A tunable dual-band bandpass filter using asymmetrical varactor-loaded HWRs and defected ground structure

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Abstract: In this paper, a tunable dual-band bandpass filter using asymmetrical varactor-loaded half-wavelength resonators (HWR) and defected ground structure (DGS) is proposed. First, varactors are added at the end of the conventional HWRs to change their resonant frequencies. And to determine the bandwidth of the passbands, the coupling coefficients are calculated to the requirements based on the theoretical analyses. However, the isolation will deteriorate if the passbands are tuned close to each other. Then in order to solve this problem, a pair of circular DGS is introduced at the ground plane of the filter. This structure can prevent electromagnetic energy from propagating at some certain frequency point and if it is designed between the passbands, the isolation will be improved. In our design, the proposed dual-band bandpass filter using varactor-loaded HWRs and DGS is simulated and fabricated. The simulated results and measured results are in good agreement and the proposed filter can be applied in microwave circuits and communication systems.

Keywords: tunable, filter, dual-band
Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

Tunable bandpass filters are widely used in modern wideband communication systems and lots of researches have focused on their properties and applications [1, 2, 3]. In order to realize tunability, devices with changeable capacitance or inductance should be added in the circuit. In most of the cases, varactors have been applied in tunable filters due to their quick tuning speed, compact size and reliability [4, 5]. Changing the voltage applied on the varactor leads to the increase or decrease of its capacitance, which causes the resonant frequency shift. This method has been proved to be feasible and applicable in mono-passband bandpass filters.

As for the tunable multi-passband bandpass filters, the isolation is an important to specification to consider. And in order to improve isolation, transmission zeros (TZ) should be introduced between two adjacent passbands. Some previous literatures [6, 7] used resonators with self-resonant TZs and have achieved great isolation.

Defected ground structure (DGS) is similar to the “photonic bandgap (PBG) structure” in the microwave region that prohibits the propagation of certain bands of frequencies [8, 9]. This structure is simply applied by etching the ground plane of the microstrip to periodic or non-periodic patterns [10] and has been used by many researchers to increase the output power and efficiency of power amplifiers, improve the isolations between the passbands of the muti-bandpass filters and reduce unwanted harmonics in the mixer applications.

In this paper, a tunable dual-band bandpass filter using asymmetric varactor-loaded HWRs and DGS is proposed in this paper. The TZ produced by DGS is much more flexible in the process of designing and optimization since DGS is on the ground plane of the microstrip line and is an independent structure to HWRs. It will be shown in the simulated and measured results that the two different structures can work in great harmony to achieve good performance and the proposed method is a feasible way to design tunable multi-band bandpass filters.

2 Theory and analysis

The basic physical structure of the varactor-loaded HWR is shown in Fig. 1(a). A varactor is loaded at one end of a conventional HWR and the other end remains

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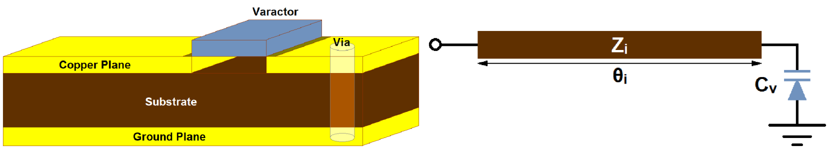
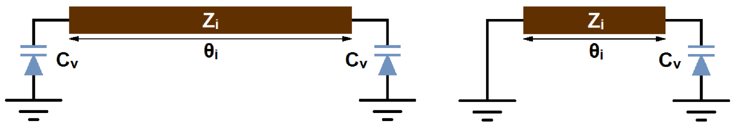
open. Its equivalent circuit is shown in Fig. 1(b). In most of the time, conventional half-wavelength resonators (shown in Fig. 2(a)) and quarter-wavelength resonators (shown in Fig. 2(b)) with varactors are often employed in the tunable filter applications. For comparison, let's suppose all these three types of resonators have the same fundamental resonant frequency under the same bias voltage, and all the microstrips and varactors are of the same type. At the resonant frequency, the half-wavelength resonator is equivalent to the quarter-wavelength resonator due to their patterns of the electromagnetic wave distribution. Since the resonator in Fig. 1(b) has only one varactor and the quality factor of a microstrip is usually higher than that of a varactor, the asymmetric varactor-loaded HWR has the higher quality factor than the resonators in Fig. 2. For demonstration, the quality factors are simulated at the frequency of 1 GHz, and the quality factors of the resonators in Fig. 1(b), 2(a) and 2(b) are 65, 52 and 54, respectively. It is essential to take quality factors into consideration in filter designs because high quality factors can improve the performance of the designed filters.



