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RESEARCH ARTICLE

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A high isolation quad-channel microstrip diplexer based on codirectional split ring resonators

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Abstract

In this study, a novel microstrip diplexer with four channels is designed by using codirectional split ring resonators (CDSRRs). Since CDSRRs provide dual resonance behavior, dual-band bandpass filter with two poles at each passband can be created by coupling identical CDSRRs to input/output ports. Based on this approach, quad-channel diplexer can be designed by coupling two more CDSRRs in different electrical length to another output. Both filters are fed by similar feeding lines. High isolation can be observed between the output ports by means of CDSRRs. The designed quad-channel microstrip diplexer was also fabricated and tested for experimental verifications. The measured results are in a good agreement with the simulated results. Center frequencies of the channels were measured at 2.12, 2.45, 3.90, and 4.48 GHz with the minimum insertion losses of 2.27, 2.88, 2.00, and 2.71 dB, respectively. Isolation was observed as better than 44 dB from DC to 6 GHz.

KEYWORDS

codirectional split ring resonators (CDSRRs), diplexer, high isolation, quad-channel

1 | INTRODUCTION

Importance of multiband bandpass filters and multi-channel multiplexers increases in recent years due to the popularity of multifunction communication systems. Multichannel multiplexers can be generally designed on microstrip structures due to their advantages in terms of compact circuit size, design simplicity, low loss, and high isolation.

To date, many microstrip diplexers have been introduced by different researchers.[1–10] Nevertheless, number of quad-channel diplexers is less as compared to the diplexers with two channels. As is well known, quad-channel diplexers can be designed by combining two dual-band bandpass filters.[1–10] Configuration of the dual-band bandpass filters determine the structure of the matching circuit that is required for the suitable integration of two bandpass filters. Stub loaded quad-mode resonators have been utilized in Lin et al.[1] Although good isolation and compact circuit size can be obtained, a matching circuit is needed. In Xu,[2] short-circuited stub loaded resonator has been used to obtain dual passband at each output. High isolation and compact circuit size have been achieved by using stepped impedance resonators. However, a matching circuit is again required in this design to reach good return losses. In Jiang et al.[3] dual-open/short-stub loaded resonator has been used to design a balanced quad-channel diplexer. The dual-open-stub loaded resonator and dual-short-stub loaded resonator have provided differential mode and common mode resonant frequencies for dual-band filters. A compact quad-channel diplexer based on stub loaded open loop resonator was designed in Rezaei et al.[4] However, the proposed structure suffers from the isolation level between channels. Quad-mode resonators have also been utilized in Tantiviwat et al.,[5] but low isolation level has been observed. Coupled lines, spiral and U-type structures have been used to obtain quad channels as in Rezaei et al.[6] This diplexer again suffers from the low isolation level. Another quad-channel diplexer was designed by means of a novel stub loaded U-shape resonator in Yahya and Nouri.[7] Although very low insertion losses have been obtained at four channels, the proposed diplexer suffers from the poor isolation level. In Chen et al.,[8] high isolation and high selectivity quad-channel microstrip diplexer design has been presented. Multiple coupling paths between input and output ports have been used to obtain better frequency selectivity and higher order multiplexers.

In this study, a novel quad-channel microstrip diplexer is presented. The designed diplexer consists of two bandpass filters without using a matching circuit. The bandpass filters are designed by using codirectional split ring resonators (CDSRRs) with a similar manner in Gorur.[11,12] Two filters constructed by the CDSRRs in different electrical lengths are directly connected to the input/output (IO) ports to create four channels at two outputs. The designed quad-channel microstrip diplexer was also fabricated and measured in a very good agreement with the simulations. The proposed circuit has the channels at 2.12, 2.45, 3.90, and 4.48 GHz with isolation levels of better than 44 dB.

