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RESEARCH ARTICLE

Miniaturized half mode SIW diplexer loaded by CSRR

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Abstract

This article proposes a novel high-performance and compact size diplexer that implemented by the half-mode substrate integrated waveguide and loaded by complementary split ring resonator. The diplexer operates below the characteristic cutoff frequency of the waveguide. High isolation, low loss, low cost, easy fabrication, miniaturization of size, and integration with other circuits are remarkable attributes of the structure. A higher number of poles and better out of band response causes to give valuable results. Designing steps equivalent circuit, simulation and experimental results are presented. Simulation and measurement results are in good agreement.

KEYWORDS

complementary split ring resonator, diplexer and microwave components, half-mode substrate integrated waveguide

1 | INTRODUCTION

Undoubtedly, diplexers are one of the most important sections in transceivers for millimeter and microwave multiband and service systems.[1–7] Diplexer proverbial as a three ports structure which two output ports are located at the end of two filters with different passband. In fact, three ports are employed to isolate transmit/receive signal linked a common antenna. Therefore, a high band isolation between output ports causes to avoid interference with each other. To realize a desirable characteristic for high-performance diplexer in terms of low strong channel rejection, insertion losses, high isolation, quality factor, and compact size must be resorted different filter configuration and low loss transmission line.[1–3] As filter elements of the diplexers, according to the compact size and high-quality factor characteristics, substrate-integrated waveguide (SIW) has been chosen instead of a rectangular waveguide. SIW structure, to pass signal above cutoff frequency, often suffers large size in low frequency bands.

To conquer this issue, two main techniques have been realized: (1) complementary split ring resonator (CSRR) and (2) half mode SIW (HMSIW). Until now, several works to reduce the size of SIW filter in low frequency by utilizing complementary split ring resonator have been presented.[8] This technique first time introduced by ref. [8] and then developed in to use in diplexer.[1] However, employing CSRR in the HMSIW are presented in ref. [9] but up to now, no development of it to use in diplexer has been reported. In this article, a novel compact diplexer by relying on HMSIW loaded by CSRR is presented. The proposed T-shaped component with high performance is capable to work below the cutoff frequency. To valid results, it has been fabricated and measured and, consequently, it displays some attractive characteristics such as compact size, high isolation, low loss, low cost, and so forth.

2 | DESIGNING OF DIPLEXER

2.1 | Configuration

Figure 1 displays the configuration of the proposed HMSIW diplexer. It is a three-port component with a CSRR HMSIW transmitter and a receiver filter cascaded inline. To transient between SIW structure and input microstrip feed line is used a coplanar waveguide transition which it causes to impedance matching between SIW and 50 Ω input line. As

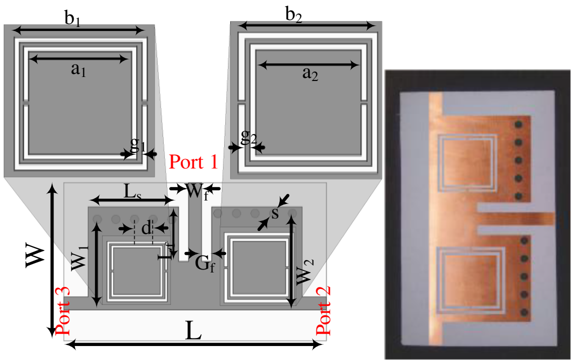

FIGURE 1 A, Configuration of the proposed HMSIW-CSRR diplexer ($a_1 = 3.9$, $a_2 = 4.3$, $b_1 = 4.9$, $b_2 = 5.8$, $g_1 = 0.15$, $g_2 = 0.17$, $s = 0.7$, $d = 1.55$, $W_f = 1.1$, $G_f = 0.85$, $W_1 = 7.5$, $W_2 = 8$, $L_s = 7.5$, $W = 13$, $L = 21$, and $L_f = 4.52$ [all values are in mm]). B, Fabricated photo of the proposed diplexer

