A Compact Substrate Integrated Waveguide Diplexer Using Dual-mode Filters

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Abstract— This paper presents a novel approach for designing compact integrated substrate waveguide diplexer fed by coplanar-waveguide. To reduce the size, conventional T-junction for impedance matching and isolation at the input port is replaced by the coplanar-waveguide-fed structure. It also contributes to size reduction of the diplexer. Two dual-mode integrated substrate waveguide filters are vertically stacked which results in further size reduction. A diplexer with lower and upper channels centered at 10 and 11 GHz, respectively, is designed to verify the proposed concept. Good agreements are achieved between measurement and simulation.

1. INTRODUCTION

Microwave diplexers are widely used in communication systems to allow two different devices to share a common communications channel [1]. For example, one application of diplexers is to allow two receivers working at different frequencies to share one antenna. Such a diplexer typically consists of two channel filters connected to the common input port through impedance transformers.

T-junction is the mostly common used impedance transformer in a diplexer design [2]. However, it occupies large area. It is a significant drawback for a communication system which has size requirements. Moreover, it would introduce extra insertion loss which increases with its length. Therefore, a lot of investigations have been carried out and various design approaches have been proposed to alleviate this problem [3, 4]. One approach is to use the reactance component to shorten the T-junction arms [3]. But some unwanted resonance would rise. And readjustment is required due to the short T-junction would affect the performance of each channel filter. In [4], common resonator sections were used to realize compact microstrip diplexers. By properly locating the fundamental and the first spurious resonant frequencies of the common resonators, these resonators can be shared by both filter channels. In this way, the T-junction was removed and the total number of resonators was reduced. Thus, the circuit size was dramatically reduced.

Substrate integrated waveguide (SIW) dual-mode resonators have the ability to reduce the total number of resonators. Meanwhile, the unloaded Q of the dual-mode is higher than that of the fundamental mode [5–8]. In this letter, these resonators are adopted in the channel filter design. The filters are fed by coplanar-waveguide (CPW) at the common port. On one hand, this feeding structure has a wider range of Q_e. On the other hand, the circuit size is dramatically reduced without the T-junction. The design procedure is simplified since no T-junction or common resonators are required. The diplexer size is further reduced by vertically stacking the two channel filters. To demonstrate, a diplexer centered at 10 GHz and 11 GHz is implemented.

2. CHARACTERISTICS OF THE DUAL-MODE SIW CAVITY

Figure 1 illustrates the structure of the dual-mode SIW resonator. Two perturbation vias with a diameter of d_1 are placed in the diagonal line of the square. Where, a is the width of the square cavity, h is thickness of the substrate, d is the diameter of the sidewall vias, p is the distance between two adjacent vias' center, and t is the distance from the perturbation vias to the sidewalls.

Dual-mode SIW resonator is adopted here for its high unloaded Q value which may lead to a low insertion loss of the diplexer. Table 1 compares the unloaded Q values of different resonant modes. All the cavities are squared-shaped. In the dual-mode cavity, two metallic perturbation vias with diameter of 0.8 mm are located along the diagonal line of the square cavity with 4 mm perpendicular to the sidewall. Table 1 demonstrates that diagonal TE_{201} and TE_{102} modes have higher unloaded Q values than the fundamental mode TE_{101} mode.

The first degenerate modes in a square cavity are diagonal TE_{102} and TE_{201} mode. When the two perturbation vias move along the diagonal line of the cavity, the resonant frequency of one degenerate mode stays the same, while the other one increases with t, as shown in Fig. 2. It is because the electrical field is zero in the diagonal line for the former one mode. Thus, the perturbation vias would not influence the electrical field distribution. On the other hand, the

Table 1: Comparison of different resonant modes in a square cavity.

Mode	Q_u and frequency
TE_{101}	578 @ 9 GHz
diagonal TE_{201}/TE_{102}	591 @ 9 GHz /605 @ 9.62 GHz

where, the substrate thickness is 0.8 mm, relative permittivity is 2.65, loss tangent is 0.001, the foil is copper with a thickness of 0.018 mm.