2 | DESIGN PROCEDURE OF QUAD-CHANNEL DIPLEXER

The proposed CDSRRs-based quad-channel microstrip diplexer is illustrated in Figure 1. As known from Gorur,[12] CDSRRs have two odd mode resonant frequencies and they can also produce a transmission zero between the resonant frequencies. Thus, dual passbands with two transmission poles can be obtained by using two identical coupled CDSRRs. As shown in Figure 1, two CDSRRs in different electrical lengths are used to create four resonant frequencies. The CDSRRs consist of inner and outer open-loop resonators and they have interdigital capacitors located at the open ends of the inner open-loop resonator. It should also be noted that the CDSRRs are coupled to IO ports by feeding lines and same coupling topologies are used at both output ports. The feeding line structures are also same at the IO ports, so that the requirement of the matching circuit is removed.

The diplexer shown in Figure 1 is constructed on a Rogers 4003C substrate with the relative dielectric constant of 3.38 and a thickness of 0.813 mm. Dimensions of the diplexer shown in Figure 1 are given in Table 1, and they are determined so as to adjust the center frequencies of the channels to 2.15, 2.45, 3.85, and 4.5 GHz. All gaps between the inner and outer open-loop resonators, and also between the feeding lines are 0.2 mm. In addition, widths of the feeding lines are 0.3 mm except the feeding transmission line with the length of l_{f5}, which is 0.4 mm. These dimensions are obtained from the parameter sweeps realized in a full-wave electromagnetic simulator. Figure 2 represents the simulated frequency responses with respect to the changes in the interdigital capacitors for both resonators. In Figure 2A, frequency responses of the diplexer with respect to the existence of the interdigital capacitors are demonstrated. As can be seen from the figure, the interdigital capacitors actually serve to separate the passband into two passbands. Effects of the length of

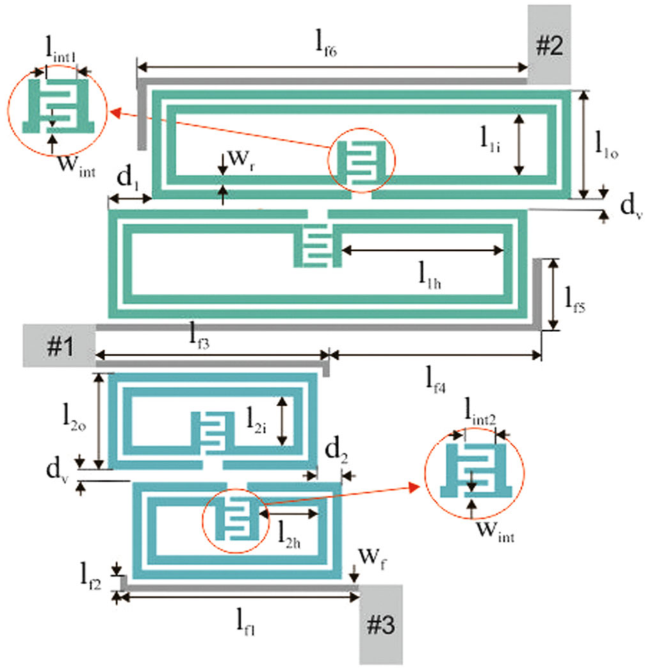

FIGURE 1 Layout of the proposed quad-channel microstrip diplexer.

TABLE 1 Dimensions of the proposed quad-channel diplexer (all in millimeters)

l_{f1}	9.8	l_{1i}	2.5	l_{f6}	16
l_{f2}	0.7	l_{1o}	4.5	W_f	0.3
l_{f3}	9.6	l_{1h}	6.6	l_{2h}	2.4
l_{f4}	8.7	l_{2i}	2	W_r	0.4
l_{f5}	3	l_{2o}	4	W_{int}	0.2
l_{int1}	1	l_{int2}	0.8	d_v	0.4