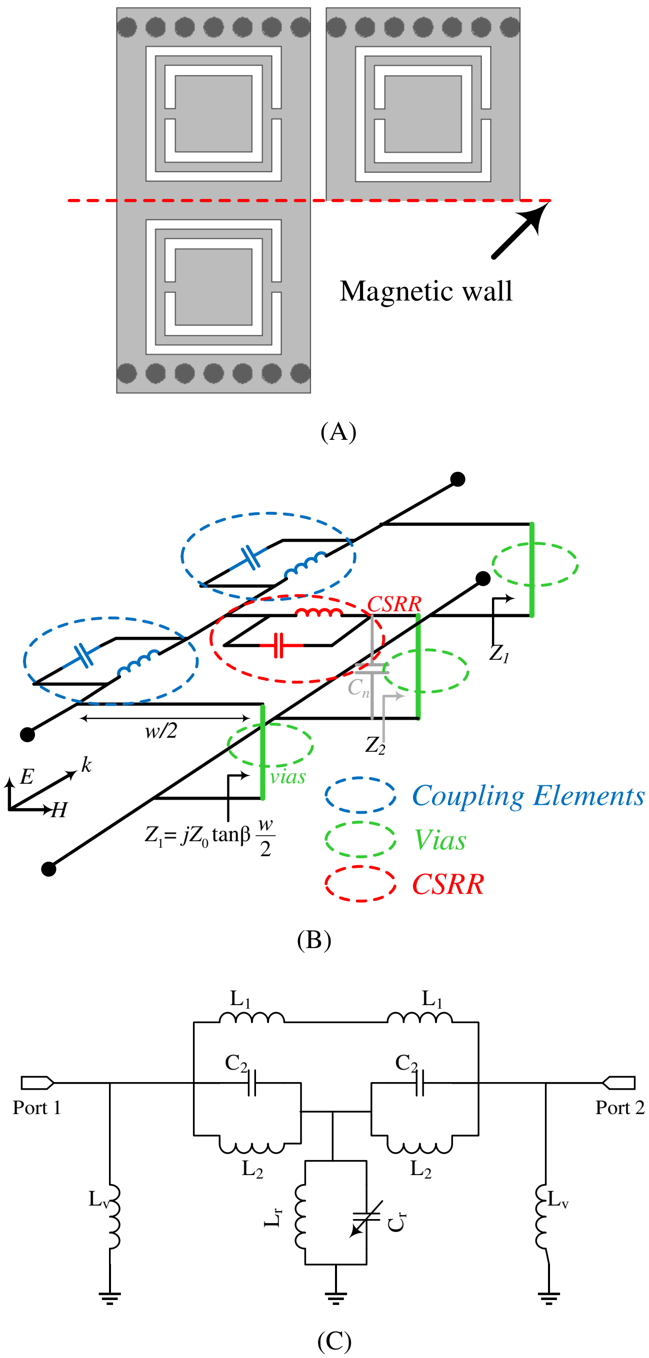

FIGURE 2 A, SIW and HMSIW-CSRR filter; B, transmission line model of the SIW-CSRR filter; C, equivalent circuit of HMSIW-CSRR filter

mentioned, the structure of two filters is constructed by the CSRRs incorporated into HMSIW. To control passband of two filters, the width of HMSIW and dimensions of CSRRs are optimally designed. Therefore, two filters are designed independently to have different pass band. To design proposed diplexer, the Rogers 4003 with a thickness of (h) 0.508 mm and a relative permittivity of (ε_r) 3.55 is used.

2.2 | CSRR HMSIW filter analysis

The concept of the HMSIW was reported recently in ref. [10]. It can be perceived, despite both the waveguide width and the surface area of the metallic sheets are decreased by nearly half compared with the SIW, the fabrication complexity is maintained at the same level as for the SIW.[10] As one of the most important aspects for a transmission line, the propagation properties of the HMSIW is found that for identical materials and arrangement of the Vias, the losses in the HMSIW can be at the same level or even lower compared to those of the SIW.[10] The basic structure of CSRR HMSIW filter is inspired of ref. 8. As seen in Figure 2, HMSIW as evolution from the SIW cut along its longitudinal symmetry plane, and among wall treats such as a magnetic wall. The transmission line model of CSRR SIW is displayed in Figure 2B. As seen in Figure 2B, the SIW is considered as a conventional two-wire transmission line burdened with infinite number of short-circuited stubs (shaped by via-walls).[8] To model via-walls, viewed from center of SIW and therefore via-walls treats such as inductive after a piece of transmission line (Figure 2B) and it is modeled as L_v. This part makes a high-pass influence.