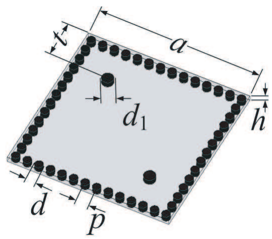

Figure 1: Structure of the dual-mode SIW resonator.

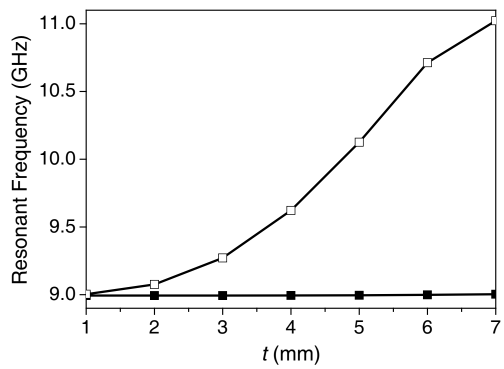

Figure 2: Variation of the resonant frequencies of diagonal TE_{201} and TE_{102} mode with respect to the position of the perturbation vias. ($a = 23.7$ mm, $h = 0.8$ mm, $p = 1$ mm, $d = d_1 = 0.8$ mm).

electrical field is not zero for the latter mode. So the resonant frequency changes with the location of the perturbation vias.

The resonant frequency of the TE_{mnl} mode is decided by [9]

$$f_{mnl} = \frac{c}{2\pi\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{h}\right)^2 + \left(\frac{l\pi}{b}\right)^2}, \tag{1}$$

where a, b, and h are the cavity's length, width and height respectively, c_0 is the light velocity in vacuum, μ_r and ε_r are the relative permeability and relative permittivity of the cavity substrate. According to (1), the effective length of the square cavity can be calculated by

$$a_{eff} = \frac{c_0}{2f_{201}} \sqrt{\frac{5}{\varepsilon_r}}, \tag{2}$$

where, f_{201} is the resonant frequency of TE_{201} mode. According to (2), we can get the length of the cavity, which can expressed as [10]

$$a = a_{eff} + \frac{d^2}{0.95p}. \tag{3}$$

Thus, according to the resonant frequency, we can decide the size of the cavity.

3. DESIGN OF THE PROPOSED DIPLEXER

As illustrated in Fig. 3, the diplexer consists of two substrates. On each substrate, there is a square cavity. On the metal layer II, a 50-Ω CPW feeding line is fabricated to feed the two channel filters. On the metal layer I and II, Port 2 and 3 are fed though microstrip to CPW transition. The design procedures of the two dual-mode filters are similar to that described in [5]. Each channel filter can be designed separately, but with the same CPW feeding structure at the input port. Then, combine them into a diplexer. No impedance match work is needed. Thus, the design procedure is simplified.

The CPW feeding line on metal layer II is dependent on the external quality factor of the two channel filters. In order to meet each channel filter's bandwidth specification, the common port is required to have wider tunable range of Q_e. For comparison, two dual-mode SIW resonators

