cells is placed with a periodic separation of 5.5 mm to
study lowpass filtering characteristics. By cascading three cells under microstrip line as shown in Fig. 1, we are able to achieve sharp and wide stopband characteristics.

The structure is simulated with MOM based IE3D commercial software. S-parameters are plotted in Fig. 2(a) and observe cutoff frequency at 4.7 GHz and stopband center frequency at 5.7 GHz respectively. We obtain 20 dB rejection bandwidth of 5.0 GHz and the sharpness factor of 30 dB/GHz at lower cutoff edge, which shows good lowpass filtering characteristics.

Figure 1: Layout of Microstrip line with DGS cells

Figure 2: Simulated (a) S-parameter plots and (b) slowwave factor plot of microstrip DGS line

DGS etched in the metallic ground plane under microstrip lines, yields high slow-wave factor compare to microstrip line without DGS as shown in Fig. 2(b). The slow-wave factor of the microstrip line is defined by square roots of effective dielectric constant. From classical definition, the value of effective dielectric constant lies between air dielectric constant and substrate dielectric constant. But the effective dielectric constant of the microstrip line with DGS is greater than substrate dielectric constant. It increases towards the edge of stopband. It changes either with the number of DGS cells or with the dimension of each DGS cell. So, the slow-wave factor at passband increases towards the edge of stopband with incorporation of DGS, whereas the slowwave factor is almost constant with frequency for simple microstrip line as shown in Fig. 2(b). The passband at the edge of transition knee of DGS is utilized here to improve the passband characteristics of the bandpass filter.

3. Design of microstrip bandpass filter

We have design a three-pole microstrip parallel-coupled bandpass filter (BPF) with midband frequency at 3.5 GHz and fractional bandwidth of 0.12. It uses half-wavelength line resonators. They are positioned so that adjacent resonators are completely parallel to each other and therefore give relatively large coupling for a given spacing between resonators.

The layout of the filter is shown in Fig. 3. The width of feed line is made 1.92 mm towards port and 0.5 mm towards couple line for proper matching of impedance. The couple lines have width of 2 mm and they are separated by a gap of 0.4 mm. The gap between feed line and couple line are made of 0.2 mm. The length of the parallel coupled lines is half of the guided wavelength and we have designed the value of 26 mm, taking center frequency at 3.5 GHz and for substrate having dielectric constant 3.2 and thickness 0.79 mm.

Figure 3: Layout of parallel-coupled-line BPF

The simulated S-parameters of the filter are plotted in Fig. 4(a). We observe the 3-dB bandwidth of 0.41 GHz (12%) at pass-band center frequency of 3.5 GHz. The pass band insertion loss of 1.9 dB has been obtained. The calculated 20 dB-Rejection bandwidth is 0.8 GHz.

We have fabricated the prototype filter using Arlon make PTFE substrate. Experimental measurement has been carried out with Agilent make vector network analyzer of model N5230A. The measured result is shown in Fig. 4(b), which almost comply the simulated result. The differences in insertion loss and bandwidth are due to fabrication tolerances. We also observe unwanted higher harmonics centered at 7 GHz and 10.5 GHz and 13.5 GHz.
4. Filter incorporating defected ground structure

DGS cells etched in the metallic ground plane of microstrip under coupled lines. The slow-wave factor of a DGS increases towards the edge of stopband. So if we design the passband of a BPF near the edge of the stopband of DGS, we can avail the maximum effect of slowwave characteristics. Due to slowwave, the effective electrical length of the resonator increases. Therefore, the cutoff frequency decreases and thus provides compactness in design. A DGS etched in the metallic ground plane under the coupled lines of parallel coupled filter enhances the coupling between the lines due to its slow-wave effect and therefore, yields higher bandwidth of the bandpass filter.

Three DGS cells have been put here under the three-coupled lines as shown in Fig. 5. We choose the dimensions of the DGS cells such that the passband of the bandpass filter is kept close to the stopband edge frequency of the DGS and avail the maximum slowwave factor.

The simulated result is shown in Fig. 6(a). We observe the 3-dB bandwidth of 1.2 GHz (42%) at the passband center frequency of 3.1 GHz and insertion loss of 0.5 dB, when the dimension of DGS cell is chosen as follows:

- Rectangular slot length (c) = 4.4 mm
- Rectangular slot width (b) = 2.5 mm
- Connecting slot length (d) = 2 mm
- Connecting slot width (g) = 0.4 mm
- Periodic separation between cells (a) = 5.5 mm

We also observe the 25 dB rejection bandwidth of 1.6 GHz, which yields excellent selectivity of 50 dB/GHz at transition on both side of passband. The experimental measurement result in Fig. 6(b) gives a 3-dB bandwidth of 1.1 GHz around the center frequency of 2.9 GHz. The measured result almost comply the simulated result. The small difference in insertion loss and bandwidth is achieved due to fabrication tolerances.

So we can say that a measured fractional bandwidth of 38% (42% from simulation result) has been achieved by incorporating the DGS under the coupled lines, which is about 3.4 times more than the bandwidth of the filter as shown earlier in Fig. 4(a). The insertion loss has been reduced in this case to near 0.5 dB in the passband. The 20-dB rejection bandwidth is 1.6 GHz that yields excellent selectivity of 50 dB/GHz. But the frequency response shows poor stop band performance due to the harmonics developed around 5.7 GHz and 7.4 GHz.

5. Tuning of bandwidth of the filter

When we vary the slot dimension of DGS, the slowwave factor charges and subsequently the passband of the filter improves. Here, we vary the rectangular slot width of DGS cell to 1.5 mm, 2.5 mm and 4.0 mm keeping other dimension fixed.

Plots of the transmission coefficient with different slot width are shown in Fig. 7. We achieve 28%, 42% and 55% bandwidth (3-dB) at center frequencies of 3.1 GHz, 3.1 GHz and 2.9 GHz respectively for slot width 1.5 mm, 2.5 mm and 4.0 mm. So we can say that bandwidth increases with increment of slot-width of DGS cell. Again the pass band cutoff frequency decreases with increment of slot-width. The insertion loss of the filter improves with DGS cell.

Figure 4: $S_{21}$ plots of BPF (a) simulated; (b) measured

Figure 5: Layout of the filter with DGS cells under coupled lines of BPF

Figure 6: 
(a) Simulated result with DGS
(b) Experimental measurement result with DGS

Figure 7: Transmission coefficient plots with different slot width
Figure 6: S-parameter plots of BPF with DGS cells (a) simulated; (b) measured.

Figure 7: Simulated $S_{21}$ with different slot width

6. Conclusion

A microstrip DGS structure is proposed, which consists of three rectangular headed dumb-bell shaped DGS cells under microstrip line for achieving a wide and steep slope lowpass characteristics with fine tuning capability. The proposed DGS cells are etched under coupled lines of a microstrip parallel-coupled bandpass filter, which yields higher passband width maintaining low insertion loss. It also offers lower passband center frequency, which conforms circuit size reduction. By varying the dimension of DGS cell, we can tune the passband characteristics like center frequency, bandwidth and selectivity of the filter. But such filter shows poor stopband performances. In future work, we shall incorporate DGS structures under both input and output feed lines to improve stopband performance by removing higher harmonic signals.

Reference