The CSRR is equalized by using the shunt resonant tank formed by the C_r capacitance and the L_r inductance. The capacitive coupling, which is realized by the slot coupling between HMSIW and CSRR, is modeled by C_2, and inductive contribution of HMSIW are displayed by L_1 and L_2 (Figure 2C). As displayed in Figure 2B, the CSRRs are coupled to the ground by a small capacitance C_n in a parallel form. In comparison, capacitive coupling, which is mainly perceived by the center patch of the resonator and the ground, the inductive connection by the via-walls is dominant, therefore, is neglected. The value of impedance Z_2 is much smaller in compared with Z_1. We consider Z_2 value as zero, which means the CSRR and ground are directly connected.[8] These circuit models are useable only for a restricted frequency range and they cannot generalization for the high-order modes of the resonators.

The comparison between electromagnetic simulation by high-frequency structure simulation (HFSS) and circuit simulation by Advanced Design System (Agilent ADS) is

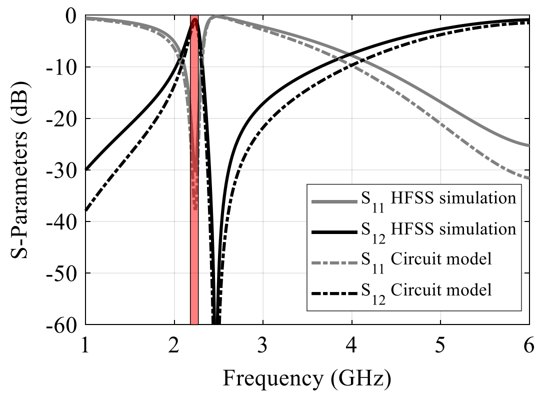

FIGURE 3 The comparison transmission responses by circuit model and full-wave simulation

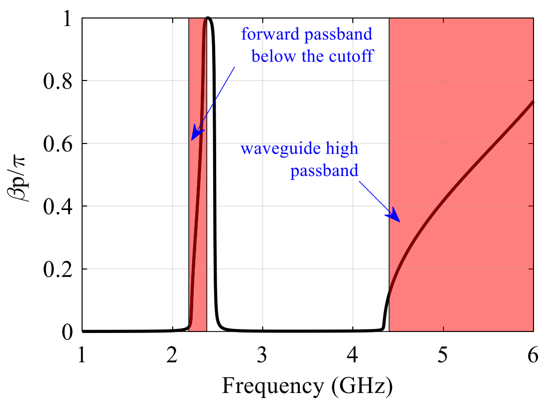

FIGURE 4 Dispersion diagram of HMSIW-CSRR

illustrated in Figure 3. The good agreement is crystal clear. The designed optimum values are obtained to be L_r = 1.2405 nH, C_r = 7.0795 pF, L_1 = 2 μH, C_2 = 4.0643 pF, L_2 = 0.8818 nH, and L_v = 3.012 nH.

The normalized dispersion diagram is shown in Figure 4. As shown, a positive slop at the notice frequency approves the forward wave nature of the passband below the waveguide cutoff.[8] A CSRR can be treated as an electric dipole, which can be stimulated by an axial electric field. As known from refs. [1,8], in HMSIW with a CSRR, the electric field and magnetic field of the dominant mode are perpendicular to the surface and sidewalls, respectively. Figure 5 demonstrates the electric field distribution of the CSRR HMSIW at dominant mode. It easily proves which electric field is limited around CSRR. It can be observed that the electric field is restricted around the CSRR.[1–8]

