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A novel miniaturized quarter mode substrate integrate waveguide tunable filter

Kaiwei Zuo, Yongzhong Zhu[a], Wenxuan Xie, and Le Li

Engineering University of Chinese People Armed Police, Xi'an, Shaanxi 710086, China

a) *bsbs1980@sina.com*

Abstract: A novel quarter mode substrate integrated waveguide (QMSIW) resonator is proposed, based on which a plane cascade QMSIW tunable filter is designed. Miniaturization of the filter is achieved, whose area is only $0.51\lambda_g \times 0.34\lambda_g$. The filter works at 1.2 GHz with the tunable range of 31.6% and the fabricated insertion loss less than 1.9 dB and return loss greater than 15 dB, respectively.

Keywords: substrate integrated waveguide (SIW), tunable filter, quarter-mode

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

The substrate integrate waveguide (SIW), as a new type of waveguide structure, is favored by microwave researchers due to its small size and low loss. SIW technology is widely used in tunable filter design progress. The literature [1, 2, 3, 4, 5, 6, 7, 8] describes the application of different tuning techniques in SIW tunable cavity design. In [1, 2], the switch is loaded to the tuning column directly. In [3, 4, 5, 6], the tuning column is loaded by diodes. In [7], the embedded ferrite material is applied to the design of the tunable cavity. In [8], a new structure that opens ring gap on the surface is proposed for realization of the tunable cavity. A variety of tuning methods are proposed to make SIW tunable filter's center frequency and bandwidth adjustable. In the research of SIW filter miniaturization, the literature [9, 10, 11, 12] propose different methods of SIW miniaturization. However the miniaturization of SIW resonator is seldom studied in current tunable filters, so the study of miniaturization SIW tunable filter is of great significance.

In this paper, the design of tunable resonator is carried out by using RF-MEMS switch to load the tuning column directly and QMSIW is used to achieve miniaturization, after that a plane cascade two-order tunable QMSIW filter is designed and its area is only $0.51\lambda_g \times 0.34\lambda_g$. The filter works at 1.2 GHz with the tunable range of 31.6%, and the fabricated insertion loss and return loss are $-1.7\sim-3.1$ dB and -15 dB.

2 Miniaturized tunable filter

2.1 QMSIW resonator discussion

The QMSIW works in the same way as the full-mode SIW cavity at TE101 mode. The formula for the resonant frequency is determined by:

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$$f_{101}^{QMSIW} = \frac{c}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{1}{2a_{eff}^{QMSIW}}\right)^2 + \left(\frac{1}{2b_{eff}^{QMSIW}}\right)^2}$$

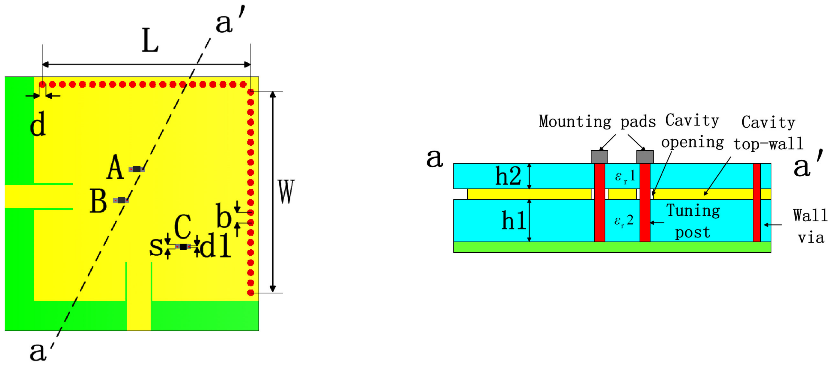
$$a_{eff}^{QMSIW} = \frac{1}{2} a_{eff}^{SIW} + \Delta a$$

$$b_{eff}^{QMSIW} = \frac{1}{2} b_{eff}^{SIW} + \Delta b \qquad (1)$$

$$a_{eff}^{SIW} = a_0 - \frac{d^2}{0.95l}$$

$$b_{eff}^{SIW} = b_0 - \frac{d^2}{0.95l}$$

Where c is the speed of light in the vacuum, d is the diameter of the metal via, l is the side length of the cavity, μ_r and ε_r are the relative permeability and relative permittivity of the dielectric substrate. a_{eff}^{SIW} and b_{eff}^{SIW} are the equivalent dimensions of the full-mode SIW, a_0 and b_0 are the actual dimensions of the full-mode SIW, Δa and Δb are the dimensional error due to factors such as open boundary and feeding structure.



