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Spurious Suppressed Substrate Integrated Waveguide Bandpass Filter Using Stepped-Impedance Resonator

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Abstract

A spurious suppressed bandpass filter is proposed and discussed using the stepped impedance resonator(SIR) on a substrate-integrated waveguide(SIW) structure with a double-layer substrate. The second resonance of the fundamental TE_{10} mode can be controlled by adjusting the electrical length and impedance ratio of each SIR. The spurious suppressed SIW bandpass filter shows the measurement results of the insertion loss of 3.98 dB and return loss of less than 11.58 dB at the center frequency of 12 GHz. Also, the second spurious frequency is improved to about $1.5f_0$ compared with $1.33f_0$.

Key words : Substrate-Integrated Waveguide(SIW), Stepped Impedance Resonator(SIR), Bandpass Filter, Spurious, Double Layer.

Ⅰ. Introduction

The integrated planar circuit technique has been considered as a reliable candidate for low-cost mass production of millimeter-wave circuits and systems. The microstrip structures have advantages such as high integration, low cost, simple fabrication and a low Q factor. The waveguide as a traditional transmission-line is used in many communication systems because it can be made for high-Q devices. However, the waveguide is very difficult to integrate with other circuit elements. With respect to more facile integration, substrate-integrated waveguide(SIW) structures have been suggested over the past decade[1]~[5]. The SIW structures can be approximated as the rectangular waveguide using a common dielectric substrate with metalized posts. Also, for the application of the SIW structures, several transitions have been proposed to excite the waveguide[5]~[7]. In all these transition structures, the planar circuits, such as a microstrip line or coplanar waveguide, and the rectangular waveguide are built onto the same substrate, and the transition is formed with simple matching geometry between both structures.

The demand for microwave filters with better performance and low production cost is increasing in the fast-growing wireless communications market. In particular, when out-of-band rejections are concerned, distributed microwave filters usually present unwanted spurious transmission whose level might be unsatisfactory in some instances. In order to recover the required level of rejection, the stepped impedance resonator(SIR) is employed within the filter structure, leading to low cost, and easy control for the spurious responses.

In this paper, the SIW filter is suggested in order to replace the SIR with a cavity resonator. In addition, a spurious suppressed SIW filter using SIR structure is designed and then discussed for its microwave characteristics.

Ⅱ. Waveguide Properties of SIR

All resonant frequencies of a uniform impedance resonator(UIR) are determined by the electrical length of the resonator itself, which represents the only degree of freedom of the structure. In other words, the fundamental resonant frequency, f_0 is controlled by the electrical length of the resonator and thus all the higher resonant frequencies are fixed correspondingly.

In this paper, the focused will be on the ability to control the second resonance. For this purpose, the symmetrical SIR shown in Fig. 1 is analyzed as follows. From the figure, the input impedance and admittance are defined as Z_i and Y_i, respectively.

When ignoring the influence of step discontinuity and edge capacitance at the open end, Z_i can be expressed as

$$Z_i = jZ_2 \frac{Z_1 \tan\theta_1 + Z_2 \tan\theta_2}{Z_2 - Z_1 \tan\theta_1 \tan\theta_2} \tag{1}$$

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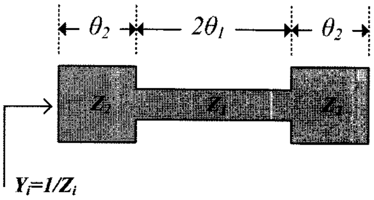

Fig. 1. Structure of the stepped-impedance resonator(SIR).

Let $Y_i=0$, and the parallel resonance condition can then obtained as

$$\tan\theta_1 \tan\theta_2 = \frac{Z_2}{Z_1} = R_Z , \qquad (2)$$

where R_z is the ratio between two impedances of each section[8]. From equation (2), we understand that the resonance condition of the SIR is determined by the electrical length of each section, θ_1, θ_2, and the impedance ratio, R_z. In the case of a conventional UIR, this condition is determined solely by transmission-line length. However, for SIR, both the electrical length and the impedance ratio must be taken into account. This gives the SIR an extra degree of freedom in design as compared to the UIR.