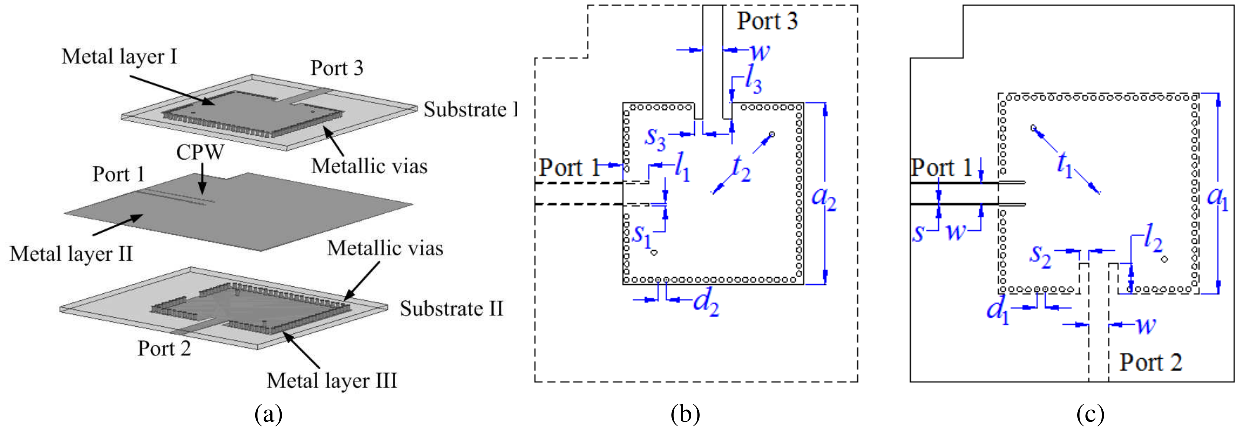

Figure 3: Structure of the proposed diplexer. (a) Exploded 3D view; (b) top view of Substrate I and (c) top view of Substrate II. ($w = 2.3$ mm, $l_1 = 3$ mm, $l_2 = 3.5$ mm, $l_3 = 1.8$ mm, $s = 0.1$ mm, $s_1 = 0.2$ mm, $s_2 = s_3 = 1$ mm, $t_1 = 10.55$ mm, $t_2 = 9.48$ mm, $d_1 = 0.96$ mm, $d_2 = 0.9$ mm, $a_1 = 22.8$ mm, $a_2 = 20.6$ mm).

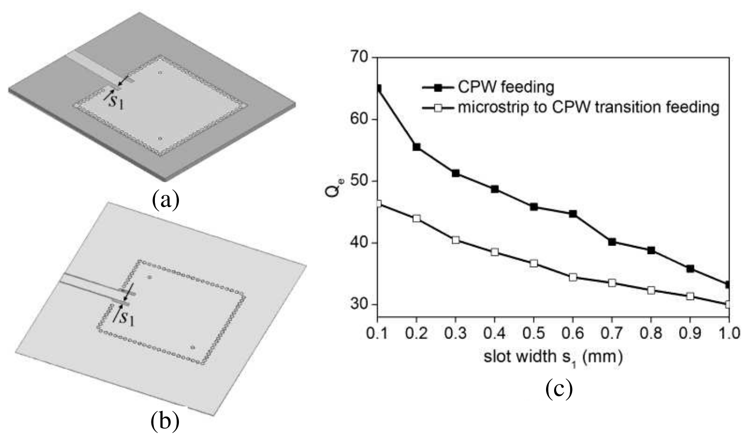

Figure 4: (a) Dual-mode resonator fed by microstrip to CPW transition structure; (b) Dual-mode resonator fed by CPW structure and (c) comparison of external quality factors between direct CPW feeding and microstrip to CPW transition feeding configurations. (Both the resonators have the same dimensions.)

with the same dimensions are fed by microstrip to CPW transition and CPW lines as shown in Figs. 4(a) and (b). A full-wave simulator is used to extract the Q_e of these two structures. Q_e can be extracted as

$$Q_e = \frac{f_0}{\Delta f_{\pm 90^\circ}}, \tag{4}$$

where f_0 denotes the resonant frequency, and $\Delta f_{\pm 90^\circ}$ is the bandwidth over which the phase shifts $\pm 90^\circ$ with respect to the absolute phase at f_0 [11]. The extracted Q_e with different slot width s_1 are compared in Fig. 4(c). As can be observed, the direct CPW feeding configuration obtains a wider range of Q_e, therefore, can be used to design filters with wider bandwidth ratio.

