Novel Bandwidth-Agile Bandpass Filter using Defected Ground Structure

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Abstract ─ A novel microstrip bandpass filter (BPF) with tunable passband width using defected ground structure (DGS) is proposed. In this DGS, a pair of slotted radial stubs that can be equivalent to a capacitor and an inductor in parallel are incorporated to realize an attenuation pole (AP) in the higher stopband of the proposed BPF without increasing the circuit size, and the equivalent circuit of the BPF is also given. By properly adding varactor diodes into the slotted stubs to tune the equivalent capacitance of the stubs, the corresponding AP can be shifted, and then the passband width of the BPF can be accordingly tuned, leading to a bandwidth-agile BPF.

Index Terms – Bandpass filter (BPF), defected ground structure (DGS), and tunable filter.

I. INTRODUCTION

Bandpass filter (BPF) [1-10] is an essential component in various microwave and wireless communication systems. However, a single filter may not be able to satisfy the demands for all operating bands. It is well known that the frequency spectrum is valuable and limited, and it is always being used for several purposes. Therefore, electronically reconfigurable or tunable microwave filters are drawing more attention for research and development because of their significance in improving the capability of current and future design. Since microstrip filters can easily promote this kind of integration with a small size, there has been increasing interest in developing tunable or reconfigurable filters based on microstrip line. So far, much work in this field has been conducted [11-18], and most of them employ the varactor diode to tune center frequency [11-15] and the passband width [16-18] due to its high tuning speed (in nanoseconds) and low cost. However, the varactors are all loaded onto microstrip line structure in these bandwidth-agile filters.

Defected ground structure (DGS) [19-23], which is etched from the ground plane of the transmission line, is broadly applied to the designs of microwave circuits owing to its numerous advantages, such as band-gap feature, slow-wave effect and so on. For instance, in the past few years, the DGS is used to design various microwave filters [19-22], showing attractive performance.

In this paper, a novel DGS bandwidth-agile BPF is proposed. By incorporating a pair of slotted radial stubs in the original DGS in [20], the attenuation pole (AP) in the higher stopband can be obtained. Accordingly, the varactor diodes are added in the slotted stubs to tune the AP, and then vary the passband width of the proposed BPF. Finally, a demonstration BPF is designed and fabricated. The measured results shows good agreement with the theoretical predictions.

II. PROPOSED BPF DESIGN

Figure 1 shows the layout of the proposed DGS BPF. A pair of slotted radial stubs are added in the middle of the original DGS in [20] without increasing the overall DGS size, and there is a slit on the 50 Ω microstrip line. The substrate material utilized in this structure is FR4 with thickness of 1mm and dielectric constant of 4.6. The operation frequency of the proposed BPF is determined by the DGS area ($a_1 \times a_2$), and the larger the area, the

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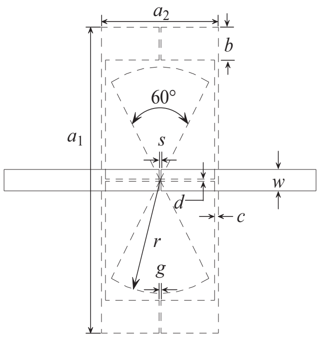
lower the operation frequency, as shown in Fig. 2. Benefiting the quasi-elliptic function of the DGS without the slotted radial stubs [20], an AP in the lower stopband can be obtained, as shown in Fig. 2.



Parameters	a_1	a_2	b	c g		d	s	w
Value (mm)	27	12	2.9	0.4	0.2	0.2	0.2	1.884

Fig. 1. Layout of the proposed DGS BPF; (solid line is layout of microstrip line and dashed line is layout of the DGS).

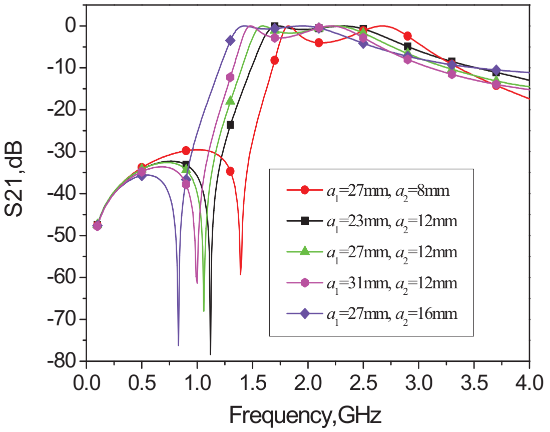


Fig. 2. Simulated results of the proposed BPF with tunable operation frequency (the DGS without the slotted radial stubs).