The resonant frequencies depend on the electrical length ratio, $\alpha = \theta_2/(\theta_1+\theta_2)$ and the impedance ratio, R_z. Taking the R_z as 1, the resonant frequencies have been normalized with respect to the fundamental frequency. If the R_z is larger than 1, the total electrical length is longer is shorter than its normalized value, and if the R_z is smaller than 1, the total electrical length is shorter than its normalized value. So, if the value of R_z is determined, which means that the impedance elements, Z_1 and Z_2 are correspondingly determined as a ratio, there are two undetermined electrical length parameters, θ_1 and θ_2. Then, either θ_1 or θ_2 is determined through the relationship between the resonant electrical length of the SIR, θ_{total} and α for R_Z=0.25, 0.4, 1, 2, and 4 as a parameter as shown in Fig. 2[8]. Here, θ_{total} is given by$(\theta_1+\theta_2)/\pi$, whose solutions are dependent on the choice of α and R_Z.

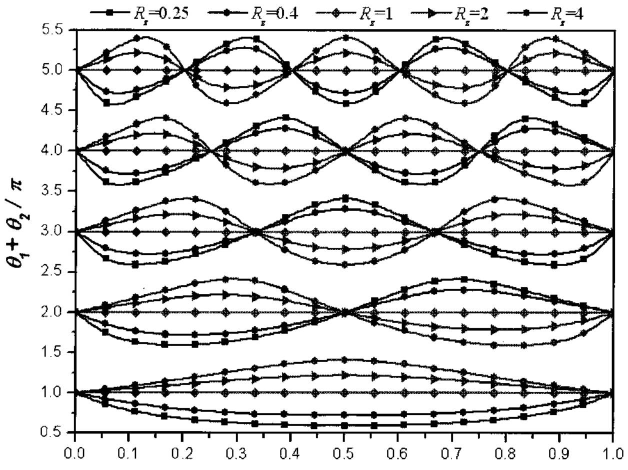

Fig. 2. Normalized resonant frequencies for the SIR.

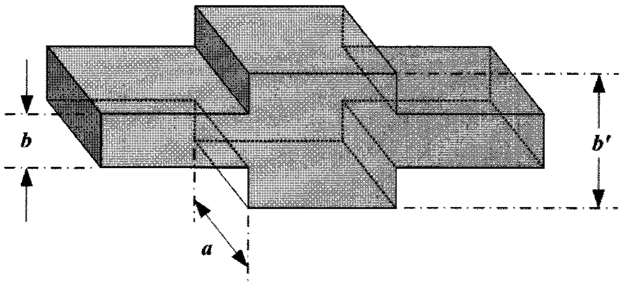

Fig. 3. Rectangular waveguide E-plane SIR($Z_2/Z_1=b'/b$).

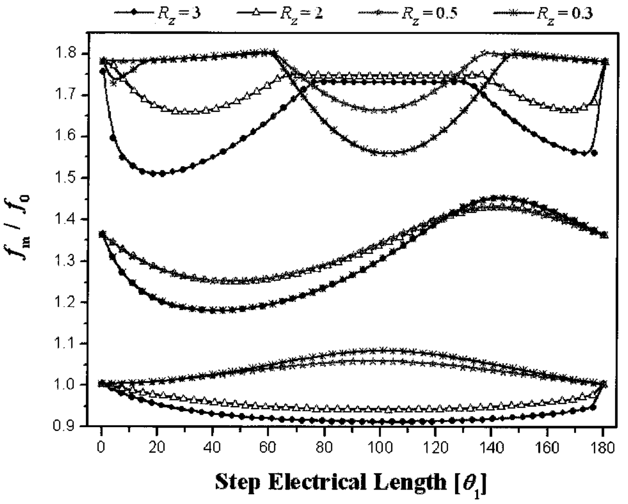

Fig. 4. Relationship between impedance ratio and normalized spurious resonance frequencies of SIW cavity.

As far as rectangular waveguide resonators are concerned, change of impedance can be realized by E-plane or H-plane steps as shown in Fig. 3. For an H-plane SIR on a waveguide, the cut-off frequencies of the propagation at the center frequency of the filter, the ratio between the two dimensions(b and b'), is limited. As a consequence, the impedance ratio is also restricted to a limited range. Indeed, for an E-plane SIR on a waveguide, the constraint does not hold and a wider range of impedance is achievable. Hence, the interest will be focused on an E-plane SIR on a waveguide. The relationship between the impedance ratio and normalized spurious resonance frequencies of the SIW cavity can be obtained by simulation using Ansoft HFSS software. These results can be designed with a fixed fundamental frequency and various higher modes frequencies by choosing different combinations of θ_1 and R_z as shown in Fig. 4.