(a) Top view (b) Sectional view

Fig. 1. Top and sectional view of the tunable QMSIW resonator

Fig. 1(a)(b) are the top view and side sectional view of the resonator, respectively. The bottom dielectric substrate used in the resonator is Taconic TLT(tm) ($\varepsilon_r = 2.55$, $\tan\delta = 0.0006$) and its thickness h1 = 1 mm. The top dielectric substrate used in the resonator is FR4_epoxy ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) and its thickness h2 = 0.2 mm. The structure consists of two layers of substrate and three layers of metal. The feed uses a microstrip line through a concave transition to the QMSIW cavity. The tuning column's diameter d1 = 0.8 mm and the square hole in the middle metal layer whose square side s = 1.2 mm, so that the tuning column is not short with the middle metal layer. The specific dimensions of the QMSIW cavity are shown in Table I. As shown in Fig. 1(a), the tuning columns are loaded in three positions A, B, C, and the coordinates were given in Table II.

In Fig. 2, when observing the vector magnetic field distribution of the upper metal surface when loading and unloading, it can be seen that the vector magnetic field is obviously disturbed after the tuning column is loaded into the cavity. The RF-MEMS switch is used to make the QMSIW resonator a tunable cavity and to

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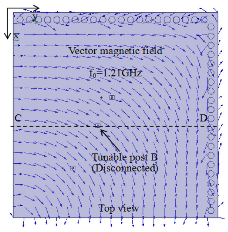
Table I. Specific parameters of the QMSIW resonator (Unit: mm)

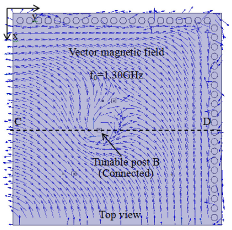
L	W	b	d
54	54	2.6	1.8

Table II. The position of the tuning-column in the QMSIW tunable resonator (Unit: mm)

Post	x	y
A	22	26
B	30	22
C	42	34



(a) unloading



(b) loading

Fig. 2. Disturbance of the magnetic field distribution

prepare for the design of tunable filter. The use of RF-MEMS switch has a specific introduction in literature [13].

As shown in Fig. 3, the QMSIW tunable resonator's frequency range is 1.21–1.5 GHz, and the variation of its unloaded Q value is 309–479. Table III gives the number of states corresponding to the combination of tuning column access, in which '0' represents that the switch is off, while '1' represents short-circuited.

Table III. The position of the tuning-column in the QMSIW tunable resonator (Unit: mm)

State	ABC	State	ABC
1	000	5	001
2	100	6	101
3	010	7	011
4	110	8	111

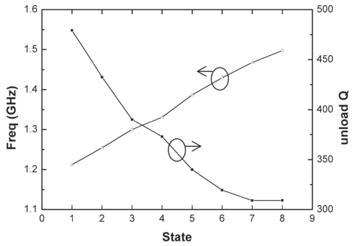


Fig. 3. The range of frequency and unloaded Q value in the QMSIW resonator

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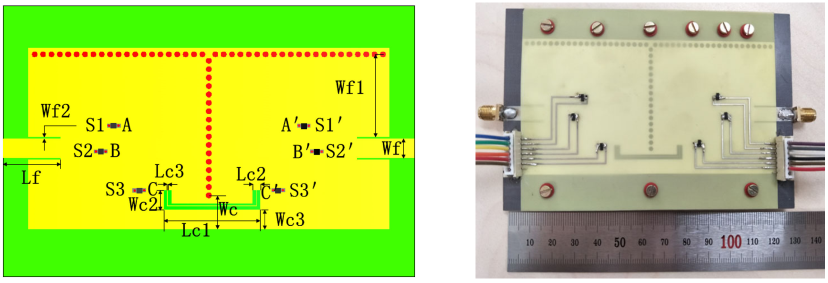
2.2 Miniaturized QMSIW tunable filter

Based on the QMSIW tunable resonator, a plane cascaded two-order QMSIW tunable filter is designed. In Fig. 4, two QMSIW resonators are implemented in a back-to-back manner by cascading the common metal vias, and the coupling between the two resonators is achieved by removing the common metal vias to form the inductive windows and loading the U-shaped coplanar waveguides. Fig. 4(a) is the top view of the QMSIW tunable filter and the related structure size parameters are in Table IV. Fig. 4(b) is the picture of fabricated filter.