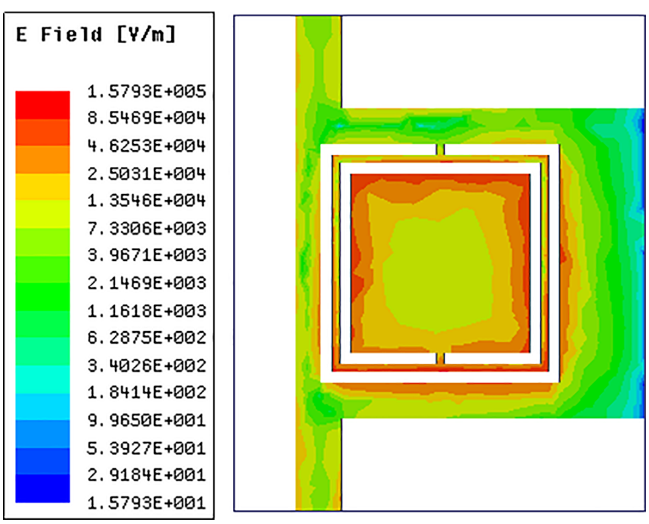

FIGURE 5 The E-field distribution in the HMSIW loaded by CSRR

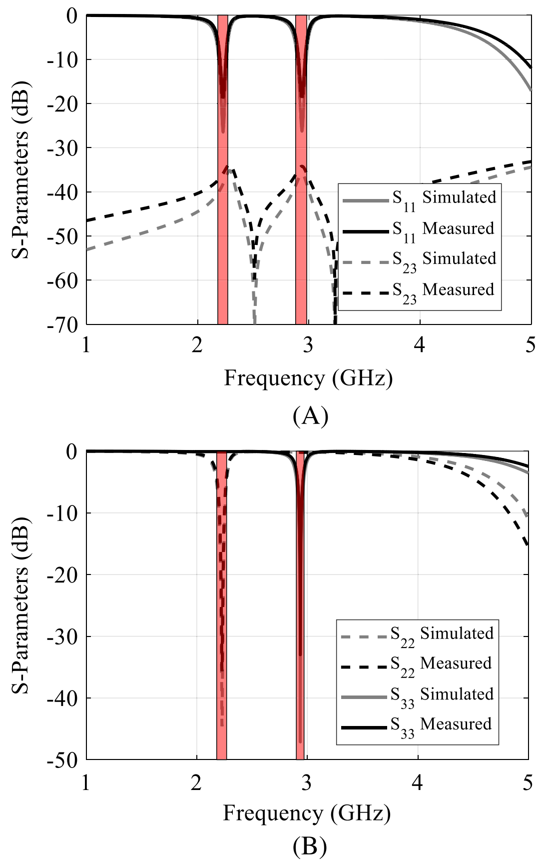

FIGURE 6 The comparison between simulated and measured (A) input port (port 1) return loss (S_{11}) and isolation between filter channel ports (S_{23}); and (B) channel filter return losses (S_{22} and S_{33})

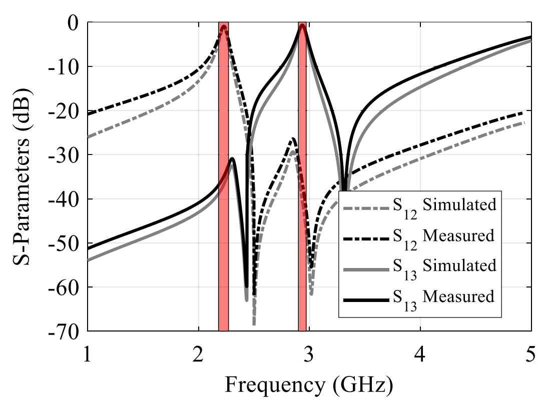

FIGURE 7 The comparison between simulated and measured transmission loss (S_{12} and S_{13})