The slotted radial stubs in the middle of the DGS are similar to the dumb-bell slot in [20] and the equivalent circuit for the proposed entire DGS filter is shown in Fig. 3. The slotted radial stubs, which can be equivalent to a capacitor C_2 and inductor L_1 in parallel, is used to realize an AP in the higher stopband to improve the attenuation skirt, as shown in Fig. 4. As the radius r of the radial stub is increased, the AP in the higher stopband is shifted down. As a result, the higher passband edge is also moved down, while the lower passband edge is fixed, resulting in the decrease of the passband width. Therefore, it is predictable that the passband width can be controlled by adding the varactor diodes in the radial stubs to tune the value of C_2 in Fig. 3.

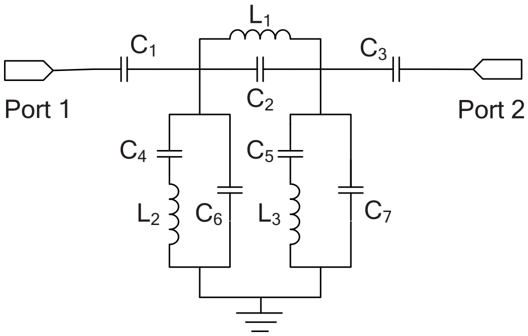


Fig. 3. Equivalent circuit model for the BPF in Fig. 1.

Figure 5 shows the sketch of the implemented BPF with tunable bandwidth, while Fig. 6 shows the fabricated BPF for demonstrating the aforementioned prediction. In the slotted radial stub, a pair of arced metal strips with width w_1 is used for loading the varactor diodes (Var). By tuning the reversed bias voltage V_b of the diodes, the AP in the higher stopband changed, resulting in tunable passband width. In Fig. 5, the dimensions r_1, r_2, and w_1 are fixed at 10mm, 8mm, and 1mm, respectively, while other dimensions are shown in Fig. 1. The employed varactor diodes are JDV2S71E from Toshiba in this design, and its SPICE model is shown in Fig. 7.

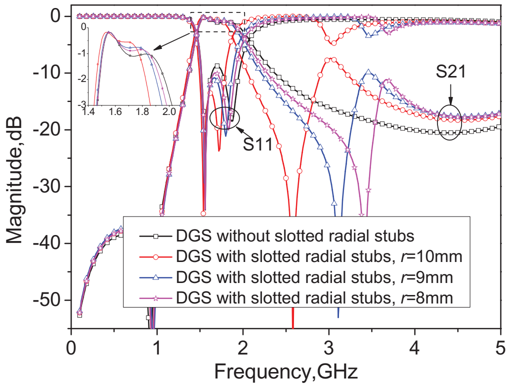


Fig. 4. Simulated results of the DGS BPF with and without the slotted radial stubs.

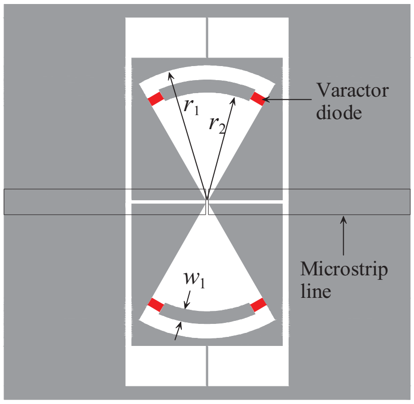
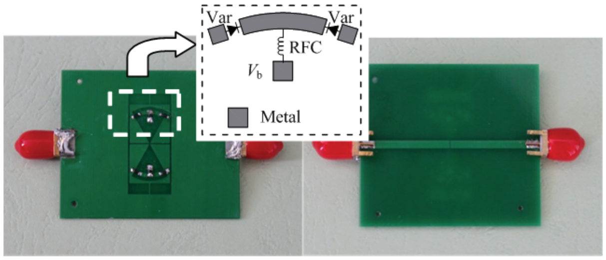


Fig. 5. Sketch of the implemented DGS bandwidth-agile BPF (the biasing circuit of the varactor diodes is not given).



(a) (b)

Fig. 6. Photograph of the fabricated circuit; (a) bottom view and (b) top view.