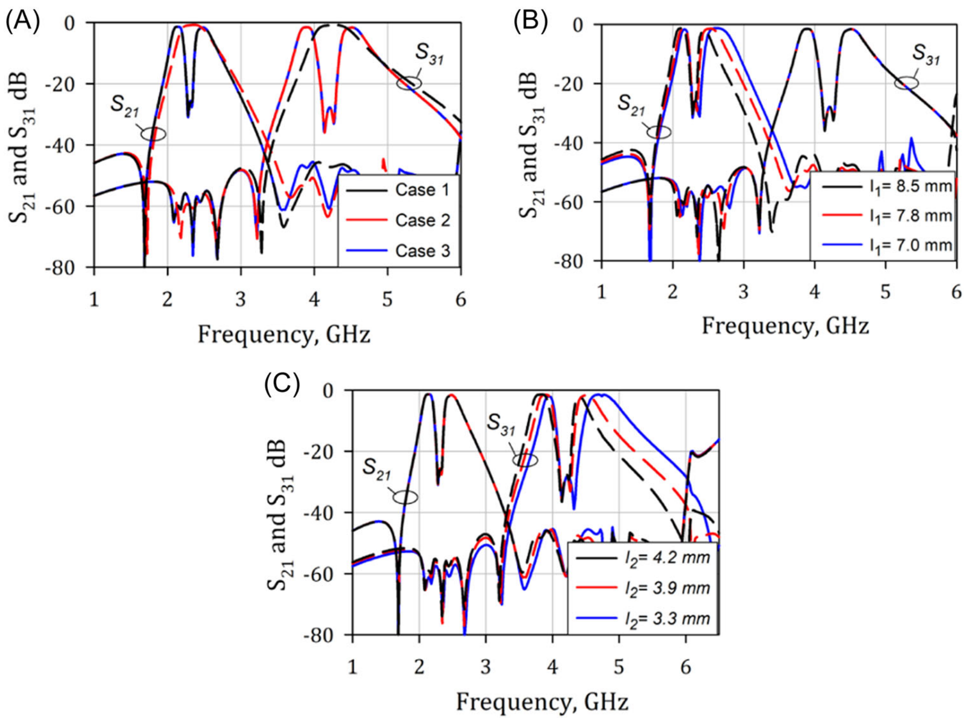

FIGURE 2 (A) Existence of interdigital fingers (Case 1: at only bottom co-directional split ring resonators [CDSRRs], Case 2: at only upper CDSRRs, Case 3: at both CDSRRs); (B) effects of l_1 on the first and second channels; (C) effects of l_2 on the third and fourth channels.

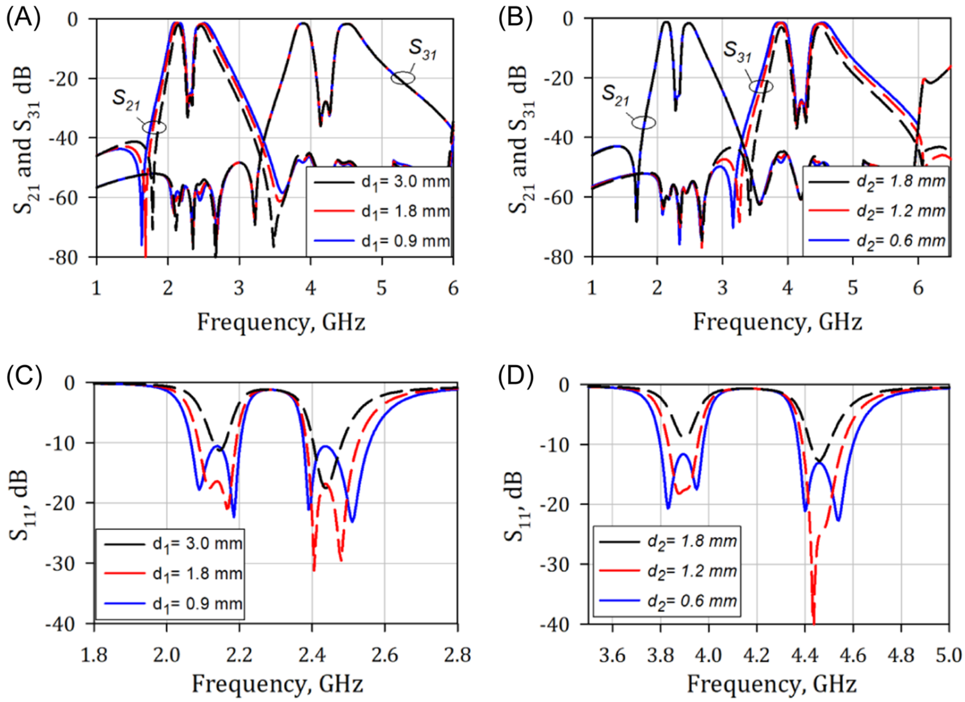

FIGURE 3 Bandwidth controls of the both output ports with respect to the changes in: (A) d_1; (B) d_2; (C) close view of S_{11} for the first and second channels; (D) close view of S_{11} for the third and fourth channels.