Ⅲ. Design of Spurious Suppressed SIW Filters Using SIR

An inductive windows waveguide filter has a dual relationship with a gap-coupled filter that has a half-wavelength resonator. For the gap-coupled filter, J-inverter is generally used while for the inductive window waveguide filter, the K-inverter is adopted[5].

That is, the inductive windows waveguide filter is composed of transmission-line resonators which are approximately a half-wavelength long at the mid-band frequency, and K-inverters, which can be presented by shunt inductive coupling. Fig. 5 shows a structure of conventional inductive-windows waveguide filters. In the inductive windows waveguide filter, an inductive window is corresponds to the equivalent shunt inductance, and its reactance can be decided by [9].

$$\frac{X}{Z_0} \approx \frac{2a}{\lambda_g} \times \frac{\alpha^2}{A+B}$$

$$A=0.429(1-1.56\,\alpha^2)(1-6.75\,\alpha^2 Q)$$

$$B=0.571(1-0.58\,\alpha^2)\sqrt{1-(2a'/\lambda)^2} \tag{3}$$

$$Q=1-\sqrt{1-\left(\frac{2a}{3\lambda}\right)^2},\quad \alpha=\frac{a'}{a}\ . \tag{4}$$

where a is the horizontal length of the waveguide and a' is the length of an inductive window. Table 1 shows parameters of the SIW filters. The stop-band performance of the SIW filters can be improved by employing the SIR structure ratio in the SIW cavity, where the multi-layer substrates are needed. In this paper, for the spurious suppressed inductive windows waveguide filter, two-layers are used with the impedance ratio, R_Z as $2(R_Z=2)$, as shown in Fig. 6.

The spurious suppressed SIW bandpass filter is designed for the 3rd-first-order Chebyschev prototype with a ripple of 0.01 dB and fractional bandwidth of 3 %. The size of the filter with back-to-back transition between the SIW and microstrip structure is 6.8×24.5 mm^2 as shown in Fig. 7. For each layer, the RT-duroid substrate is used with a dielectric constant of 10.2 and a height of 0.635 mm.

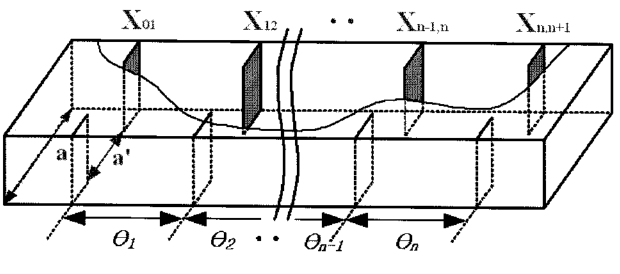

Fig. 5. Structure of the inductive windows waveguide filters.

Table 1. Parameters of the SIW filter.

Prototype		K inverter		Admittance		Window gap [mm]	
g_1	0.629	K_{01}/Z_0	0.361	X_{01}/Z_0	0.415	gap_1	2.75
g_2	0.970	K_{12}/Z_0	0.105	X_{12}/Z_0	0.106	gap_2	1.67
g_3	0.629	K_{23}/Z_0	0.105	X_{23}/Z_0	0.106	gap_3	1.67
g_4	1	K_{34}/Z_0	0.361	X_{34}/Z_0	0.415	gap_4	2.75

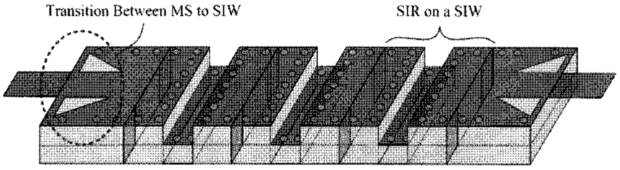

Fig. 6. Structure of the spurious suppressed SIW bandpass with SIR.

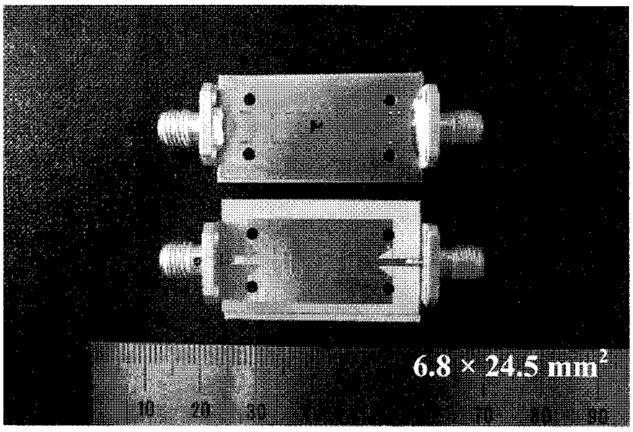

Fig. 7. Photograph of the spurious suppressed SIW bandpass filter with SIR.