(a) Top view (b) QMSIW tunable filter

Fig. 4. The top view of QMSIW tunable filter

Table IV. The parameters of the plane cascade two-order QMSIW tunable filter (Unit: mm)

Lc1	Lc2	Lc3	Lf	Wc
30	2.4	0.2	17.8	10.4
Wc2	Wc3	Wf	Wf1	Wf2
6	6	6	25.5	0.5

The center frequency of the filter can be adjusted by simultaneously loading the tuning column in both resonators. Three sets of tuning columns are loaded in the symmetrical position of the cavity. Each set of tuning columns has a set of switches to control whether they are accessed or not.

3 Fabrication and measurement

Fig. 5(a) and (b) show the simulated results of the filter, the center frequency is 1.05–1.43 GHz, while the interval of the frequency is about 100 MHz. The variation of insertion loss ranges from −1.5 dB to −3.1 dB, and the return loss is less than −15 dB. Fig. 5(c) and (d) show the measured results of the filter. The center frequency is in good agreement with the simulation results.

When the tuning column is loaded in the cavity, the disturbance of the column to the cavity is almost the same as that of the cavity field. That is, the closer the tuning column is to the metalized vias, the smaller the center frequency of the cavity is. In the process of designing a tunable filter with QMSIW, it is necessary to achieve control of the degree of the disturbance.

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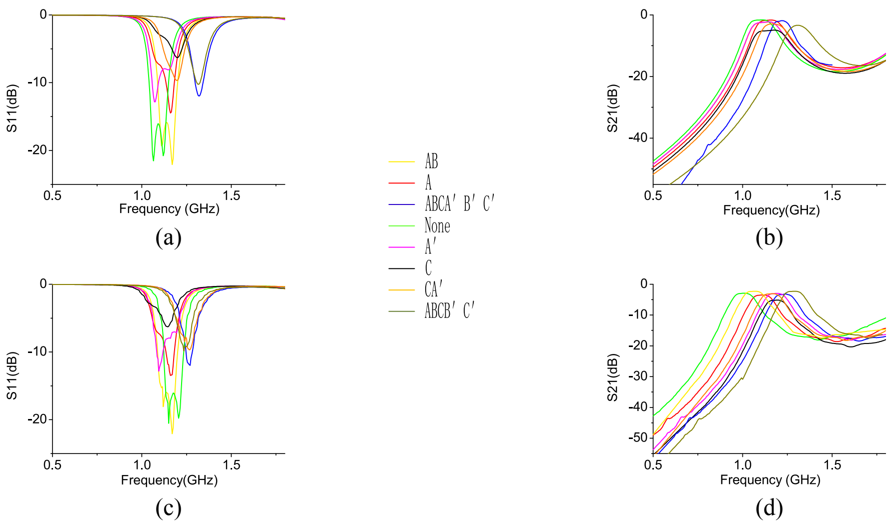

Fig. 5. The simulated and measured results of the filter

Table V. Parameters comparison

Works	CF (GHz)	FTR (%)	Q
[1]	1.73	25	221–225
[2]	1.4	28	93–132
[5]	2.76	2.8	160
[8]	0.9	66	84–206
This	1.17	31.6	309–479

Table VI. Size reduction ratio comparison

Works	Size reduction ratio
[10]	48%–50%
[11]	26%
This	25%

4 Conclusion

Table V compares some parameters of tunable filters in this letter with those literatures has been reported.

Table VI compares the size of the proposed tunable filter with reported ones.

A new type of QMSIW resonator is proposed, and the performance of resonant cavity is analyzed. Then a plane cascade two-order filter is designed by using QMSIW resonator. The measured results show a good agreement with simulation and a favorable performance. Besides, miniaturization is better achieved by the proposed filter, which brings a certain practical value.

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