A SIW diplexer operating at 10 and 11 GHz is designed to demonstrate the above analysis. A F4B substrate with a relative dielectric constant of 2.65, a thickness of 0.8 mm, and a loss tangent of 0.001 is chosen for the diplexer design. Fig. 5 shows the photograph of the fabricated diplexer. The dimensions of the diplexer are illustrated in Fig. 3. The simulated and measured results are shown in Fig. 6. The simulated insertion loss at the two filter's center frequencies are 0.77 and 0.7 dB. The measured center frequencies of the lower and higher channel filters are 9.93 and 10.94 GHz respectively, and the corresponding insertion loss at the center frequencies is 2.31 and 1.75 dB. The simulated bandwidths for each filter are 0.52 and 0.59 GHz while the measured ones are 0.43 and 0.49 GHz. The simulated isolation is larger than 27 dB from 9 to 13 GHz while the measured one is larger than 29 dB in that band. The frequency shift is conjecturally caused by the errors of the substrate dielectric constant and the large insertion loss is conjecturally resulted from assembly

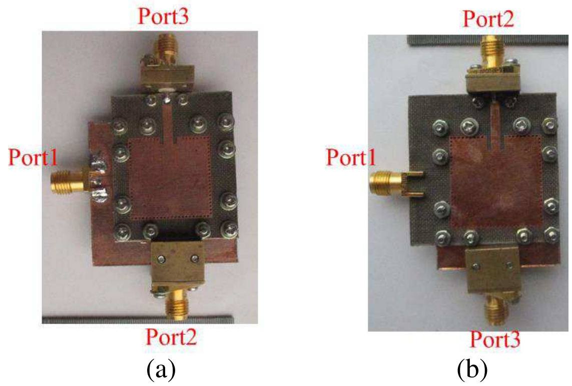

Figure 5: Photograph of the fabricated diplexer. (a) Top view and (b) bottom view.

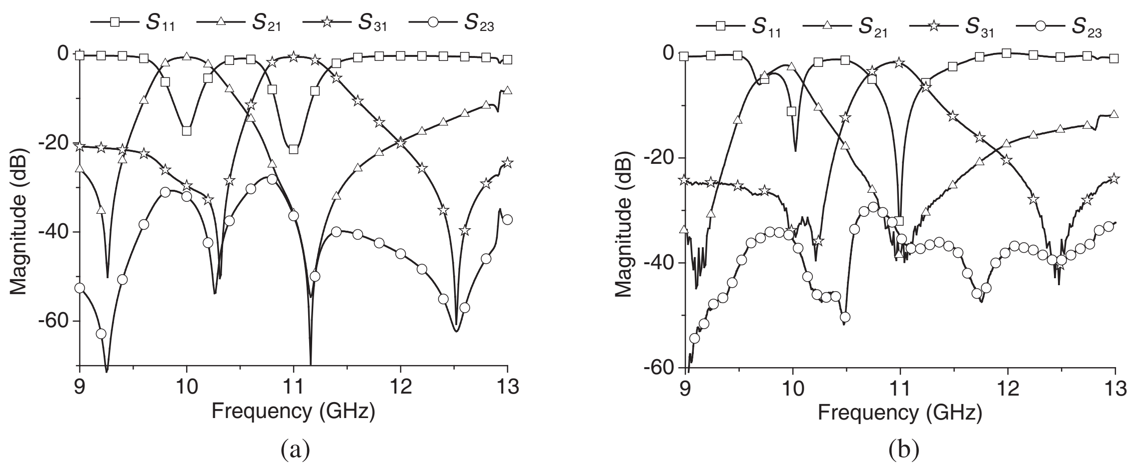

Figure 6: Simulated and measured results. (a) Simulation and (b) measurement.

errors and mismatch of the SMA connector.

4. CONCLUSIONS

A compact SIW diplexer using CPW-fed dual-mode filters has been studied in this letter. Extra combination circuits at the common port, as required in the conventional diplexer, are eliminated, which greatly simplifies the design procedures and reduces circuit size. Meanwhile, the multi-layer structure of the proposed diplexer allows further size reduction compared with planar diplexers. Good agreement between simulation and measurement has proved the validation of our concept.

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