(a) (b)

Fig. 1. The physical structure (a) and the equivalent circuit (b) of the asymmetric varactor-loaded HWR



(a) (b)

Fig. 2. (a) Conventional half-wavelength resonator with two varactors and (b) conventional quarter-wavelength resonator with one varactor

In order to obtain the coupling coefficients, the resonant frequencies at two different coupling lengths should firstly be obtained. The coupling structure of the upper resonators in the proposed filter is shown in Fig. 3(a). The resonators are coupled to each other with the coupling length ΔL. If the parasitic effects are ignored, the varactor can be regarded as a segment of a microstrip line with an open end. And the equivalent microstrip line becomes longer with the increase of the capacitance of the varactor, and its corresponding resonant frequency becomes lower.

In order to achieve another tunable passband, a stub-loaded resonator with one varactor is added at the other side of the feed lines (shown in Fig. 3(b)). At its resonant frequency, if the proximity effects are ignored, the equivalent circuit can be described as a T microstrip line loaded with a changeable capacitor C_v.

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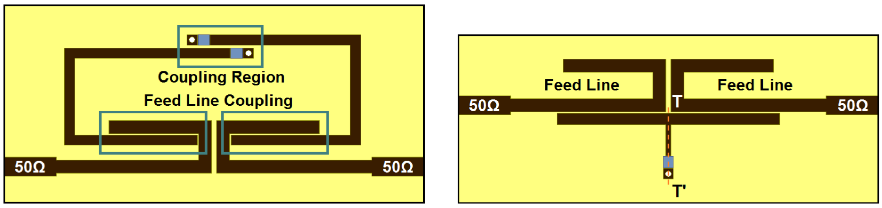
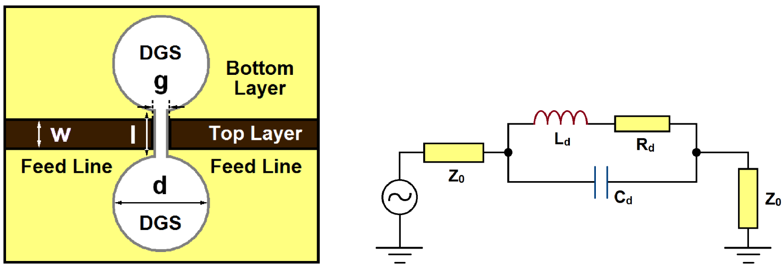


(a) (b)

Fig. 3. (a) The coupling structure of the upper resonators and (b) the topology of the lower resonator

The DGS is developed based on the photonic bandgap (PBG) research. The PBG is a periodic or nonperiodic structure that can provide the rejection of certain frequency points or bands in the optical frequency region. The DGS can be regarded as the PBG in the microwave and millimeter wave region due to their same working mechanism. In real application, the dumbbell DGS (shown in Fig. 4(a)) is often utilized because its structure is simple and the rejection level is excellent. The equivalent circuit is shown in Fig. 4(b). In our design, in order to create an extra transmission zero and to increase the out-of-band rejection between the two passbands, the dumbbell DGS is added below the feed lines.



(a) (b)

Fig. 4. (a) The structure of the dumbbell DGS and (b) the equivalent circuit of the DGS

3 Simulation and measurement

The topology of the filter is shown in Fig. 5(a). The filter consists of a pair of asymmetrical varactor-loaded HWRs on the upper side and a T shaped resonator loaded with a varactor on the lower side. A dumbbell DGS is etched at the bottom of the ground plane. The resonators are coupled with the input and output feed lines with the impedance of 50 Ω. The fabricated filter is shown in Fig. 5(b). It is

Table I. The values of the parameters in the filter (in mm)

parameter	value	parameter	value	parameter	value	parameter	value
w_0	1.5	w_1	1.0	w_2	0.8	w_3	0.9
w_4	0.4	w_5	0.8	l_1	22.0	l_2	29.1
l_3	17.2	l_4	2.4	l_5	17.1	l_6	1.6
s_0	0.4	s_1	0.1	s_2	0.2	s_3	0.1
s_4	1.0	d_1	0.5	d_2	3.6		

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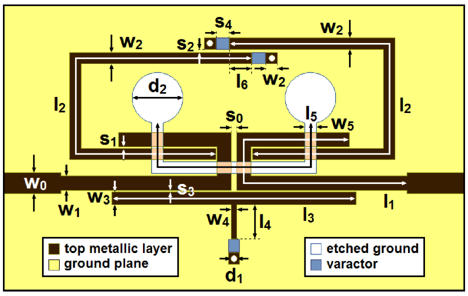
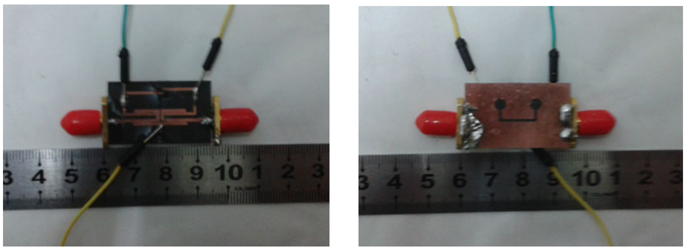