the outer open-loop resonator for the upper CDSRRs are depicted in Figure 2B. It is clear that the second passband is more affected from that change. Figure 2C demonstrates the same behavior for the bottom CDSRRs, so that the fourth passband is more impressed from that change. Based on these investigations, the passband adjustments can be achieved by the changes in the interdigital capacitors and the outer lengths of the CDSRRs.

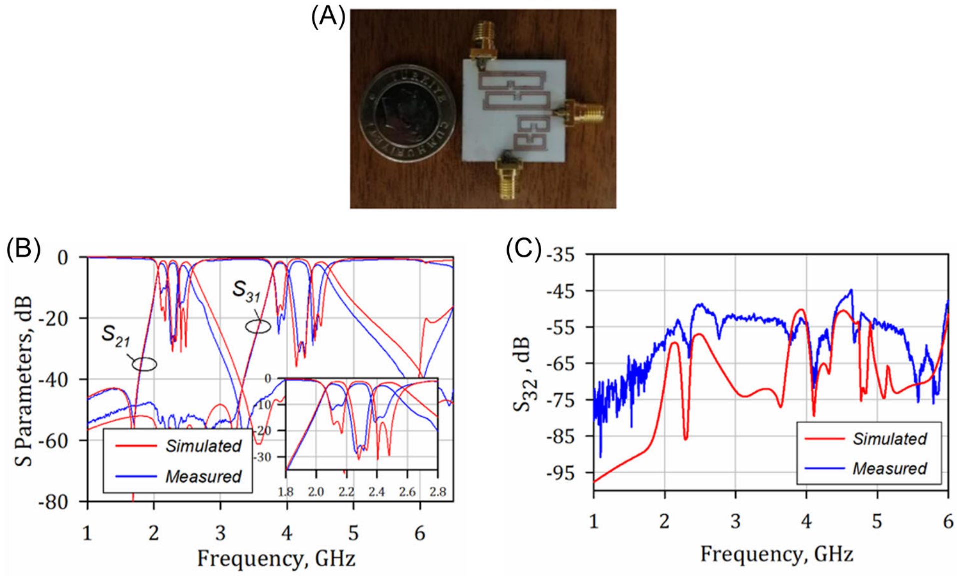

FIGURE 4 (A) Photograph of the fabricated diplexer; (B) comparisons of the simulated and measured results for insertion and return losses; (C) isolation levels of the simulated and measured results.

Interresonator coupling investigations are illustrated in Figure 3 for both CDSRRs. It is clear from Figure 1 that the coupling between the CDSRRs can be adjusted by moving any resonator horizontally or vertically. The horizontal shift of any CDSRR allows more sensitive coupling adjustment as compared to the vertical shift. This is because of the coupling mechanism of the CDSRRs, since vertical shift causes much more coupling variation. Therefore, horizontal shift may be more useful to adjust the coupling strength between the CDSRRs. Figure 3A shows the changes in d_1 on the frequency response. As can be seen from the figure, bandwidths of the first and second channels can be simultaneously increased. In addition, variations in the third and fourth channels with respect to the changes in d_2 are given in Figure 3B. Similar bandwidth behaviors can also be observed here.