Fig. 8 shows the results of the simulation of the spurious suppressed SIW bandpass filter. From the figure, the insertion loss and return loss is 1.06 dB and less than 15 dB, respectively, at the center frequency of 12 GHz. Also, the second spurious frequency is improved to about 1.73 f_0 from 1.33 f_0. The spurious suppressed SIW bandpass filter has the insertion loss of 3.98 dB and return loss of less than 11.58 dB at the center frequency of 12 GHz as shown in Fig. 9. The second measured spurious frequency is slightly lower than the simulated one because of misalignment of the two dielectric substrates. The differences between the simulation and measurement results in S-parameters due to fabrication error for top and bottom substrate patterns

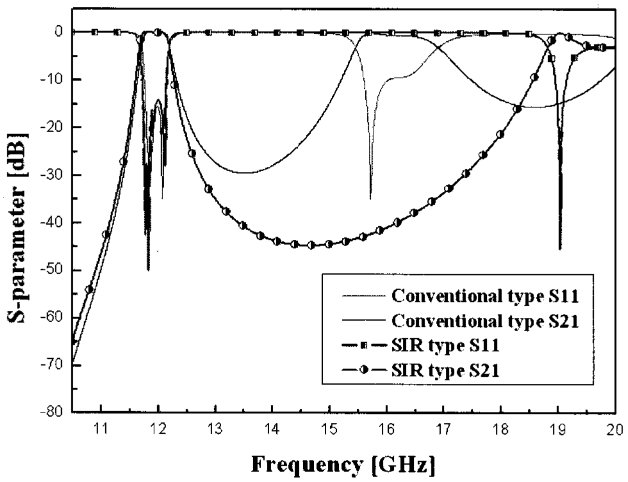

Fig. 8. Simulation results of the conventional and SIR-type SIW bandpass filter.

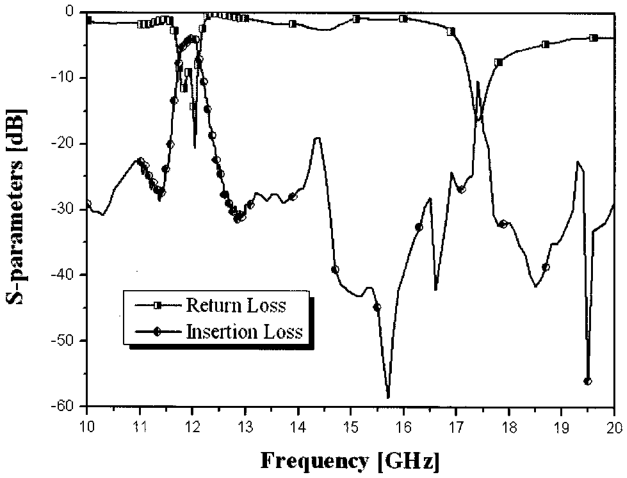

Fig. 9. Measurement results of spurious suppressed SIW bandpass filter with SIR.

and via-hole position. The SIW is a sensitive structure depending on via-hole position.

Ⅳ. Conclusion

In this paper, SIW components with planar circuits on a double-layers substrate have been proposed and discussed. In addition, the use of SIR has been extended to the design of SIW bandpass filters. The measured spurious suppressed SIW filter has a second spurious frequency of about 1.5 f_0. Compared to standard UIR filters, steps are added to the half-wavelength resonator. The SIR provides the designer with an extra degree of freedom to achieve the best compromise in terms of insertion loss, stop-band performance, and cost. The proposed spurious suppressed SIW filter, which uses SIR structure can be applied to low-temperature co-fired ceramic(LTCC), RF-MEMS, and other multilayer technology.

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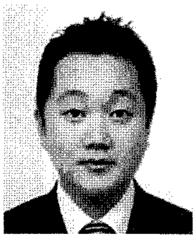

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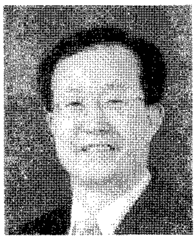

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