TABLE 1 Comparison between the proposed diplexer and the references

References	Size ($\lambda_0 \times \lambda_0 \times \lambda_0$)	Insertion loss (S_{12} or S_{13}) Channel 1 (dB)	Insertion loss (S_{12} or S_{13}) Channel 2 (dB)	Suppression (S_{12} or S_{13}) Channel 1	Suppression (S_{12} or S_{13}) Channel 2	Isolation (S_{23}) (dB)
[1]	0.27 × 0.217 × 0.008	1.6	2.3	43 dB @ 4.66 GHz	28 dB @ 5.80 GHz	32
Type 1[2]	0.15 × 0.14 × 0.007	1.6	3.2	24 dB @ 4.33 GHz	23 dB @ 5.99 GHz	30
Type 2[2]	0.22 × 0.13 × 0.007	1.8	2.3	22 dB @ 4.78 GHz	52 dB @ 5.77 GHz	26
[3]	2.71 × 3.35 × 0.009	2.6	3.2	55 dB @ 5.42 GHz	55 dB @ 5.93 GHz	53
Part 1[4]	0.17 × 0.272 × 0.003	2.7	2.8	40 dB @ 1.5 GHz	48 dB @ 2.0 GHz	42
Part 2[4]	0.187 × 0.30 × 0.003	2.8	3.2	38 dB @ 1.5 GHz	39 dB @ 1.76 GHz	30
[5]	2.04 × 0.65 × 0.053	1.6	2.1	42 dB @ 9.5 GHz	37 dB @ 10.5 GHz	35
[6]	1.44 × 0.98 × 0.022	2.2	2.4	22 dB @ 7.75 GHz	22 dB @ 8.25 GHz	-
Diplexer 1[7]	3.06 × 1.38 × 0.019	1.92	2.14	33 dB @ 7.4 GHz	42 dB @ 8.2 GHz	-
Diplexer 2[7]	2.96 × 1.38 × 0.019	1.83	2.13	34 dB @ 7.4 GHz	43 dB @ 8.2 GHz	-
This work	0.16 × 0.1 × 0.004	1.65	1.72	37 dB @ 2.21 GHz	39 dB @ 2.93 GHz	35

3 | FABRICATION AND MEASUREMENT

To authenticate simulated results, the proposed diplexer has been fabricated and then measured by Agilent 8722ES vector network analyzer. As aforementioned, the proposed diplexer is experimentally implemented on a substrate of Rogers 4003. The comparison between simulated and measured insertion losses at two bands are displayed in Figure 6. As seen, a good agreement between simulated and measured results governs. The measured insertion loss at two bands have rates ~1.60 and 2.30 dB, respectively. The main effects of losses at two bands are related to the loss of SMA connectors.

The comparison of measured and simulated $|S_{ii}|$ (i = 1, 2, and 3) is displayed in Figure 7. The minimum value of the measured $|S_{ii}|$ (i = 1, 2, and 3) at the lower and higher band is 12.9 dB. The isolation between two output ports of each channel filter is better than 30 dB. Table 1 exhibits a performance comparison between the proposed HMSIW diplexer and other designs in literature. As seen, the proposed structure has a compact size and sensible prominent features in compared with microstrip and SIW reported components.

4 | CONCLUSION

A miniaturized planar diplexer based on HMSIW structure and implemented by CSRRs has been studied in this article. The electric dipole nature of the CSRRs has been applied to obtain a forward passband in a waveguide area. This passband is located below the waveguide cutoff frequency of the dominant mode in HMSIW. The results show that the device insertion loss is 1.65 and 1.75 dB, suppression is 37 and 39 dB, and isolation is 35 dB. Thanks to these outcomes and compact size, the proposed structure could be a good candidate for generating high spectral pure signals with low phase noise in dual-band microwave systems. A prototype of the device has been fabricated for verification.

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AUTHOR BIOGRAPHY

Saeid Karamzadeh received his MS and PhD in Department of Communication Systems, Satellite Communication & Remote Sensing program at Istanbul Technical University in 2013 and 2015, respectively. He won the award of the most successful PhD thesis form Istanbul Technical University. He is an Assistant Professor in the Istanbul Aydin University, Department of Electric and Electronics

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