3 | EXPERIMENTAL RESULTS

To demonstrate the validity of the proposed design methodology, a quad-channel microstrip diplexer was fabricated. Figure 4A illustrates the photograph of the fabricated diplexer. Overall circuit size excluding the IO ports is $0.23 \times 0.25\,\lambda_g$, where λ_g is the guided wavelength at the center frequency of the first channel. The corresponding physical length is 19.5×21.1 mm. Measurements of the fabricated diplexer have been performed by using a Vector Network Analyzer of Keysight PNA N5222A. Comparisons of the simulated and measured results are given in Figure 4B,C. As can be seen from these figures, measured results show an acceptable agreement with the simulated ones. In Figure 4B, The insertion and return losses are compared. In simulations, center frequencies of the channels are 2.14, 2.47, 3.88, and 4.51 GHz with the fractional bandwidths (FBWs) of 6.5%, 6%, 4%, and 4.3%, respectively. The measured center frequencies are 2.12, 2.45, 3.90, and 4.48 GHz with the FBWs of 5.66%, 6.12%, 6.15%, and 5.13%, respectively. Minimum insertion losses of the four channels have been measured as 2.10, 2.82, 1.95, and 2.60 dB. Return losses have been obtained as better than 10 dB for all channels. In addition, isolation between the channels are better than 44 dB in the measurements, while it is better than 50 dB in the simulated results. Isolation levels are also depicted in Figure 4C. Reasons of the differences between the simulations and measurements are especially resulted from the fabrication errors, and unexpected connection losses, and so on. It is expected that the proposed quad-channel diplexer may have a promising future since it can exhibit high isolation within a compact circuit size.

4 | CONCLUSION

A novel compact quad-channel microstrip diplexer has been designed, fabricated and tested. The proposed diplexer has been constructed by interdigital capacitor loaded CDSRRs having dual resonance behavior. There is no requirement of matching circuit for the integration of two dual-band bandpass filters. The measured results have been observed in a good agreement with the predicted results. Center frequencies of the designed diplexer have been measured at 2.12, 2.45, 3.90, and 4.48 GHz with an isolation of better than 44 dB.

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DATA AVAILABILITY STATEMENT

Research data are not shared.

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REFERENCES

1. Lin L, Zhao YT, Wu B, Liang CH. Design of compact quad-channel diplexer using quad-mode stub-loaded resonators. *Prog Electromagnet Res Lett*. 2015;51:87-93.
2. Xu J. Design of a compact quad-channel diplexer. *Frequenz*. 2016;70(1-2):29-32.
3. Jiang W, Huang Y, Wang T, Peng Y, Wang G. Microstrip balanced quadchannel diplexer using dual-open/short-stub loaded resonator. IEEE MTT-S International Microwave Symposium (IMS); 2016:1-3.
4. Rezaei A, Noori L, Jamaluddin MH. Design of a novel microstrip four-channel diplexer for multi-channel telecommunication systems. *Telecommun Syst*. 2019;72:189-197.
5. Tantiviwat S, Ibrahim SZ, Razalli MS. Design of quad-channel diplexer and tri-band bandpass filter based on multiple-mode stub-loaded resonators. *Radioengineering*. 2019;28(1):129-135.
6. Rezaei A, Noori L, Mohammadi H. Miniaturized quad-channel microstrip diplexer with low insertion loss and wide stopband for multi-service wireless communication systems. *Wireless Netw*. 2019;25:2989-2996.
7. Yahya SI, Nouri L. A low-loss four-channel microstrip diplexer for wideband multi-service wireless applications. *AEU Int J Electron Commun*. 2021;133:153670.
8. Chen C, Lin CY, Tseng BH, Chang SF. A compact microstrip quad-channel diplexer with high-selectivity and high-isolation performances. IEEE MTT-S International Microwave Symposium (IMS); 2014.
9. Luo D, Chen FC, Qiu JM, Chu QX. Design of quad-channel diplexer using short stub loaded resonator. 2015 IEEE International Wireless Symposium (IWS); 2015.
10. Wu H, Huang S, Chen Y. Design of new quad-channel diplexer with compact circuit size. *IEEE Microw Wireless Compon Lett*. 2013;23(5):240-242.
11. Gorur AK. A dual-band balun bpf using codirectional split ring resonators. *IEEE Microw Wireless Compon Lett*. 2020;30(10):949-952.
12. Gorur AK. A novel dual-band bandpass filter using co-directional split ring resonators with closely spaced passbands and wide upper stopband. *Int J RF Microw Comput Aided Eng*. 2018;28:e21230.

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