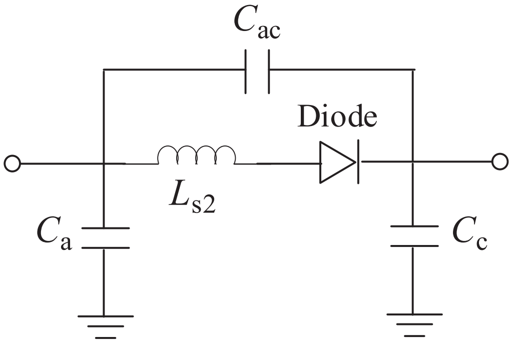
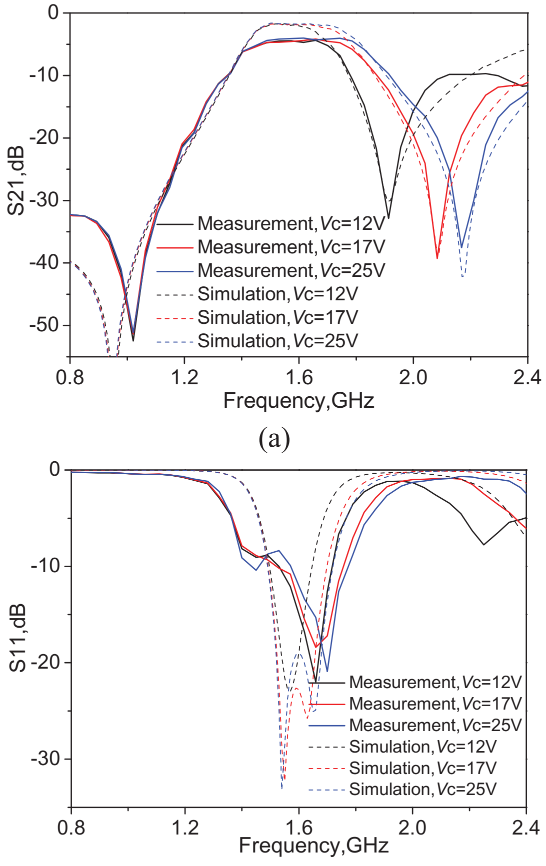


Fig. 7. SPICE model of the varactor diode JDV2S71E.

III. RESULTS

The simulation and measurement are carried out by Ansoft HFSS and Agilent E5071C network analyzer. Figure 8 shows the simulated and measured results of the proposed DGS BPF with tunable bandwidth, showing good agreement. Table I summarizes the measured performance of the BPF. As V_b reduces from 25 V to 12 V, i.e., the capacitance of the varactor diodes increases; the AP in the higher stopband is shifted down from 2.168 GHz to 1.913 GHz, as shown in Fig. 8. The higher passband edge also moved down from 1.807 GHz to 1.701 GHz while the lower passband edge is fixed at 1.446 GHz, resulting in the decrease of the 1-dB passband width from 361 MHz to 255 MHz. Figure 9 shows the nonlinear performance of the proposed BPF in the case of two-tone test with 500 KHz frequency spacing. The measured input 3rd inter modulation point (IIP$_3$) keeps almost the same and is about 24 dBm as V_b varies, as shown in Table II. As can be seen from Fig. 8, some discrepancy between the simulated and measured results can be observed, especially for the insertion losses of the passband. This can be attributed to the resistance (1 Ω for each diode) of the varactor diode and the unexpected tolerance of fabrication.



(a)

(b)

Fig. 8. Simulated and measured results of the proposed bandwidth-agile BPF; (a) S21 and (b) S11.

Table I. Measured performance of the proposed bandwidth-agile BPF against V_b.

V_b(V)	12	17	25
1-dB Bandwidth (MHz)	255	318	361
1-dB Lower Passband Edge (GHz)	1.446	1.446	1.446
1-dB Higher Passband Edge (GHz)	1.701	1.764	1.807
Minimum Insertion Loss (dB)	4.35	4.18	4.0

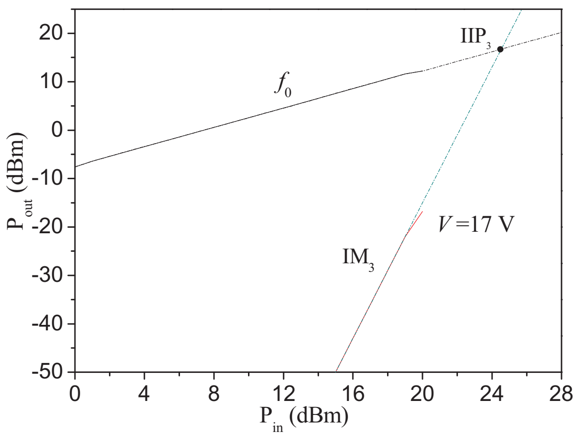


Fig. 9. Measured IIP$_3$ at 1.5 GHz.

Table II. Measured IIP$_3$ in the case of different V_b.

V_b (V)	*IIP_3 (dBm)*
12	23
17	24.5
25	24

VI. CONCLUSION

In this letter, a novel DGS pattern with a pair of slotted radial stubs has been developed for the design of mircrostrip bandwidth-agile BPF. The radial stubs in the middle of the proposed DGS are used to realize an AP in the higher stopband. By properly adding the varactor diodes in the radial stubs, the AP can be varied, leading to tunable passband width. Equivalent circuit for the proposed bandwidth-agile filter has been given to provide detailed design process and explain the transmission response for the bandwidth-agile bandpass filter. The measured results show good agreement with the simulated data. These would make the proposed DGS bandwidth-agile BPF useful for modern wireless communication systems.

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