(a)

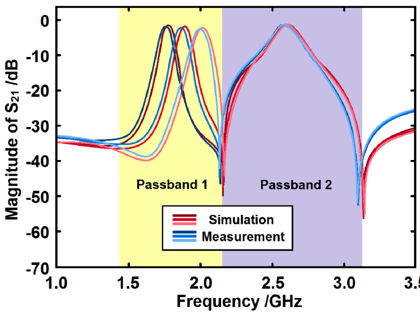


(b)

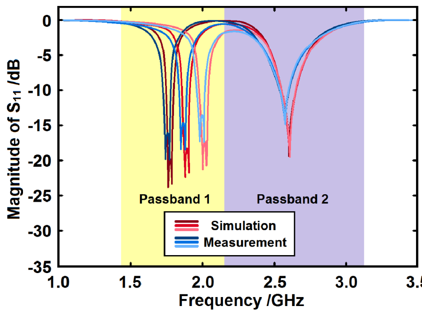
Fig. 5. (a) The topology of the proposed filter (b) The photograph of the fabricated filter

fabricated on the substrate Rogers 5880 with the relative dielectric constant $\varepsilon_r = 2.2$, the loss tangent $\delta = 0.0009$ and the thickness $h = 0.508$ mm. The silicon varactors used in the filter are 1sv277 of Toshiba. The values of the parameters of the filter are listed in Table I.

The simulated and measured results of tuning the first passband is shown in Fig. 6. The simulated tuning range is from 1.77 GHz to 2.08 GHz with the insertion loss from 1.49 dB to 2.38 dB. The transmission zero produced by the DGS has the rejection level over 50 dB. The simulated absolute 3 dB bandwidth of the first passband is about 82 MHz and keeps almost constant. It can also be noted that the tuning of the first passband does not have much influence of the second passband due to the parallel structure of the filter. The measured results in the tuning of the first passband are in good agreement with the simulated ones.



(a)



(b)

Fig. 6. Tuning of the first passband (a) S_{21} and (b) S_{11}

The simulated and measured results of tuning the second passband is shown in Fig. 7. The simulated tuning range is from 2.60 GHz to 2.85 GHz with the insertion

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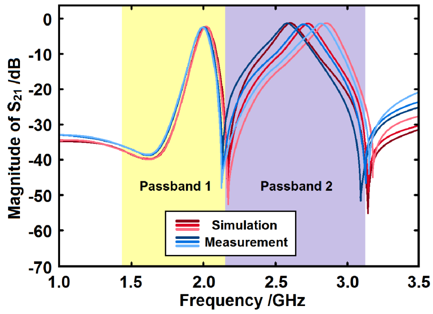
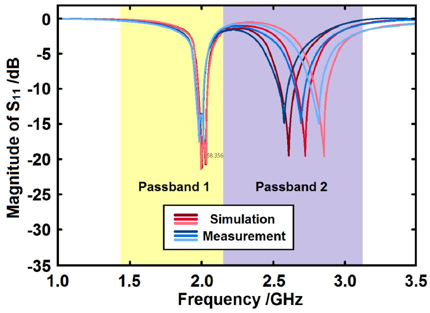


(a)



(b)

Fig. 7. Tuning of the second passband (a) S_{21} and (b) S_{11}

loss around 1.31 dB. The insertion loss of the second passband is lower that the first passband because the distance between the tuning range and the TZ created by the DGS is farther than that of the first passband. The simulated absolute 3 dB bandwidth slightly decreases from 158 MHz to 142 MHz. Another TZ is created at 3.14 GHz. This TZ is produced by the odd mode of the resonator and is determined by the length of l_4 (in Fig. 5). At this resonant mode, the voltage of the symmetrical plane of the resonator is zero, so its resonant frequency is independent to l_4, and therefore independent to the capacitance of the varactor. Since the filter utilizes the parallel structure, the tuning of the second passbands does not have much influence upon the first passband. The simulated results in the tuning of the second passband are also in good agreement with the measured ones.

4 Conclusion

In this paper, a tunable dual-band bandpass filter using asymmetrical varactor-loaded HWRs and DGS is proposed. The resonant frequencies of the passbands change with the increase or decrease of the capacitance of the varactors. The DGS is added to increase the isolation between the passbands. Good agreement has been observed and the proposed filter can be applied in modern microwave circuits and communication systems.

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